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REVIEW

Impact of Traffic Congestion on Transportation Systems: Challenges and Remediation − A Review

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Abstract

Traffic congestion is a growing problem in urban transportation networks around the world with major economic and environmental consequences. As metropolitan populations rise and more people rely on automobiles for mobility, traffic congestion is becoming more common and severe. This review paper presents an overview of the economic and environmental issues caused by traffic congestion in urban areas, as well as proposed ways to reduce its negative effects. It discusses potential traditional transportation solutions such as traffic management infrastructure development, improving public transportation, and intelligent transportation solutions to address traffic congestion problems such as smart parking systems and accident detection. The paper begins by defining traffic congestion and its causes, highlighting the extent of the problem in urban areas and its impact on the quality of life and economic productivity, and explores the economic costs of traffic congestion, including lost productivity, increased infrastructure expenses, reduced quality of life for residents, population growth, urban sprawl, and inadequate public transportation systems. Most of the research indicates that the intelligent transportation systems plays a major role in reducing many problems such as air pollution, fuel consumption, traffic congestion, and accidents, and reducing emissions of carbon dioxide by 80%. The study recommended that the road transportation sector contribute significantly and develop a framework for understanding the various sources of congestion, methods to address congestion by targeting these sources, and performance measures for monitoring congestion trends, as well as future recommendations in the field of intelligent transportation systems to make it more user-friendly and accessible.

Keywords: Economic impact, Environmental impact, Traffic congestion, Transportation application technologies

1. Introduction and background

Road transportation is considered very important for the day-to-day activities of mankind, whether in terms of the social or economic status of a country. Traffic congestion is a growing problem in many cities around the world. Everything indicates that the matter will continue to get worse, which is an undoubted threat to the quality of urban life where in recent years, there has been a considerable increase in the negative effects of traffic congestion on society, the economy, and the environment (Almatar and Almulhim, 2021). The most common definition of congestion is an imbalance between traffic flow and capacity, which causes increased travel time, cost, and modification of behavior (Akhtar and Moridpour, 2021). Congestion has a huge impact on the urban transport system, especially in highly populated areas, as it causes significant delays and costs. Traffic congestion can result from various sources, including traffic incidents, work zones, weather, special events, recurring congestion, and nonrecurring congestion as shown in Fig. 1 (Jilaniv et al., 2023).

Peak traffic in cities occurs in the mornings and evenings, mostly as a result of commuters going to and coming back from work. As the demand for transport services grows at an alarming rate, there is an urgent need for an efficient transit infrastructure (Fleming, 2019). The cities experience traffic

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Fig. 1. Classification of congestion (Jilaniv et al., 2023).

congestion due to various factors, such as the underutilization of public transportation, resulting in a higher number of private vehicles; in addition, the existing street networks often prove insufficient in accommodating the escalating demand for urban traffic (Lu et al., 2021). A good and efficient transport system accelerates a country's economic development and directly benefits businesses, people, and the environment. However, the increase in heavy vehicles and traffic activities on the roads has an impact on traffic congestion. Traffic congestion is a major problem in providing sustainable transport systems in many cities around the world. Congestion increases travel costs, increases travel time, and reduces accessibility (Svanberg, 2018). Congestion has many negative consequences, including increased noise pollution, driver stress, decreased mental satisfaction, city economic growth, and increased passenger time pressure. Congestion also has serious environmental consequences, such as increased fuel usage and air pollution emissions. Traffic congestion, as well as its social and environmental consequences, has been rising in urban and rural regions across the world, whether in industrialized or developing nations (Bivina et al., 2016). The primary focus of any policy-making process is to determine the financial consequences of traffic delays on the entire national economy. In addition, estimating the costs associated with delays provides a useful measure that can be applied to road users, making it an effective and commonly used method for managing traffic demand (Albalate and Fageda, 2019). Especially in Egypt, the traffic congestion problem has detrimental effects on both the well-being of its citizens and its economic stability, apart from the time wasted in standstill traffic, which could be used more productively (Gabr et al., 2022). In recent years, researchers have been paying particular focus to the difficulties of road transportation and traffic congestion, especially due to the rapid development of cities and road networks (Olayode et al., 2020). Recently, advanced techniques for managing and controlling traffic have demonstrated their effectiveness in enhancing the efficiency of urban transportation and mitigating traffic congestion (Kapitanov et al., 2018). Intelligent transportation systems (ITS) use computers, big data, 5 G technology, and information systems to establish a unified transportation system that is secure, effective, and energy efficient. Sensor technologies, electronic control systems, fuzzy control mechanisms, and artificial intelligence (AI) are used for vehicle transportation, management, control, and manufacturing, alleviating road construction demands and enhancing infrastructure growth (Lv and Shang, 2023). Wang et al. (Wang and Guo, 2018) used an analytical approach to investigate the impact of various factors on carbon emissions in urban traffic. Their findings revealed that economic factors, population growth, passenger and freight traffic volumes, as well as private car ownership, played crucial roles in influencing the levels of carbon emissions in urban areas. Bani Younes and Boukerche (Bani Younes and Boukerche, 2015) presented a protocol called efficient congestion detection that focuses on assessing the traffic patterns of individual road segments. The efficient congestion detection protocol has proven to be highly effective and dependable in identifying areas within urban grid layouts that experience significant traffic congestion. Fattah et al. (2022) presented a two-tier system to reduce total CO_2 emissions from all vehicles passing through isolated intersections by simultaneously increasing vehicle approach speed and traffic signal illumination interval. Lv and Shang (2022) analyzed how ITS affect the ability of transportation networks to conserve energy and reduce emissions. The management system's ability to visually display traffic data has a significant impact on reducing vehicle energy conservation and emission reduction and traffic congestion and to achieve the aim of a suitable transportation system, it is important to select the best vehicle specifications. Also, Gomes et al. (2023) examined preprocessing methods in ITS. They emphasized the potential of these techniques in enhancing our understanding of recent advancements in ITS, ultimately leading to the development of more efficient and sustainable transportation systems that can benefit both individuals and society as a whole. However, Rahman and Thill (2023) discovered that autonomous vehicles could potentially have a significant impact on urban transportation and human mobility. Their research indicated that these vehicles could reduce the need for individual car ownership, alleviate traffic congestion, and lower travel expenses. Moreover, autonomous vehicles have the potential to improve accessibility, enhance mobility options, and increase the distance traveled by vehicles, thereby generating more revenue for commercial operators. Furthermore, the introduction of autonomous vehicles could encourage urban growth in various locations, decrease the demand for parking spaces, and improve the overall capacity of transportation networks. They might also minimize energy use, protect the environment, and reduce road accidents caused by human mistakes. However, there are still issues regarding personal safety, security, and privacy (Rahman and Thill, 2023). According to the challenges mentioned above, the current traffic framework is inadequate to encounter the traffic demand due to an exponential increase in population as well as vehicle. A review paper aims to discuss the traffic congestion problem, providing a comprehensive review of the economic and environmental challenges associated with traffic congestion in urban transportation systems. It assesses the effectiveness of monitoring traffic conditions and mitigation measures, identifies future research directions, and offers recommendations.

2. Selection method

This paper analyses and evaluates the relevant literature on the economic and environmental challenges of transportation systems. Also, this review discusses intelligent solutions, taking into account the economic and environmental impacts. The method involved compiling relevant material through a thorough search of databases (like Scopus), which are regarded as the most complete and trustworthy databases for scientific study. Furthermore, the following standards were used to choose which findings to include and exclude:

(1) General keywords such as ‘traffic congestion of transportation systems,’ ‘pollution from traffic,’ ‘traffic congestion of urban transportation systems,’ ‘intelligent transportation systems,’ ‘intelligent transportation applications,’ and ‘road traffic,’ ‘were used.
(2) Statistics have been established about the articles tackling the traffic congestion problems from the Scopus database. Only articles published between 2012 and 2023 were chosen since this was the time frame in which the majority of works about this idea were published, guaranteeing a sample that provided adequate coverage for this review study. Fig. 2 illustrates

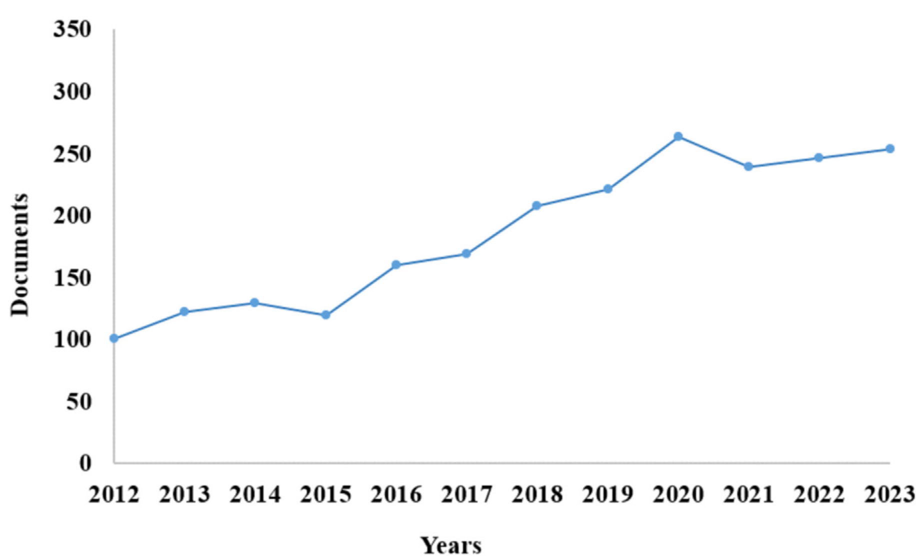

Fig. 2. Number of publications on traffic congestion during 2012−2023.

the chronological progression of articles on traffic congestion, showcasing the growing academic attention in recent years.

(3) Were limited to articles published in journals that are indexed in the Scopus and/or Clarivate Analytics databases, as these databases are thought to have more stringent revision processes and guarantee acceptance by the scientific community.

(4) This methodological approach allowed for the synthesis and comparison of different traffic congestion-related aspects of transport systems and connected roads. A comprehensive examination was carried out to identify widespread trends, challenges, and important developments in the field. The findings from the chosen studies were combined and arranged by the topics and goals of the investigation. Moreover, the limitations of the reviewed studies were also acknowledged and highlighted for future research directions.

(5) Finally, the literature review was critically evaluated to identify strengths, weaknesses, and limitations of traffic congestion in transportation systems applications, providing recommendations for further research, technological advances, and possible improvements in the design and operation of transportation systems. Fig. 3 shows the layout of the paper organization.

3. Main challenges

3.1. Economic challenges

Transportation holds a prominent position within the economy, serving as a fundamental pillar for its growth and development. Its indispensable role lies in facilitating the movement of essential inputs to production sites and ensuring the efficient transportation of finished products to storage or market locations. This pivotal function directly influences and shapes various aspects of social and economic life within society (Fattah et al., 2022). The impact of

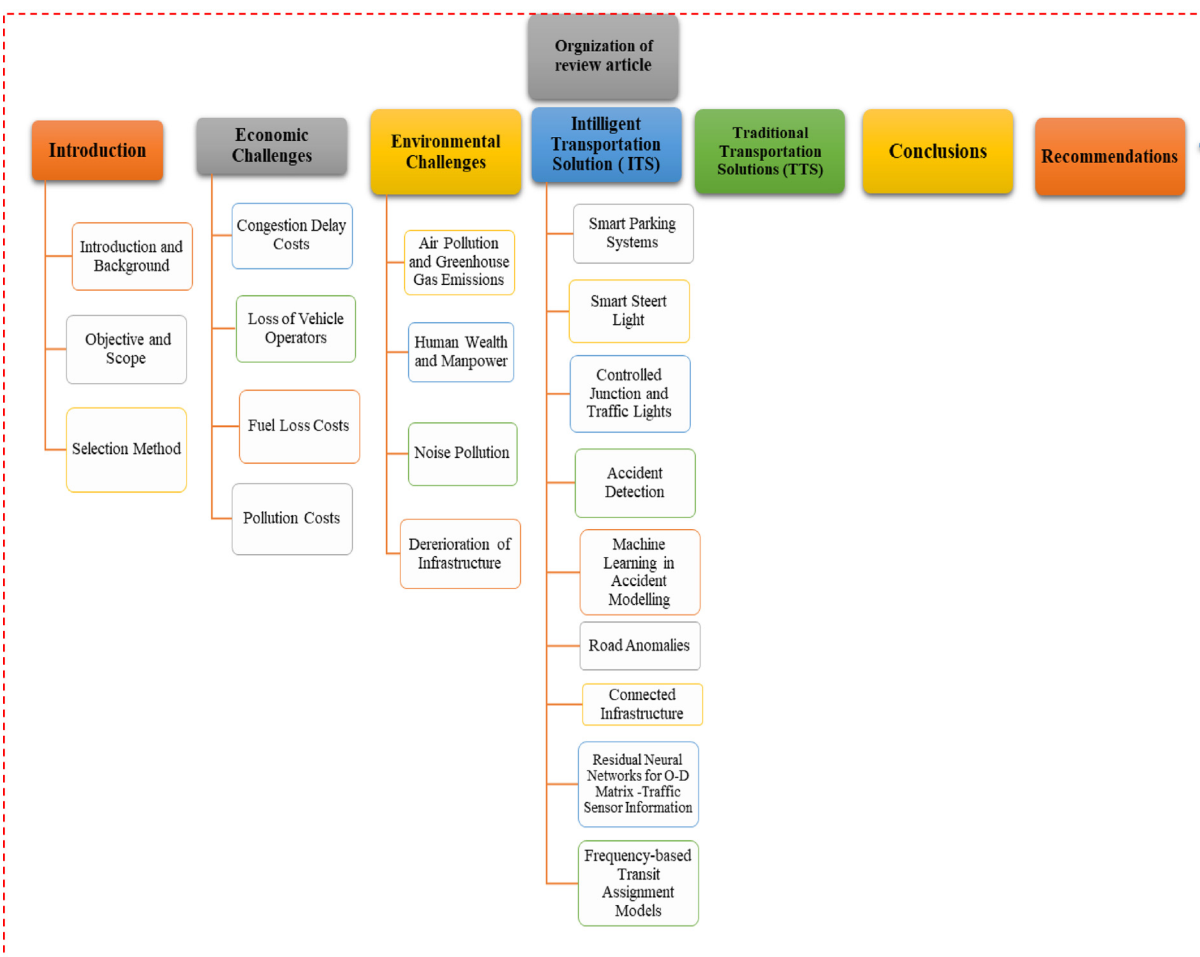

Fig. 3. Schematic of the paper structure.

increasing traffic congestion on business productivity has been emphasized in another field of transportation research. A study conducted in the United States has presented a structure for defining congestion and examining its effects on regional economic competitiveness and growth. It shows that congestion can undermine some of the advantages of agglomeration (returns to scale) that businesses experience when operating in larger urban markets (Akhtar and Moridpour, 2021). Recent research conducted in the United Kingdom has highlighted the negative impact of urban road traffic congestion on the productivity levels in congested urban areas. This congestion hinders the benefits of agglomeration, thereby reducing the achievable levels of productivity (Weisbrod and Fitzroy, 2011). However, previous research on this subject has primarily concentrated on a broad scale when addressing productivity and accessibility. None of these studies have explored the precise mechanisms at the individual level by which businesses encounter a decrease in productivity as a result of traffic congestion. The heightened congestion not only results in increased operational expenses for businesses but also restricts the geographical areas that can be reached from a specific business establishment. These concerns regarding business expenses and location have sparked concerns among regional business associations about the long-term viability of vital industries and freight transportation operations in the face of mounting traffic congestion. As a result, numerous studies have been conducted to analyze the business ramifications of urban traffic congestion (Ayantoyinbo, 2018). Transportation plays a vital role in the development of a society. It provides physical access to resources, markets, healthcare, education, and other social services. Without efficient transportation, the quality of life suffers, economic growth stagnates, and poverty reduction becomes unsustainable (Afrin and Yodo, 2020). The propensity for industrial development relies heavily on the effective means of communication and transport. However, when there is an inadequate transportation system and frequent traffic jams, it becomes challenging to achieve progress. This situation leads to violations of traffic rules and the use of private motorcycles and bajajs for commuting to work. Such practices are not only expensive but also risky in terms of time, safety, and the overall economy. Unnecessary delays, especially during peak hours in the morning and evening, further exacerbate these issues (Lwesya et al., 2021).

Zulkifli et al. (Zulkifli and Ponrahono, 2018) discovered that late arriving to work due to traffic reduces productivity. In this aspect, the time lost to traffic delays reduces the employees' regular working hours, which has an impact on the business as a whole. Lwesya et al. (2021) found that traffic congestion hinders the ability to move freely, interferes with city business operations, and diminishes productivity, all of which have an impact on both local and national activity. According to Manisalidis et al. (2020) Fig. 4 compared the economic costs of congestion with mortality risks, highlighting time and fuel waste and premature mortality due to urban traffic congestion. Time wasted accounts for the majority of economic costs, expected to increase from $56 billion in 2000 to $96 billion in 2030 where the value of time (VOT) method is used to estimate delay costs, highlighting the direct

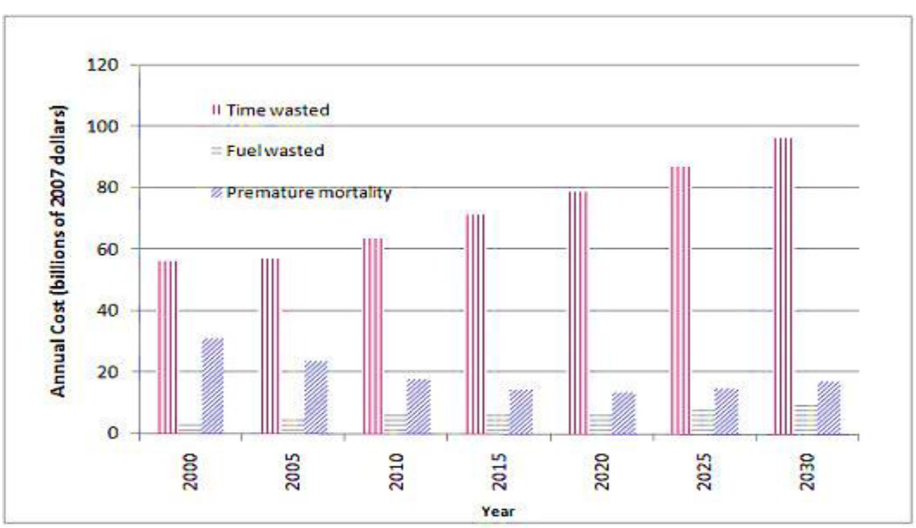

Fig. 4. Comparison of the economic costs of congestion with the monetized estimates of related mortality risks (Manisalidis et al., 2020).

proportionality of congestion. ITS can be used to create free-flow traffic by implementing various approaches. These systems use machine learning techniques, such as predictive classification and regression, to help determine the congestion status of available roads in advance, allowing traffic users to avoid congested areas and minimize congestion levels (Palander et al., 2019). The use of cameras and video fixation allows for the monitoring of traffic parameters, such as vehicle movement, safety distance between vehicles, and vehicle type, which can help forecast the movement of vehicles and optimize traffic flow management (Yijing et al., 2023). Furthermore, the development of automated traffic flow control algorithms based on optimization problems and recurrent calculations can redistribute capacity from underloaded to overloaded sections, reducing the number of congested sections and promoting free-flow traffic. By using these ITS and their associated technologies, it is possible to create more efficient and free-flowing traffic conditions (Hamadeh et al., 2021). Zhang et al. (2021) proposed a comprehensive intelligent transportation model that aims to alleviate traffic congestion by optimizing both predictive traffic signal control and predictive vehicle route guidance simultaneously based on their feedback regulation relationship. Meena et al. (2020) implemented a unique system that uses machine learning algorithms such as support vector machines (SVM), KNN, and convolutional neural network. This novel system aims to enhance the intelligence of the existing traffic control system at a four−way junction, thereby improving traffic efficiency and reducing vehicle waiting time.

Furthermore, there are economic impact analyses that should be taken into consideration before building transportation systems, whether intelligent or traditional transportation systems.

3.1.1. Congestion delay costs

Delay time is an effective measure used to measure road performance and estimates the additional time consumed by vehicles. Cost estimates and late fines are typically calculated using the VOT (Muneera and Karuppanagounder, 2018). Travel time expenses were calculated using equation (1). VOT refers to a traveler's willingness to pay for a unit reduction in journey time and is influenced by several variables, including the itinerary, routes taken, the socioeconomic situation of the traveler, and the amount of time spent traveling (Fazal Abbas Baqueri et al., 2016):

$$\text{Travel time costs} = \Sigma\, \Sigma_i \left(t_f - t_n\right) \times \text{VOT} \times V_i \tag{1}$$

where VOT is the value of time; V_i is the volume of the vehicle; i is the type of the vehicle; t_f is the average travel time; and t_n is the average travel time at the free-flow speed.

3.1.2. Loss of vehicle operators

Travel delays cause drivers to incur large financial losses, particularly bus, truck, and lorry drivers. Traffic congestion significantly lowers their quality of life due to their low income. More passengers result from more trips, which increases the bus driver's income. As a result of increased route length due to traffic congestion, the number of trips and daily income are decreased. The hourly wages of various vehicle drivers were used to quantify the financial cost of time lost due to traffic congestion. This was estimated using equation (2) (Fattah et al., 2022):

$$\text{Loss of vehicle operators} = \Sigma\, \Sigma_i \frac{I^i\text{day}}{NH^i\text{day}} \times DT \times V_i \tag{2}$$

where I^i hours is the average income per hour by i vehicle driver; DT is the delay time in an hour to congestion; V_i is the volume of i vehicle types, I^i day is the income of the vehicle's driver per day, and NH^iday is the average working.

3.1.3. Fuel loss costs

The term fuel economy refers to the ratio between the distance a vehicle travels and the amount of petrol it consumes. As the number of vehicles on the road increases rapidly, they use the same section of the road, generating traffic congestion and fuel waste in the vehicles. However, the stop-and-go movement of vehicles during congested periods further contributes to fuel wastage, resulting in higher fuel consumption and increased costs associated with fuel use. Using equation (3) the economic value of the fuel loss caused by traffic congestion is calculated (Fattah et al., 2022):

$$\text{Fuel loss costs} = \Sigma\, \Sigma\, FC_{ij} \times T_d \times V_i \times P_j \tag{3}$$

where V_i is the volume of type i of vehicles; P_j is the price of j fuel types; FC_i is the idle consumption of j types of fuel by vehicle types i (ml/min); and T_d is the delay time (min).

3.1.4. Pollution costs

As the vehicle progresses through several phases of operation, its fuel consumption increases and air pollution is a result of idleness, acceleration, and slowdown of moving vehicles The fuel emissions of traffic congestion have been calculated using equation (4) (Al-Arkawazi, 2018):

The cost of pollutants involves carbon dioxide, hydrocarbons, carbon monoxide, and nitrogen oxides.

$$\text{Pollution costs} = \Sigma\,\Sigma_{ij}\,Vi \times RL_{ij} \times Ef_{ij} \times Td \times CP_j \quad (4)$$

where V_i is the number of vehicles; RL is the length of the road; Ef_{ij} is the emission factor of j types of pollutants emitted by i type of vehicle; T_d is the delay time (min); CP_j is the costs of j types of pollutants; i is the type of vehicles, and j is the type of pollutants.

3.1.5. Congestion indices

Relative congestion index (RCI): the ratio of delayed time to free-flow travel time is defined as RCI. An RCI of 0 indicates very little congestion but values more than 2 indicates a substantial level of congestion (Afrin and Yodo, 2020). RCI is calculated as in equation (5):

$$RCI = (T_{ac} \times T_{ff}) / T_{ff} \quad (5)$$

where T_{ac} is the actual travel time, which is measured by dividing the distance traveled by the spatial mean speed of the distance traveled. The free-flow travel time (T_{ff}) may be determined using the spatial length to free-flow speed ratio.

Road segment congestion index (Ri): the normal road segment state and the length of the noncongestion state throughout the observation period can be used to calculate the road segment congestion degree, represented by R_i (He et al., 2016). The speed performance index state, which is higher than 50 km/h, is included in the noncongestion state. The R_i index value runs from 0 to 1, and the smaller the value of R_i, the more the congestion of the road segment. The road segment congestion index is expressed in equations (6) and (7):

$$R_i = (R_{avg} / 100) \times R_{NC} \quad (6)$$

$$R_{NC} = T_{NC}/T_t \quad (7)$$

where R_{NC} is the percentage of the noncongestion state; T_{NC} is the duration of the non-congestion state; T_t is the length of the observation period; and R_i is the road segment congestion index. R_{avg} is the average speed performance index.

3.2. Environmental challenges

Traffic congestion causing poor traffic performance has negative impacts on environmental quality and safety through higher fuel consumption, affecting human wealth and manpower, deterioration of infrastructure, increased air pollution, and worsened safety conditions. Based on the analysis of previous studies, it was noted that common environmental challenges revolve around many impacts, as shown in Fig. 5.

3.2.1. Air pollution and greenhouse gas emissions

Motor vehicles cause the most air pollution globally compared with any other human activity. They are responsible for virtually all of the carbon monoxide and lead in the air of cities, and a major portion of the oxides of nitrogen (NOx), volatile organic compounds, fine particles, and toxic chemicals (Wang and Zhong, 2023). Normal wear and inadequate maintenance can worsen the engine's condition, leading to increased particulate of carbon monoxide and hydrocarbon emissions. Studies before exhaust gas recirculation, fuel injection strategy, and NOx after treatment show that the impact of deterioration on emissions becomes more complex for modern engines. Modern engines heavily rely on after-treatment systems to control emissions, particularly NOx and particulate matter. These systems can achieve conversion efficiencies exceeding 95 and 99%, respectively. Even a slight system performance decline can significantly impact emissions, even if the engine continues to function as intended (Chang et al., 2014). Transportation continues to rely heavily on oil, as petroleum fuels make up 95% of the overall energy consumption in the transportation industry. Based on the information provided by the European Environment Agency, the transport sector is accountable for ~25% of the greenhouse gas emissions in the European Union. Moreover, transportation within cities and urban regions contributes to CO_2 emissions, which account for more than 25% of the total

Fig. 5. Environmental challenges of traffic congestion.

emissions produced by the transportation sector as a whole (Panchuk et al., 2020).

In addition, more than 40% of nitrogen oxide emissions and nearly 40% of primary emissions are attributed to road transport. Vehicles, being the largest consumer of oil globally, also release significant quantities of carbon dioxide and other gases that contribute to the phenomenon of global warming (Aminzadegan et al., 2022). As a result of the growing utilization of chlorofluorocarbons in automotive air conditioning systems, vehicles are also contributing significantly to the depletion of the stratospheric ozone layer. Furthermore, the detrimental effects caused by pollutants from vehicles are becoming increasingly evident (Li et al., 2020).

In 2022, the transportation sector was responsible for 38% of energy-related emissions, as reported by the Energy Information Administration. This sector made the highest contribution to carbon dioxide emissions compared with any other sector in the economy. Fig. 6 illustrates the distribution of CO_2 emissions among various modes of transportation (Bleviss, 2021). Moreover, the occurrence of traffic congestion compels drivers to frequently start and stop their vehicles, resulting in higher CO_2 emissions compared with smoother driving. In contrast, a car that maintains a consistent speed emits fewer CO_2 emissions in comparison to a car that is constantly interrupted due to external factors such as traffic congestion and cracks in the roads occurring from bad streetscape elements (Moussa, 2023). Jaller and Pahwa (2020) investigated the impact of low speed with frequent acceleration and deceleration on vehicle emissions in congested conditions. They found that these factors significantly contribute to increased emissions of CO and HC in heavy-duty diesel vehicles. The emission levels were found to be closely linked to various traffic-flow characteristics, including average flow speed, the frequency and intensity of vehicle acceleration and deceleration, the number of stops, and the vehicle's operating mode. The data presented in Fig. 7 illustrates several significant indicators of start–stop driving patterns, such as notably low average speeds. Consequently, the emission rate per kilometer is considerably higher in comparison to steady traffic flow. Furthermore, the graph highlights a correlation between driving at very low speeds and the release of elevated levels of CO_2 emissions (Neves and Brand, 2019). Machine learning algorithms can forecast different facets of a smart city, including environmental monitoring, traffic congestion, urban security, and waste management. These algorithms can be applied to sensor data, such as temperature, humidity, light, and pressure, to predict population numbers in closed spaces or soil moisture. Supervised learning approaches with cross-validation are used to verify performance. Logistic regression is also used to predict the engineering failure of structures. The importance of smart cities has been widespread due to their ability to address various living problems, such as safety concerns, traffic congestion, pollution, and noise pollution, with the help of internet of things (IoT) solutions (Sarasvathi, 2023). A research study conducted by Ayele and Mehta (2018) presented three different approaches. These methodologies solely relied on machine learning techniques. Their purpose was to track the levels of nitrogen dioxide, sulfur dioxide, and ozone by analyzing weather forecasts at various time intervals. The machine learning algorithms used in this study were built upon artificial neural networks (ANNs) and the M5P model. In 2015, at the Institute of Electrical and Electronics Engineering, Dhingra et al. (2019) designed a system for monitoring air pollution based on the IoT. This system demonstrated its effectiveness in facilitating decision-making processes and has the potential for further enhancement through the addition of more input layers. By using various layers, the city's cloud service platform successfully detects carbon emissions in the surrounding environment, thereby addressing challenges related to software, hardware, and network design. The development of the cloud service platform called City See (Raipure and Mehetre, 2015) has enabled the detection of carbon emissions in the environment. This platform consists of various layers, including an ad hoc sensor network, a sensing service cloudlet, and sensing customers. By incorporating these layers, the system effectively addresses challenges related to software design, hardware design, and network design. Patil (Patil, 2017) suggested a system that uses MQ-7 and MQ-2 sensors to detect carbon monoxide and sulfur dioxide. This device uses a Raspberry Pi

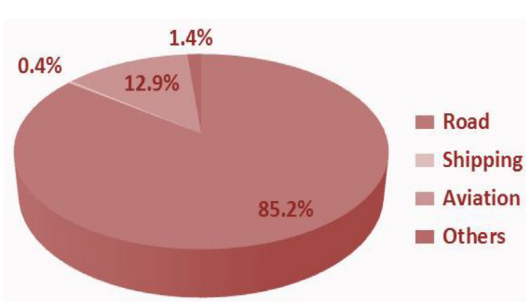

Fig. 6. Shares of different transport modes to total CO_2 emissions (Bleviss, 2021).

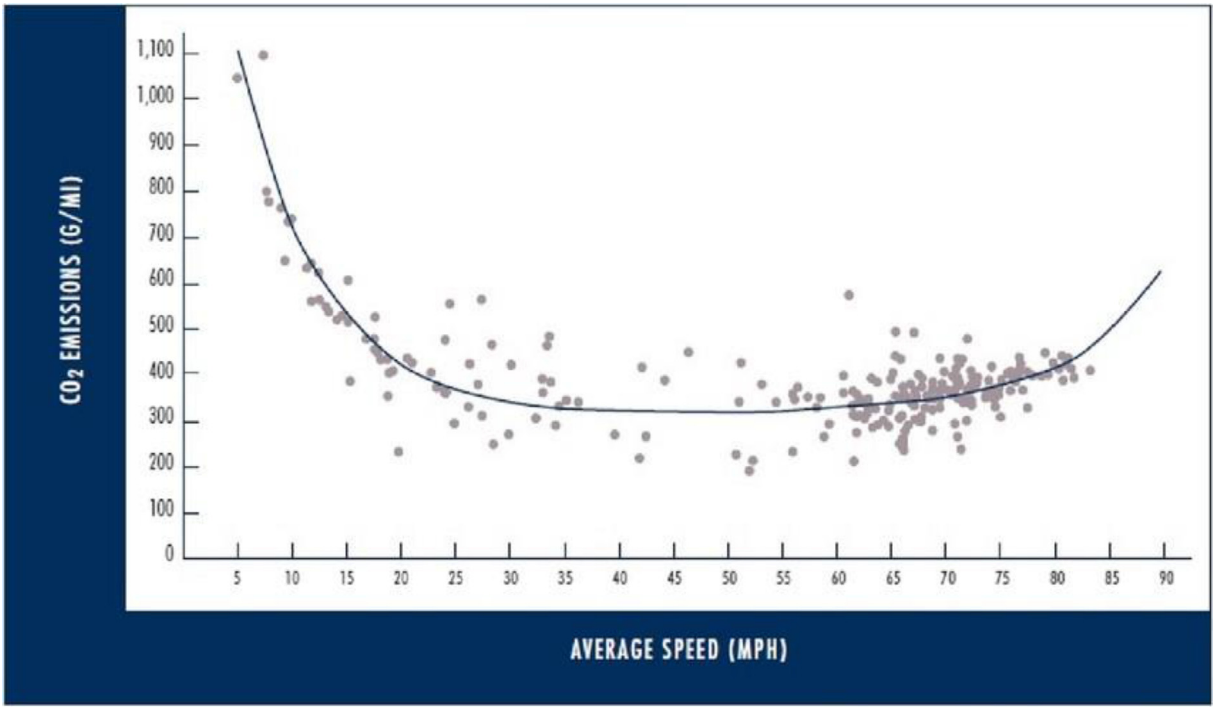

Fig. 7. Relationship between CO_2 emissions and average speed (Neves and Brand, 2019).

microcontroller to compare pollutant concentrations to the government's specified level. If the pollution level exceeds the specified threshold, both the traffic department and national environmental authorities will be notified.

3.2.2. Human wealth and manpower

Sharp increases in the number of vehicles in the city lead to longer commutes and traffic jams, which expose passengers and cargo to increased costs for transportation, an increase in accidents, and an increase in fuel consumption. In general, traffic congestion leads to socioeconomic losses (Fattah et al., 2022). The management of traffic flow on city highways and effective movement organization are crucial issues, but there is a lack of literature on the relationship between traffic congestion and road safety, particularly in terms of quantitative evidence (Lwin and Yoon, 2023). Different epidemiological studies have concentrated on the effects of motor vehicle emissions and have discovered increased dangers of respiratory morbidity, cardiovascular morbidity, cancer, and increased road death rates (Miller and Newby, 2020). For example, Retallack and Ostendorf (2019) proposed the hypothesis that there is a positive relationship between congestion and road death rates, in which volume over capacity ratio was used as a proxy to measure the level of congestion. In a separate investigation conducted by Jat et al. (2019), the correlation between traffic congestion and road safety was examined. Employing a comparable hypothesis, the researchers presented empirical data by analyzing fatality rates at various intervals throughout the day. Their findings revealed that the fatality rate during peak hours surpasses that of nonpeak hours. Albalate and Fageda (Albalate et al., 2021) found that traffic deaths are higher in more densely populated cities and found a positive relationship between congestion and density, that high levels of congestion imply more traffic deaths. Retallack and Ostendorf (2020) created a theory regarding the correlation between traffic volume and accidents. Their analysis showed that the relationship between the overall accident rate and hourly flow exhibits a U-shaped curve during uncongested traffic conditions. However, when examining data from congested traffic conditions, the accident rate demonstrates a steeper increase, indicating a stronger correlation between accident rate and hourly flow. According to Briz-Redón et al. (Briz-Redón et al., 2019), it was discovered that the frequency of accidents rises in a nonlinear manner when congestion levels are higher. They further proposed that effectively managing traffic to prevent such high levels of congestion would be the most effective approach to reducing the occurrence of accidents. Ahmad (2022) discovered a direct relationship between accidents and both the annual average daily traffic (AADT) and congestion index

(AADT/road capacity). Wang et al. (2022) also identified similar associations, attributing higher accident rates to increased traffic volumes. Furthermore, three US states demonstrated a positive correlation between AADT and collisions involving multiple vehicles. The data presented in Fig. 8 supports the notion that accident rates tend to rise with higher traffic volumes (Retallack and Ostendorf, 2020). According to Lu et al. (2021), Fig. 9 represents the nationwide estimates for premature deaths attributable to expected congested traffic for 2000−2030.

3.2.3. Noise pollution

According to the WHO, in the handbook of partner profiles on road safety collaboration, urban noise pollution is considered the third most dangerous type of pollution (World Health Organization, 2005). Road traffic is the major source of environmental noise exposure. Approximately 79% of the accumulated annoyance in the population is attributed to road traffic noise (Fig. 10) (Jadaan et al., 2021).

Noise pollution in urban areas is recognized worldwide as a major problem that impairs the quality of urban life, and as it continues to grow, so does the number of complaints from people exposed to noise (Cai et al., 2019). Anomohanran (2013) found that noise pollution from vehicular traffic becomes worse during peak hours and affects people's mental health. The correlation between the noise level and traffic volume is supported by the research conducted by Adeke et al. (2018) in their statistical examination of the noise levels during both daytime and nighttime in Ilorin metropolis, Nigeria. Previous studies have shown that traffic noise is very irritating not only to road users (pedestrians and car drivers) but also to people living in the area, especially those living near the road (Çolakkadõoğ et al., 2018). The consequences of traffic noise include impairment of vehicle control, mental illness, hearing loss, and other health issues that lead to traffic accidents (Kamandang et al., 2020). Noise is a major environmental issue that persists worldwide. Approximately 79 million people are subjected to noise levels that are deemed unacceptable, resulting in sleep disruptions and various health problems. Approximately 170 million individuals are greatly bothered by the noise in their residential areas according to the economic costs of noise on society is estimated to exceed 12 billion euros annually (Jadaan et al., 2021). The researchers have concerns that countries in Asia and less developed regions might experience more intense vehicular noise compared with the EU and relatively developed countries. Hence, researching vehicular noise pollution is of utmost importance for effective smart city management (Fu et al., 2023). Bravo-Moncayo et al. (2019) created models utilizing machine learning techniques, such as multiple linear regressions (MLR), SVM, and ANN, to forecast traffic noise unpleasantness. When compared with the MRL and SVM models, the ANN model produced the greatest results, lowering errors by 42 and 35% in training subsets, respectively. Errors decreased in testing subgroups by 19 and 24%. When ANN was used instead of MRL and SVM models in training subsets, the coefficient of determination R2 rose by 3.8 and 2.3 times, respectively, and by 1.7 times in testing subsets. This approach may be used to assess the effects of traffic noise in metropolitan areas, enhancing public health and developing relevant policies. A different study suggests a technique for forecasting individuals' inclination to pay to alleviate the annoyance caused by traffic noise. This approach incorporates factors

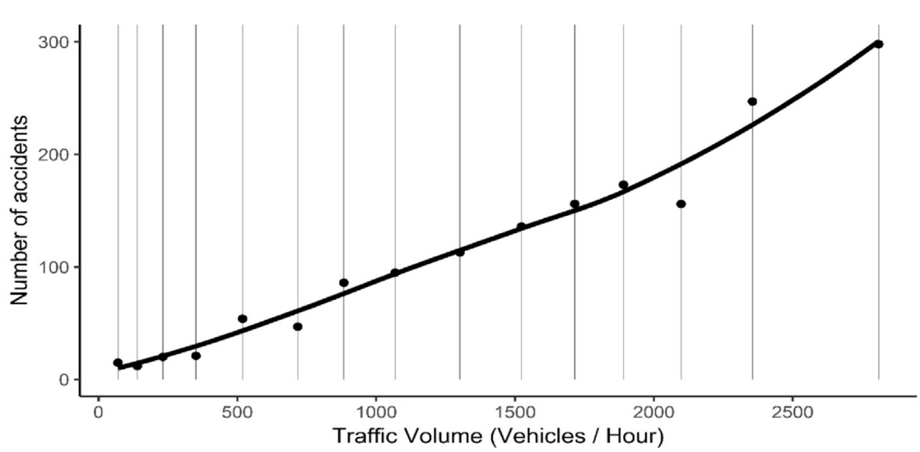

Fig. 8. Relationship between traffic volume and number of accidents (Retallack and Ostendorf, 2020).

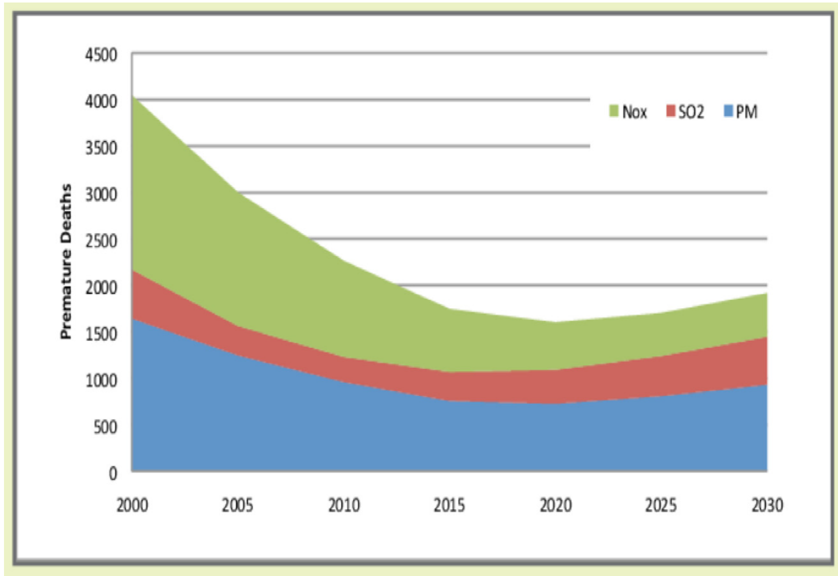

Fig. 9. Projected nationwide premature deaths attributable to expected congested traffic for 2000—2030 (Lu et al., 2021).

such as environmental noise perception, noise exposure level, demographics, and socioeconomic status of the participants, using a combination of ANN. The ANN model demonstrated a remarkable 85% improvement in accuracy when compared with a conventional econometric model (Bravo-Moncayo et al., 2019). The authors also showed in Carminati et al. (2019) have shown that a WASN is feasible to use in a range of environmental monitoring applications, with an emphasis on monitoring urban ambient noise pollution. As one of the WASN system's technological constraints, the authors continued to work on the WASN concept later on, concentrating on the issue of data transmission from the sensor nodes to the central server. However, IoT

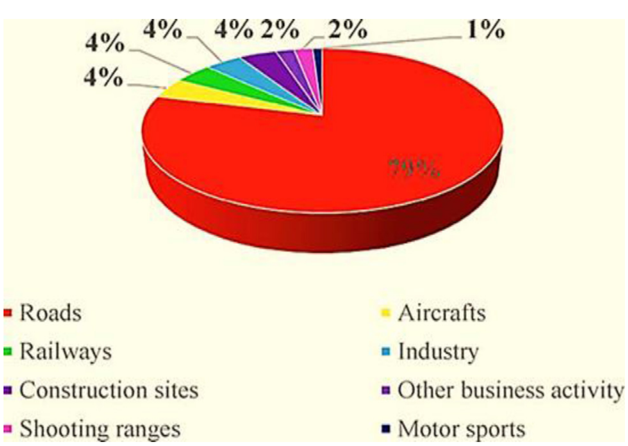

Fig. 10. Distribution of human noise pollution by the type of noise source (Jadaan et al., 2021).

technology presents promising solutions by leveraging advanced tools to enable remote monitoring capabilities. It has demonstrated its effectiveness in a wide range of applications, including monitoring vehicles from a distance, tracking performance, monitoring emissions, providing remote anti-theft capabilities, monitoring driver health, and implementing ITS in smart cities (He et al., 2016). A low-cost noise pollution monitoring system was proposed by Agha et al. (2017), which uses the IoT to offer geotagged data and real-time pollution levels to the inhabitants of smart cities. Rahim et al. (2021) suggested a smart city noise pollution monitoring system for cars that are enabled by the IoT to safeguard the health of city inhabitants. Using sensors that measure noise levels, a 360° camera, LIDAR, and GPS, the system keeps an eye on each car and those in the vicinity. Stakeholders, including car owners and local authorities, are instantly notified of real-time data monitoring. The system's objectives are to provide the best possible vehicle noise monitoring system, reduce health issues caused by noise pollution, and raise public awareness. The architecture of the environmental pollution monitoring system, which includes the sensing layer deployed in different zones across the city, was proposed by Malche et al. (2019) in addition to measuring sound levels, this system also monitors various other environmental parameters. The collected data is then transmitted to the city authority using IoT technology, enabling them to receive timely notifications. Jacyna et al. (2017) suggested a system that monitors the pollution and noise produced by vehicles. If any vehicle exceeds the set limit, it will be reported to the traffic department and national environmental agencies.

3.2.4. Deterioration of infrastructure

Infrastructure is deteriorating as a result of an increase in travel and traffic congestion on the highways. There is a tremendous strain on the preexisting infrastructure, including transportation, due to the high and growing population density. Unfortunately, due to investment and regulation restrictions, the supply side of transportation infrastructure typically stays unresponsive to the expanding demand, resulting in a mismatch between what is needed and what is available (Svanberg, 2018). Traffic congestion can cause wear and tear on roads due to increased traffic volume and weight of vehicles, which can lead to increased maintenance costs for infrastructure (Falcocchio et al., 2015). Table 1 summarizes previous studies' solutions to overcome economic, and environmental challenges and traffic congestion.

4. Traffic congestion challenges in Egypt

4.1. Case study: Greater Cairo

Egypt is one of the most populous countries in Africa and the Middle East. Traffic congestion is a significant issue in Egyptian society, with public transportation posing a significant obstacle to its use. The people have a hard time reaching their destinations or carrying any estimation about the time that would take them to reach their final destinations (El-Kadi, 2013). The Greater Cairo Metropolitan Area (GCMA) comprises more than 28.7 million people, accounting for more than one-fifth of Egypt's total population. In terms of GDP and employment, the GCMA makes a sizable contribution to Egypt's economy. The GCMA is expected to have a population of 40 million by 2027, which suggests that the area will also grow economically (Gabr et al., 2022). Therefore, the GC transport network faces many challenges such as corridor congestion, traffic delays, and overcrowding of traffic vehicles during peak hours. This insufficient network leads to repeated transfers between modes, causing users to rent or buy private cars. These adverse effects have very real and large monetary and nonmonetary costs not only for the economy of the GCMA, but the economy of Egypt as well. These financial costs include not just the increase in travel times but also increasing costs as a result of using too much fuel and negative effects on people's health due to air pollution, accidents, and economic production effects. Road development projects will reduce traffic congestion and lead to a massive drop in CO_2 emissions in developing countries, impacting global emissions from the transport sector, reducing daily travel time, and reducing accidents (Kumar et al., 2019). ITS play an important role in improving and increasing the safety, speed of movement, fluidity, and reliability of traffic and in reducing risks, accident rates, traffic jams, CO_2 emissions, and air pollution (Injadat et al., 2021).

Fig. 11 shows some indicative photos of the traffic congestion. To confront these challenges Egypt has several road development projects planned for 2023 (illustrated in Fig. 12). These projects aim to reduce traffic and facilitate citizens' movement. Some of the upcoming road infrastructure projects in Egypt include:

(1) The construction of a monorail rapid transit system is currently underway in Cairo, Egypt. This system consists of two lines: a 57 km line that connects the new administrative capital with the eastern side of the Nile, and a second 42 km line that connects the western side of the Nile with the 6th of October city. Once completed, this monorail will hold the title of being the longest driverless monorail system globally. It will have the capacity to transport an impressive 45 000 passengers per hour in both directions.
(2) Cairo–Alexandria desert road, which has been expanded to a six-lane highway.
(3) Cairo Suez highway road development project, which includes expansion and upgrading works from Cairo to Suez.
(4) Egypt secured a contract for a 2000 km high-speed rail system, consisting of three lines, in August 2022. The fully electrical network aims to reduce carbon emissions by 70% compared with current car or bus transport, connecting port cities Ain Sokhna, Marsa Matrouh, Alexandria, and Cairo.
(5) Egypt's investments in roads and bridges have increased by more than 90% over the past 3 years to reach $1.79 billion in 2020.
(6) Elsewedy Electric is constructing four crossing bridges on the Cairo–Alexandria Road, one of the biggest transportation projects in Egypt.
(7) According to the Ministry of Transportation, Egypt has built 935 bridges nationwide over the past 9 years, increasing their numbers to 2435 bridges. In addition, Egypt has been investing in the national road project, which includes the construction of 8000 km of roads and bridges.
(8) About 15 billion Egyptian pounds ($650 million) were spent on developing Sharm El Sheikh, with

Table 1. Previous studies' solutions to overcome economic, and environmental challenges and traffic congestion.

References	Issues	Type of impact	Scope	Remarks
Gohar and Nencioni (Gohar and Nencioni, 2021)	Increasing traffic congestion	Economy	Discuss communication technologies, wireless sensor networks, and the benefits of technology in smart grid applications	Proposes an innovative method for energy-efficient congestion control in wireless sensor networks, focusing on optimized rate-based routing for efficient transmissions Allow car owners and manufacturers to monitor the performance of their cars in real time Discuss the impact of 5 G on information and communication technologies in smart transportation systems
Dogru and Subasi (Dogru and Subasi, 2018)	Risk of vehicle collisions and accidents causing serious injuries	Economy	Presented an intelligent traffic accident detection system that sends traffic alerts to drivers based on vehicle speeds and coordinates using simulated data from vehicular ad hoc networks (VANETs), demonstrating the potential of machine learning methods in ITS accident detection	Developed smartphone application-based software that detects accidents and notifies emergency responders of their location using an accelerometer A mathematical model has been developed to improve vehicle-to-vehicle communication by introducing an intersection-detection system that automatically allows vehicle turns at intersections, thereby reducing crashes
Beojone and Geroliminis (Beojone et al., 2021)	Reducing greenhouse gas emissions in urban areas	Environment	Reduce congestion-related air pollution, lessens travel time, and solution to a fuel consumption problem	To solve the problem of reducing gasoline consumption, a system of traffic signals set in advance was devised, and a driving strategy with minimum fuel consumption was achieved
Al-Dweik et al. (Al-Dweik et al., 2017)	Traffic parking congestion	Environment	Reduce parking-related congestion and air pollution, public transportation, and the use of smart parking sensors, technologies, and applications and evaluate their applicability to open parking lots	Suggested an IoT-enabled parking lot and a smart sign to provide important information as part of the smart parking plan Smart management of traffic signals using wireless sensor networks
Nurhadryani et al. (Nurhadryani et al., 2022)	Increase traffic congestion, increase fuel consumption, and air pollution	Environment	IoT sensor technologies are used to check the condition of road infrastructure	Employed roadside-based IoT systems with ultrasonic sensors have been used to effectively monitor traffic congestion in real time Also, explores resource management issues in the internet of vehicles paradigm, focusing on optimizing energy efficiency and proposing a fog computing vehicular network framework to enhance local computation and storage requirements
Lv and Shang (Lv and Shang, 2022)	Vehicle exhaust emissions, and intervehicle safety	Environment	Predictive hybrid electric vehicle control to improve fuel efficiency, reduce emissions, and inter-vehicle safety in vehicle-following scenarios	Developed a predictive control system for hybrid electric vehicles to explore the correlation between fuel efficiency, vehicle exhaust emissions, and safety.

Fig. 11. Some indicative photos of the traffic congestion (https://images.app.goo.gl/d7Nk9GLEkcRGwnZ86.).

a large portion of this money going to improving the environmental aspects of the tourist city.

(9) The Tunnel Road was constructed to transfer traffic coming from Martyr Ahmed Hamdi Tunnel to Sharm El-Sheikh and vice versa and to contribute to increasing the urban sprawl and creating new urban development complexes in addition to stimulating tourism in South Sinai. It was also constructed to connect the road with the main cities. Four sublinks with two lanes for

Fig. 12. Photos of several road development projects in Egypt (https://images.app.goo.gl/qr9Q3L3CmAMtzUCk9.).

each direction were created. The tunnel road is 22 km long (5 km/Ras Sidr – 5 km/Abu Zenima – 6 km/Abu Rudies – 6 km/Al-Tor). To provide road users with security and necessary services, seven gates were built (Oyoun Moussa, Ras Sidr, Abu Zenima,- Abu Rudeis, Wadi Ferran,- Al-Tor, and Sharm El-Sheikh).

5. Traffic congestion solutions

5.1. Traditional transportation solutions

Traditional methods of expanding the network of roads have proven inadequate over time. Building new or improving existing transportation infrastructure may provide short-term relief, but often increases traffic congestion as expanded roads attract more passengers. The effectiveness of these solutions may vary depending on the local context and infrastructure (Suryani et al., 2021). To improve urban planning integration, this is crucial to constructing compact, mobile, mixed-use communities centered on excellent public transport, which is a key component of sustainable urban mobility systems in emerging nations. It can help reduce dependence on vehicles and enhance sustainable transportation options. In megacities, we must use intelligent signalization systems rather than antiquated manual signalization where the main sources of congestion are intersections, which this approach may greatly reduce. By making changes to the infrastructure of buses, trains, and subways, public transportation may become more appealing and help reduce the number of vehicles on the road. Roads should have different lanes for different vehicle types, and drivers should be compelled to maintain lane discipline through legislation and financial penalties (Kavta and Goswami, 2018). However, congestion pricing, roundabouts, and traffic signals are some examples of traffic management techniques that can help manage traffic flow ease congestion, and increase the capacity of road networks by constructing new road networks and extending existing ones to assist in relieving traffic congestion (Thondoo et al., 2020).

5.2. Intelligent transportation solutions

ITS refers to the utilization of sensing, analysis, monitoring, and communication technologies in ground transportation to enhance safety, mobility, and efficiency. ITS encompasses a diverse array of applications that facilitate the processing and sharing of information, ultimately leading to congestion reduction, enhanced traffic management, minimized environmental impact, and amplified transportation advantages for both commercial users and the general public (Kayal and Perros, 2017). The ITS consists of various technologies, including electronics, information processing, wireless communications, and control mechanisms, all aimed at enhancing the safety, efficiency, and convenience of the overall surface transportation network (Yijing et al., 2023). The primary driver of ITS investment in recent years has been to enhance transportation system operations through productivity gains and the preservation of lives, money, time, and energy. ITS can provide a variety of benefits and important transportation purposes. It can also help meet growing demand using the latest advanced communication technologies to improve safety and make full use of existing roads (Palander et al., 2019).

ITS have a wide range of uses. Based on their functions, these systems are divided into many types.

5.2.1. Smart parking systems

A smart parking system is a structural framework that combines different application platforms within embedded systems. Through a network layer, users can request reserved parking spaces, which are then processed. The network layer is used by parking providers to manage user requests and engage with the transaction layer (Kayal and Perros, 2017). The smart parking system consists of four components: the application layer, network layer, transaction layer, and the physical layer (Soaibuzzaman et al., 2019). A constant struggle in modern cultures, particularly in congested cities, is obtaining a parking spot due to the rapidly increasing number of automobiles (Badr et al., 2020). For individuals, it takes some time to find a free parking space. For example, a driver can spend ~7 and 20 min searching for a free parking space in Los Angeles (United States) and Cairo (Egypt), respectively (Li et al., 2016a). Smart parking systems are becoming increasingly popular as a viable solution to the ever-growing issue of locating vacant parking spaces. These systems incorporate IoT devices within the parking slots to monitor their availability. By establishing a direct line of communication with a parking server, these devices enable the provision of real-time information regarding parking availability to drivers. Furthermore, this technology allows drivers to conveniently make online reservations through their smartphones (Oladimeji et al., 2023). Reserved parking and intelligent parking solutions offer a groundbreaking approach to ensuring a guaranteed parking space. Moreover, they effectively mitigate carbon emissions by eliminating the necessity of aimlessly driving around in search of parking. By prebooking a parking spot and leveraging advanced technologies, the use of smart parking systems has the potential to reduce more than 80% of pollutant emissions per mile, especially when powered by alternative energy sources such as natural gas, biofuel, electricity, hydrogen cells, etc (Dong et al., 2023). Smart parking systems come in different designs, scopes, and functionalities, which are contingent upon the context, objectives, and stakeholders involved (Alsaffar et al., 2018). Several cities worldwide have adopted the concept of smart cities and have made efforts to either upgrade their infrastructure or actively pursue strategies to adapt their current assets and networks. Among these cities are London, New York, Paris, Amsterdam, Reykjavik, Tokyo, Busan, Dubai, Stockholm, and Santander (Ismagilova et al., 2020). Barcelona, a city known for its smart initiatives, has successfully integrated the IoT into its urban systems, particularly in the realm of smart parking technology. Back in 2014, the city's Les Corts district witnessed the deployment of 600 wireless parking sensors, discreetly embedded beneath the asphalt. These innovative sensors play a crucial role in identifying available parking spaces and promptly notifying motorists in real time. The program aims to reduce emissions and congestion by providing real-time directions on open parking spaces. Access to sensor data is conducted through the proprietary API of various technology vendors operating in the smart parking space (Sotres et al., 2019). Riga City provides paid parking services and operates an underground parking facility that can accommodate ~167 vehicles. This is facilitated by an automated ticketing machine, which issues drivers with tickets containing QR codes and time stamps upon entry and exit. To prevent unauthorized parking, vehicles that exceed their allotted parking time are subject to additional charges (Zacepins et al., 2017). The city of Santander in Spain has implemented a smart parking solution with more than 250 outdoor sensors in primary parking centers. These sensors detect parking space availability using ferromagnetic detection, and an API is created for information exchange between sensors and clients. Real-time data is disseminated to manufacturers and processed into free occupied events per parking spot. The framework is also used for traffic management and traffic light control (Lanza et al., 2016). Arthurs et al. (2022) analyzed the connections between traffic congestion and greenhouse gas emissions using user-generated information from Google Trends. By eliminating the need to search around parking lots for a spot, making it easier to detect open areas beforehand minimizes traffic and pollution. Additionally, machine learning algorithms are used to find open parking spaces using image data. Furthermore, Rahman et al. (2017) presented a smart vehicle parking system using IoT technology, using IR sensors to detect vehicles and available spaces. The system updates sensor data every 10 s, with vacant spaces checked online through a cloud-based server. Rizvi et al. (2019) developed an agent-oriented smart parking suggestions system, which can suggest a new intelligent parking strategy and users can establish their parking preferences through local agents, specifying their preferred sites and walking distances. The system will consider all this data when applying to a parking space. Fig. 13 shows a smart parking system that uses IoT applications to monitor and notify users about parking lot availability. The system is divided into three sections: on-field network, cloud platform, and user-side

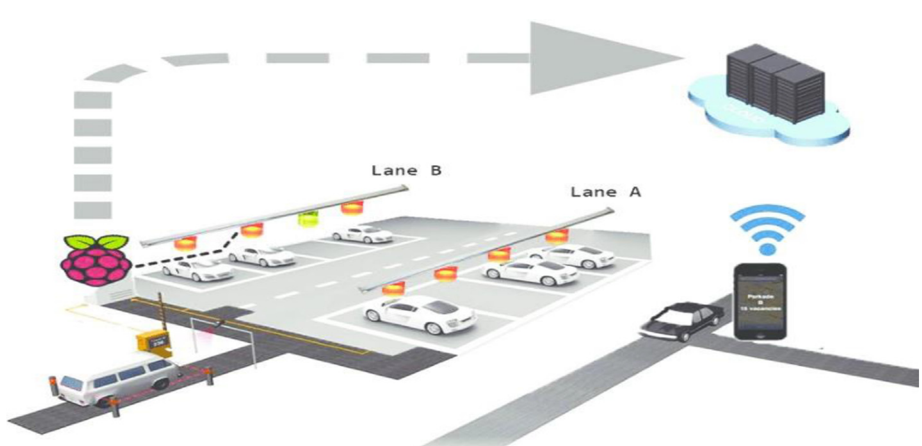

Fig. 13. A smart parking system (https://images.app.goo.gl/4zsZC2FYZbrGYVMu5.).

platform, with vehicle detection sensors detecting parking lot occupancy. IoT-enabled smart parking systems present security and privacy challenges. Ensuring responsible data collection and usage is a challenge that needs to be addressed to maintain user trust. There are risks and concerns associated with the collection and use of data by parking systems, such as unauthorized access or data misuse (Ali and Khan, 2023). A collective blockchain is established by multiple parking lots to effectively and openly administer the system. The parking offers are documented in a shared ledger, and a mechanism for fair rates is implemented. To safeguard the privacy of the driver's location, techniques for retrieving private information are used. Authentication during the booking process is conducted using a random signature, while a time-based anonymous payment method discourages noncommitment. The system ensures security, privacy protection, and imposes minimal burdens in terms of communication, computing power, and storage (Badr et al., 2020). The research conducted by Ali and Khan (2023) proposed a new trust management technique that integrates machine learning algorithms. Their primary emphasis lies on credibility, availability, and honesty. Through the utilization of SVM and ANNs, they have developed a hybrid model. This model incorporates ensemble machine learning methods to choose the most suitable model from a collection of trained models. The results of their experiments demonstrate an outstanding accuracy rate of 96.43% in precisely predicting and eliminating malicious or compromised nodes. These outcomes provide compelling proof of the efficiency of this hybrid approach. According to Alqazzaz et al. (2018) presented a security and privacy-centric architecture for intelligent parking systems. The architecture is built upon the publish/subscribe communication model to facilitate the seamless exchange of a substantial amount of data with numerous clients. On one hand, it offers functional services such as detecting parking vacancies, providing real-time information to drivers regarding parking availability, guiding drivers, and enabling parking reservations. On the other hand, it incorporates security measures at both the network and application layers.

5.2.2. Smart street lights

A smart city cannot function without smart streetlights, which fall under the category of smart transportation service, while smart streetlights may be used to increase public safety. An analysis of existing implementations of information and communication technologies such as the IoT in streetlights would be required to appreciate the numerous recommended models used in smart street lighting infrastructure (Dizon et al., 2022). Sharma and Kumar (Sharma and Kumar, 2023) proposed an easier method for smart lighting, where Raspberry Pi, a type of single-board computer, is used in this design to connect the lamp to a light. The suggested system included a brightness sensor node, IoT-based real-time street lights that controlled LED lighting, a motion sensor, and a short-distance communication network. In addition, Chen et al. (2022) proposed an intelligent lighting system in which each lamp post serves as a Wi-Fi hotspot, enabling the transmission of different kinds of collected data to a primary web server where the lights dynamically dim or turn on/off to reduce costs. The lighting poles functioning will be improved by the addition of cameras and sensors, which will be used to monitor the region and guarantee people's safety in an emergency. Sánchez et al. (Sánchez et al., 2013) studied the integration of IoT with traditional utility infrastructures and discussed the potential of adding new services to current paradigms in lighting to give a more efficient public service for the city. Fig. 14 shows the innovative design of the automatic street lighting platform for intelligent cities.

5.2.3. Controlled junction and traffic lights

At intersections, traffic flow is automatically controlled by intelligent traffic lights. By switching up which vehicles have priority, they help the flow of traffic. As a result, traffic moving in one direction can move freely, but traffic coming from another direction is kept back to wait its turn (Tomar et al., 2022). Peixoto et al. (2023) suggested a novel decentralized wireless sensor network traffic light control system. The three tiers of the system architecture are composed of wireless sensor networks, local traffic flow model policies, and high-level coordination of traffic signal agents. Yazdani et al. (2023) proposed a wireless sensor network-based adaptive traffic light control system that alters the timing and duration of traffic lights depending on the volume of real-time traffic detected, for a single intersection. Louati et al. (2018) designed a traffic signal management system based on an artificial immune system to control an isolated intersection and develop a regulatory plan as soon as congestion or an accident is detected.

Hossan and Nower (2020) created a hierarchical operating architecture for regulating traffic lights in dynamic traffic circumstances. The suggested framework, which is built on a multi-agent system, manages to reduce possible traffic congestion and

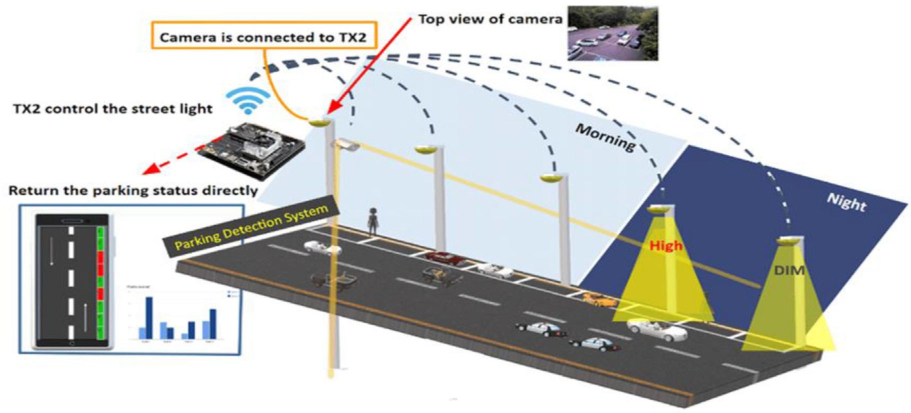

Fig. 14. Innovative design of the automatic street lighting platform for intelligent cities (Jin et al., 2016).

reduce average journey time for vehicles in urban areas. Li et al. (2016b) in their work employed a deep learning methodology to regulate the timing of traffic signals in their study. This approach enables the automatic adjustment of signal timings by considering the traffic flow and pedestrian availability. Fig. 15 depicts a dynamic traffic light control system based on fog.

5.2.4. Accident detection

Every city should prioritize accident detection and prevention because a successful prevention plan can help save lives. This is the field of ITS. An IoT cloud platform was proposed by Belkouri et al. (2022) to facilitate traffic visualization and offer early warnings of unforeseen delays that may cause accidents. Djahel et al. (2015) suggested that the volunteer automobiles will be used to gather GPS data, which is then sent to a cloud server through a 4 G network. The cloud server maintains GPS data with the aid of open street maps and open global trading system platforms. The success of the implementation depends heavily on the system's reaction time, and the offered method can send an alert over 1 km in a little under 120 ms. According to Raosaheb Patil and Suresh Pardeshi (Raosaheb Patil and Suresh Pardeshi, 2023), this system creates an alert system for accident sites using sensors, a global system for mobile communication (GSM) and GPS. When an accident occurs, an automatic alert is triggered, and information about the collision, including the victim's identity and vehicle license plate, is sent to the hospital and police station closest to the accident scene with a link to Google Maps. In addition, Akilesh et al. (2023) developed a complete operational system that uses a shock sensor to detect accidents and a GSM module to deliver SMS messages. The suggested system's reliability testing demonstrated that it is reliable, accessible, valuable, practical, and implementable, especially when the IoT device continues to provide continuous event warnings until confirmation from authorities is received. Nasr et al. (2016) introduced a system that uses the accelerometer, GPS, and other sensors in a

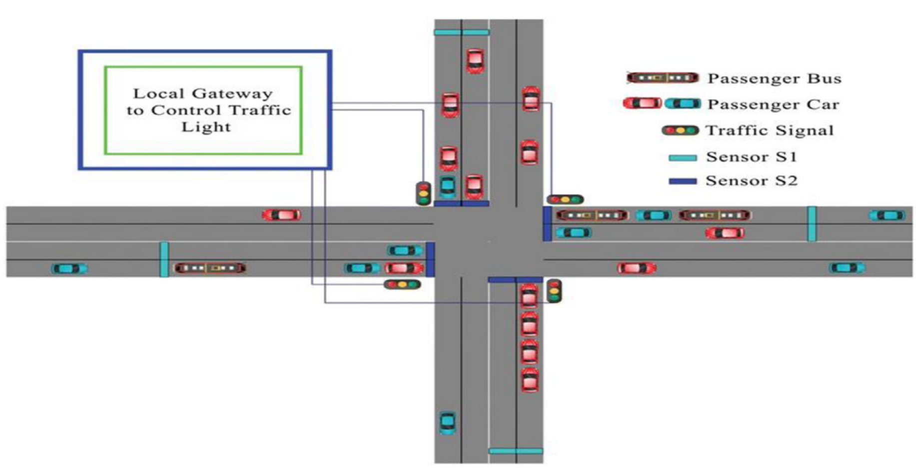

Fig. 15. Fog-based dynamic traffic light control system (Hossan and Nower, 2020).

smartphone to identify accidents and save details about them on a server. According to Khaliq et al. (2018), a prototype for automated accident detection is presented using IoT and vehicular ad hoc networks. The vehicle features mechanical and medical sensors that can detect accidents and assess the severity of emergencies, ensuring efficient and safe driving. To track down traffic accidents, Dogru and Subasi (2018) compared a random forest model to a SVM. In a traffic simulation scenario, data collection is carried out using SUMO. Oladimeji et al. (2023) created a model for improved driver assistance systems that leverage machine learning prediction and aid drivers during emergency maneuvers. Khot et al. (2018) created a smartphone-based system that detects accidents and alerts emergency personnel of their location. Furthermore, Chaturvedi and Srivastava (2018) proposed an accident recognition system that uses a single sensor to identify accidents, and the location is sent to the police station. However, Kumar et al. (2023) suggested a new traffic modeling and prediction framework, focusing on CRNN, which was introduced using a UK traffic accident dataset. The model was trained using CRNN and classified on an edge computing platform. The system alerts moving vehicle units when potential dangers are detected, transmitting an alert signal. The model outperformed other models, achieving an average accuracy of 95.10%. This research area shows promise and warrants further investigation with diverse datasets. The model's performance was assessed using metrics like accuracy, specificity, sensitivity, recall, F-score, and memory utilization. This research area shows promise and warrants further investigation with a diverse range of datasets. Fig. 16 demonstrates a prototype of automated accident detection using a vehicular ad hoc network and the IoT. The vehicle utilizes mechanical and medical sensors to detect accidents and gauge the severity of emergencies (Bhatti et al., 2019).

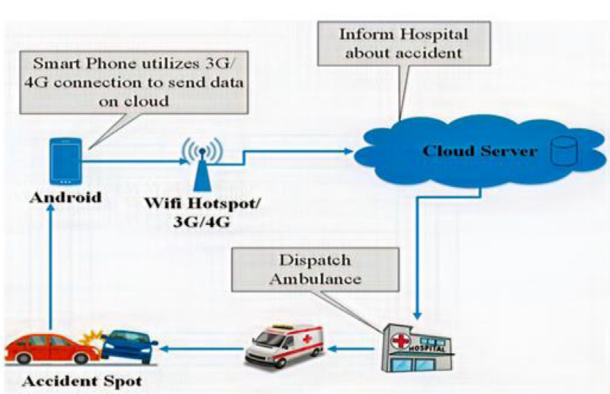

Fig. 16. Design of a notional block schematic for an accident detection system (Bhatti et al., 2019).

5.2.5. Machine learning in accident modeling

Traffic accidents are closely linked to road network congestion, which increases the risk of accidents and delays. According to the Permanent International Association of Road Congresses and the WHO, low-income countries have greater mortality rates than high-income countries (Berhanu et al., 2023). Machine learning models, including deep neural network models, and intricate optimization algorithms like UIMA, NSGA-II, and MOPS algorithms, play a crucial role in analyzing and predicting traffic accidents. By leveraging these models, proactive road safety management technologies can be developed to enhance road safety and alleviate traffic congestion (Megnidio-Tchoukouegno and Adedeji, 2023). Moussa et al. (2022) developed a deep learning technique using a Variance-Based Globa1 Sensitivity Analysis (VB/GSA) to analyze rear-end collisions in North Carolina. The technique uses a deep residual neural network structure with shortcuts, bypassing some levels in the deep network design. The trained DRNN model was used in a Monte Carlo simulation to explore the effect of explanatory components on INJ-S levels. The technique achieved an overall accuracy of 83% and outperformed the OLR model, identifying key factors influencing rear-end collisions at the INJ-S level. The study conducted by Berhanu et al. (2023) suggested a dynamic traffic incident management system that focuses on various aspects such as accident detection, identification, and resolution. The system also includes accident information dissemination, traffic incident management, and accident recording and analysis. Siswanto et al. (2023) presented an innovative approach to predict and alleviate urban traffic congestion. Their method involves analyzing real-time data and considering multiple factors such as traffic flow, road network topology, and weather conditions. The objective of this approach is to effectively manage traffic in advance, thereby preventing accidents and minimizing congestion. In Qatar, a study was carried out by Abou-Amouna et al. (2014) to investigate the factors influencing road accidents and forecast the total number of accidents in 2022. The researchers used both MLR and ANN models. Through their analysis, they determined that MLR outperformed ANN in terms of accuracy, primarily due to its capability to handle significant variations in data. Contreras et al. (2018) used an innovative ANN model to precisely predict traffic accidents in Nuevo León urban regions. The programming function of the Scilab software was used in this investigation to validate the maximum sensitivity of the predicted neural network. Ghasedi et al. (2021) used various statistical methods, such as the logit model, factor analysis, and machine learning, to uncover the main factors that contribute to accidents in suburban areas. Their research focused on the busiest highway in Guilan Province, which is located in northern Iran and resulted in the development of an accurate model for forecasting future accidents. The study emphasized the importance of environmental variables such as rainfall and inadequate lighting in worsening the severity of pedestrian accidents.

5.2.6. Road anomalies

Road anomaly detection is crucial for intelligent transportation because road condition directly affects many transportation elements. Finding potholes and other irregularities in the road and warning drivers are the main duties of the road anomaly detection system (Zantalis et al., 2019). Poor road conditions can cause accidents, traffic congestion, and vehicle damage. Routine inspections are necessary for the efficient operation and safety of car and pedestrian traffic on various roadway system components like pavement structures, culverts, and guardrail barriers (Serigos et al., 2018). Nondestructive testing technologies like GPR and falling weight deflectometer are effective tools for inspecting and assessing the state of roadways as they age. Mobile sensing and road condition surveys can automatically identify and classify road anomalies using data mining techniques from smartphone data, enhancing the inspection process (Silva et al., 2018).

Seraj et al. (2014) proposed a system that uses mobile phones equipped with inertial sensors, accelerometers, and gyroscopes to detect road surface anomalies. Saffarini and Khamayseh (2023) proposed a new method for detecting road abnormalities based on the use of the accelerometer, GPS sensor, and microphone built into the smartphone. Mohamed et al. (2015) propose a road condition monitoring system that may identify defects on the road, such as speed bumps. The accelerometer and gyroscope sensor were used in the proposed methodology to cross validate the detection results obtained from the gyroscope as primary indicators of road deformations. According to Long et al. (2021) using a mobile camera and a convolutional neural network, a technique has been developed to detect concrete cracks in images under irregular lighting conditions. The generated convolutional neural network scores with ~98% accuracy and is trained on 40 K images with a resolution of 256 × 256 pixels. According to reports, the recommended method was particularly useful for locating small cracks in dimly lit environments that are difficult to locate using more traditional methods such as Canny and Sobel edge detection. In addition, transfer learning and deep learning models that have already been trained were recommended for detecting crack damage in images of civil infrastructure taken by unmanned aerial vehicles. The results show that the suggested technique can quickly and easily achieve up to 90% accuracy in crack recognition in a real-world environment without any data augmentation or preprocessing.

5.2.7. Connected infrastructure

The adoption of IoT technology has significantly enhanced the efficiency of modern transportation. Furthermore, new applications have been developed to improve transportation. A hardware and software system are proposed by Oladimeji et al. (2023) to enable bus fleet monitoring and increase user engagement infrared sensors for RFID tags and GPS for real-time vehicle tracking are suggested. A Texas Instruments CC3200 microcontroller with a Wi-Fi module collects data and sends it to a cloud server. The unit is connected to an LCD screen at each bus stop for passengers to access information, and a mobile application is used for consumer access. According to Jain et al. (2018) a layered protocol has been developed for vehicle social networks, utilizing MAC, physical, and network levels to enhance communication speed. The media access control layer divides circular periods with rings. The physical layer of a wireless sensor network is made up of nodes, while the network layer enables communication to be forwarded from

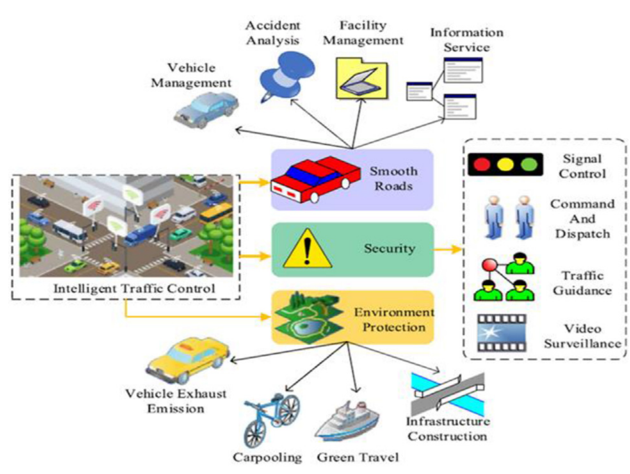

Fig. 17. Photo depicting an application in intelligent transportation management and control (https://images.app.goo.gl/C4sPjEuiGbQ6UC9x7.).

the outer rings to the fixed access point. The proposed strategy outperforms the present approach in MATLAB simulations. Fig. 17 depicts an application in intelligent transportation management and control. Applications for traffic management like WAZE (Gumasing et al., 2023) give users real-time traffic data including traffic congestion and oncoming police. For drivers and passengers, entertainment apps can be helpful, especially on a lengthy ride. For instance, a voice-based program (Jain et al., 2018) allows motorists who share interests and use the same highways to communicate through audio messages. Ramesh et al. (2020) suggested an application for traveler information service. Traffic sensing, aerial monitoring, weather monitoring, and accident detection provide information that is later sent to passengers through emergency warnings and passenger interaction (route change, departure time change, mode change, and destination change). Intelligent cities, utilizing advanced technology and population growth, are expected to enhance efficiency and sustainability in the future. These cities, which utilize IoT and AI, will monitor and analyze data to make data-driven decisions, thereby mitigating economic, and environmental challenges and traffic congestion. However, due to the complexity of the systems and the difficulty of measuring outcomes, it is difficult to quantify the full impact of smart cities (Gracias et al., 2023). Fig. 18 demonstrates the intelligent city's fixed vehicle transportation and management service platforms.

5.2.8. Residual neural networks for O-D matrix using traffic sensor information

Traffic flow information is necessary for planning and operating transport in megacities. Incomplete or insufficient traffic data hinders the implementation of most ITS (Alshehri et al., 2023). With advances in ITS, there has been great interest in traffic sensor information for flow estimation problems (Owais et al., 2019). While most ITS systems demand complete traffic flow data, it is not possible to place traffic sensors on every network on the road. Directly observing certain types of flow can pose challenges, particularly when it comes to the demand for pairs of nodes, also known as O/D flow (Owais and Matouk, 2021). To obtain a comprehensive understanding of the traffic patterns in these circumstances, it is imperative to assess the positioning of the sensors as well as the quantity and accuracy of the collected data (Owais, 2022). Furthermore, the problem becomes more complex due to the incorporation of additional factors such as installation objectives, sensor types, budgetary restrictions, sensor error/failure rates, and criteria for achieving optimal results (Owais et al., 2020a). The deployment of network traffic sensors is a complex task that cannot be taken lightly. The

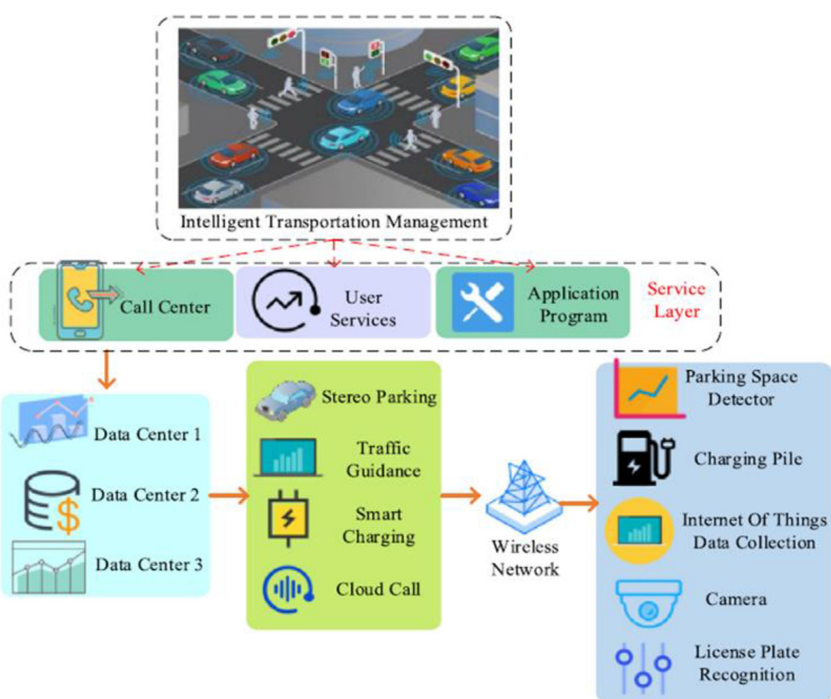

Fig. 18. Photo of a smart city's fixed vehicle transportation and management service platforms (https://images.app.goo.gl/dQXTJihSJfaswdUM9.).

intricate nature of the problem adds to the difficulty of managing real-world transportation networks. Alshehri et al. (2023) proposed the use of random priority selection method (DRNN) architecture to accurately predict O-D flow characteristics on network lines. The model identifies concealed O-D flow characteristics, creating major O-D and link flow patterns. It generates solutions close to optimal solutions or achieves superior local minima, decreasing convergence time. The technique includes FCL in O-D estimates and uses a sensor location strategy to investigate link relevance. Results show 97% accuracy on large-scale networks and 99% accuracy with only 20 sensors. Liu et al. (2015) proposed a novel method for localizing traffic sensors, aiming to determine the optimal number of traffic flows while taking into account temporal and spatial correlations. They defined the issue by using three 0−1 programming models and created an ant colony optimization algorithm with a local search technique. To assess the algorithm's effectiveness, they conducted numerical experiments on both a simulated network and the Sioux Falls network. The results showcased the algorithm's effectiveness, robustness, and potential to enhance its applicability in the design of real surveillance networks. According to Chen et al. (2021), a model for sensor deployment is developed to maximize the coverage of link and route flow information. The data from deployed sensors is fused using minimum variance weighted average technology. This study presents a novel bilevel maximum likelihood model to estimate traffic demand. The model incorporates the maximum likelihood method and stochastic user equilibrium for route choice proportion. To solve these models, sequential sensor identification and iterative algorithms are used, allowing for the determination of an optimal refitting scheme.

5.2.9. Frequency-based transit assignment models

Planning and developing a low-cost, high-quality public transportation network is crucial for increasing competitiveness and market share (Gronalt et al., 2019a). The primary concern of the transit route network design problem is to enhance efficiency by optimizing various factors including route length, permissible service frequencies, and the number of available buses. This optimization is carried out while considering operational and resource limitations, such as the quantity and length of routes (Owais et al., 2015). Owais et al. (2015) proposed a three-step methodology for route generation, selection, and evaluation through a multiobjective analysis. The effectiveness of this approach was confirmed by applying it to two real networks, demonstrating its ability to offer a range of tradeoffs between objectives. Notably, it ensures complete coverage of direct demand and constructs a direct network with the shortest route length. The advantage of its multiobjective nature is that it eliminates the need for weight coefficient calibration, simplifying the planner's task. Consequently, prior network knowledge is no longer necessary, resulting in a more efficient process. The research conducted by Owais and Ahmed (Owais and Ahmed, 2022) examined the effectiveness of two commonly used transit assignment models, namely Spiess and Florian (1989) and De Cea and Fernandez (1993), in the context of transportation network dynamics. For the first time in the literature, the two assignment approaches have been formulated within a unified mathematical notation framework to gain a deeper understanding of their inherent differences. Despite the importance of user choice behavior, these models are not frequently used in the transportation network dynamics literature due to their inherent complexity problems. These issues may arise from the alteration of user behavior assumptions or equilibrium solution techniques. Rumpf and Kaul (2021) developed an innovative approach to address congestion issues. They devised a formulation that considered the users' concern of not being able to catch their next mode of transportation. To incorporate this aspect, they introduced failure to board nodes and arcs at each bus stop in their graph model. To determine the line flows, they used Markov chains and assigned the probability of failing to board based on the remaining capacity of the vehicle. Cheung and Shalaby (Cheung et al., 2017) presented a novel framework aimed at improving the performance of congested transportation networks while considering individual travel requirements. The authors propose a unique strategy called the System Optimal Re-Routing Transit Assignment Heuristic, which aims to optimize the system by minimizing congested segments and effectively distributing demand across routes with limited capacity. This approach offers a user-constrained optimal solution, ensuring more efficient utilization of transportation resources. The study conducted by Moussa and Owais (2014) assessed the effectiveness of the Transit Route Network Design solution, which uses linear and integer mathematical models, by examining Mandl's benchmark network challenge. The study showed that this approach enhanced the network solution in various aspects, including the creation of routes, coverage of direct transit services, efficiency of transfers, and the reliability of the solution. Although it is not considered a definitive efficient solution, it can serve as a preliminary step toward utilizing meta-heuristic methods to attain a global optimum. These findings have the potential to contribute to the development of a more resilient network optimization tool for public transportation planning. However, the research by Owais and Osman (2018) presented the genetic algorithm, an extensive and multi-objective algorithm that constructs efficient transit networks by generating routes from the beginning and combining them. This algorithm effectively addresses problems with multiple criteria and identifies optimal solutions on the Pareto front. Furthermore, a unique technique for frequency setting is developed, using simulation results at the bus stop level and incorporating bi-level decision-making. Oliker and Bekhor (2020) conducted a study that introduced a transit assignment model. This model takes into account factors such as frequency, online information, and strict capacity constraints. To address the problem, the researchers used a heuristic approach that involves reallocating surplus passengers to overloaded lines. The model demonstrates high efficiency and shorter running times when compared with existing capacity-constrained models. Passengers are provided with online information regarding predicted arrival time and occupancy conditions, enabling them to make informed decisions about their route selection. The availability of prior occupancy data further reduces the duration of commuting, highlighting the potential benefits of equipping passengers with occupancy information.

6. Traffic congestion solutions in Egypt

Bus networks are an essential component of urban public transportation systems, but traffic congestion frequently results in reduced service quality (Owais et al., 2015). The majority of established networks in major cities were constructed several years ago and were designed with varying coverage objectives, leading to a higher number of transfers required for passengers to reach their desired destinations. To address this issue, there is a requirement for a system that can accurately assess the current number of intersections and offer route planning alternatives to alleviate this problem (Owais et al., 2021). To solve these problems, the municipality is making efforts to address these issues by focusing on the expansion of metro lines, aiming to enhance public transportation. This would allow for the identification of unsatisfied demand centers and the facilitation of direct planning in situations involving large-scale networks with inaccurate demand data (Owais et al., 2020b). The use of available transportation resources is optimized through the concept of intermodal transportation, which integrates road and rail networks to efficiently transport orders along the most effective routes. This methodology enables the enhancement of diverse goals, such as minimizing costs, saving time, mitigating risks, and reducing greenhouse gas emissions. Consequently, it can create tradeoffs among these objectives in multi-objective optimization (Sun et al., 2022). Developing an intermodal system poses significant challenges as it involves the input of a vast amount of data originating from diverse fields (Gronalt et al., 2019b). Moreover, the exceptional cost required makes the design process more difficult and demands large compromises to satisfy the majority of expectations. When planning a metro system, a multivariant analysis is usually necessary to evaluate the prospective future methods of urban agglomeration expansion (Król and Król, 2019). Based on the challenges mentioned above, Owais et al. (2021) introduced an analytical model for the design of a circular metro line in Greater Cairo. The model focused on improving the integration of the metro and bus networks using the passenger transfer number as a noncriterion goal. The passenger transfer number was used as the primary criterion for designing and evaluating additional lines in the overall transit network. To create a transfer passenger origin–destination matrix, the scholars used the NetBeans integrated development environment and Java programming language. The TransCAD software was used to design the current metro and bus networks. The metro network comprised of three primary lines, whereas the bus network consisted of 12 main lines. To improve the connectivity of the network, seven supplementary ring metro lines were suggested and assessed based on the state of the network. This approach not only addressed the challenge of creating and assessing routes in large-scale networks but also proved that ring lines are effective in reducing passenger transfers between stations at a minimal construction cost. The findings of this study provide valuable insights for strategic transit line design and offer initial solutions in situations where demand information is unavailable (Owais et al., 2020b). However, the study conducted by Owais and Hassan (2018) proposed a methodology for integrating dynamic bus stop simulation into a static transit assignment model. This approach combines the advantages of dynamic models with the ease of use of static models. The researchers developed an algorithm to simulate passenger and bus arrival load profiles, which were subsequently used in the transit assignment process to enhance the representation of line choices.

7. Conclusions and recommendations

This review paper aims to analyze the current state of road traffic congestion measures and proposes intelligent solutions to tackle the challenges that arise from it. By examining the related work, we can establish a fundamental building block toward developing a resilient and sustainable transportation system that can withstand the challenges of the future. Critical key points are discussed below. It concluded that:

(1) The utilization of information technology is crucial for enhancing the efficiency of transportation networks by enabling efficient transmission, traffic flow control, and network management through the latest advancements in communication, electronics, and computers.
(2) Using intelligent solutions for transportation systems reduces emissions of carbon dioxide by 80%.
(3) Intelligent transportation solutions achieve a fuel saving of 45% on urban roads, which is significantly higher than the reductions brought by advanced vehicle and engine technologies (2–8% and 4–10%, respectively).
(4) Vehicle-to-vehicle and vehicle-to-infrastructure communication address 79% of vehicle crashes, improving transportation system safety.
(5) ITS decrease the number of accidents from between 22 and 48% expected, with the critical accident rate shrinking from 22 to 9%.
(6) The data collected indicated that providing curb availability information to drivers resulted in a significant 27.9% decrease in cruising for parking time and a 12.4% decrease in cruising distance.
(7) Using ITS technology, congestion can be eliminated, and an uninterrupted path can be suggested, where the vehicle can maintain its green speed, resulting in optimal fuel efficiency and minimal pollution levels.

Despite the widespread adoption and recognition of ITS, it is important to acknowledge that these systems are not flawless, despite their ability to offer efficient and convenient services. As a result of this analysis, we offer the following recommendations for planners and policymakers.

(1) Cyberattacks on transportation infrastructure can have an impact on the economy, public safety, and national security. The security of data processing, storage, and transmission may be enhanced in the future by way of research into technologies like intrusion detection, access control, and cryptography.
(2) Examination of the impact of intelligent transportation on enhancing accessibility and mobility for marginalized communities, including the elderly, disabled individuals, and those with low income, is of utmost importance. It is highly recommended that researchers delve into the efficacy of these innovative solutions and devise effective strategies to address any obstacles hindering their widespread adoption.
(3) Addressing the misparking and parking reservation assurance issues requires in-depth investigation.
(4) Research should be focused on the investigation of intelligent parking systems, the promotion of environmental sustainability, and the preservation of energy resources.
(5) Large investments in infrastructure, software, and hardware are required for smart transportation systems as well. It takes specialized knowledge and abilities in data analysis, AI, and IoT technologies to create complex smart transportation systems.
(6) Communication is very important in ITS. Intelligent vehicle systems rely heavily on data and communication networks to function properly. If these networks are disrupted or interrupted, it can cause serious problems such as traffic congestion, delays, and safety risks.
(7) The use of blockchain technology has the potential to enhance transportation security, efficiency, and dependability. By providing a secure and transparent transaction record, blockchain technology can contribute to improving the overall safety and reliability of transportation systems (van der Heijden et al., 2017). Furthermore, researchers and scholars can delve into the possibilities of integrating blockchain technology into ITS, thereby creating innovative applications and scenarios that further enhance the efficiency of transportation networks.
(8) ITS can prioritize eco-friendly modes of mobility like public transit, cycling, and electric vehicles. This approach effectively decreases greenhouse gas emissions and enhances the overall air quality within urban areas.

Authors contribution

Amira M. El Shorbagy and Mohamed E. Gabr: Provided access to crucial research components.

Hamdy B. Faheem and Mohamed E. Gabr: Provided stylistic/grammatical revisions to manuscript. Hamdy B. Faheem and Amira M. El Shorbagy: Primary author (wrote most of the paper or drafted the paper). Hamdy B. Faheem and Amira M. El Shorbagy: Provided revisions to scientific content of manuscript. Hamdy B. Faheem and Amira M. El Shorbagy: Principal investigator (advisor, manager).

Conflicts of interest

None declared.

References

Abou-Amouna, M., Radwan, A., Al-Kuwari, L., Hammuda, A., AlKhalifa, KJIJoI., 2014. Prediction of road accidents in Qatar. Int. J. Ind. Manuf. Eng 8 (2), 458−463.

Adeke, P., Atoo, A., EJNJoT, Zava, 2018. Modelling traffic noise level on roadside traders at Wurukum market area in Makurdi town, Benue state−Nigeria. Niger. J. Technol 37 (1), 28−34.

Afrin, T., Yodo, N.J.S., 2020. A survey of road traffic congestion measures towards a sustainable and resilient transportation system. Sustainability 12, 4660.

Agha, A., Ranjan, R., Gan, W.S., 2017. Noisy vehicle surveillance camera: a system to deter noisy vehicle in smart city. Appl. Acoust 117, 236−245.

Ahmad, N.S., 2022. Considering Trip Generation and Route Selection in Regression-Based Prediction of Traffic Volumes. PhD Thesis. Purdue University Graduate School.

Akhtar, M., Moridpour, S., 2021. A review of traffic congestion prediction using artificial intelligence. J. Adv. Transport 2021, 1−18.

Akilesh, B., Ashfaq, A., Jagan, V., Malathi, S., 2023. Accident detection and avoidance using vehicle to vehicle communication (V2V). Int. Res. J. Eng. Technol 10 (5).

Al-Arkawazi, S.A., 2018. Measuring the influences and impacts of signalized intersection delay reduction on the fuel consumption, operation cost and exhaust emissions. Civil Eng. J 4 (3), 552−571.

Al-Dweik, A., Muresan, R., Mayhew, M., Lieberman, M., 2017. IoT-based multifunctional scalable real-time enhanced road side unit for intelligent transportation systems. In: 2017 IEEE 30th Canadian Conference on Electrical and Computer Engineering (CCECE). IEEE, pp. 1−6.

Albalate, D., Fageda, X.J.S., 2019. Congestion, road safety, and the effectiveness of public policies in urban areas. Sustainability 11 (18), 5092.

Albalate, D., Fageda, XJTp, 2021. On the relationship between congestion and road safety in cities. Transp. Policy 105, 145−152.

Ali, J., Khan, M.F.J.S., 2023. A trust-based secure parking allocation for IoT-enabled sustainable smart cities. Sustainability 15 (8), 6916.

Almatar, K.M., Almulhim, A.I., 2021. The issue of urban transport planning in Saudi Arabia: concepts and future challenges. Int. J. Sustain. Dev. Plan 2021, 16−17.

Alqazzaz, A., Alrashdi, I., Aloufi, E., Zohdy, M., Ming, HJJoIS., 2018. SecSPS: a secure and privacy-preserving framework for smart parking systems. J. Inf. Secur 9, 299−314.

Alsaffar, N., Ali, H., Elmedany, W., 2018. Smart transportation system: a review of security and privacy issues. In: 2018 International Conference on Innovation and Intelligence for Informatics, Computing, and Technologies (3ICT). IEEE, pp. 1−4.

Alshehri, A., Owais, M., Gyani, J., Aljarbou, M.H., Alsulamy, S.J.S., 2023. Residual neural networks for origin−destination trip matrix estimation from traffic sensor information. Sustainability 15 (13), 9881.

Aminzadegan, S., Shahriari, M., Mehranfar, F., Abramović, B., 2022. Factors affecting the emission of pollutants in different types of transportation: a literature review. Energy Rep 8, 2508−2529.

Anomohanran, O.J., 2013. Evaluation of environmental noise pollution in Abuja, the capital city of Nigeria. IJRRAS 14, 470−476.

Arthurs, P., Gillam, L., Krause, P., Wang, N., Halder, K., Mouzakitis, A., 2022. A taxonomy and survey of edge cloud computing for intelligent transportation systems and connected vehicles. IEEE Trans. Intell. Transp. Syst.

Ayantoyinbo, B.J., 2018. The effect of road traffic delay on supply chain performance of manufacturing firms in Lagos State, Nigeria. Int. J. Manag. Technol 5 (3), 9−20.

Ayele, T.W., Mehta, R., 2018. Air pollution monitoring and prediction using IoT. In: 2018 Second International Conference on Inventive Communication and Computational Technologies (ICICCT). IEEE, pp. 1741−1745.

Badr, M.M., Al Amiri, W., Fouda, M.M., Mahmoud, M.M., Aljohani, A.J., Alasmary, W., 2020. Smart parking system with privacy preservation and reputation management using blockchain. IEEE Access 8, 150823−150843.

Bani Younes, M., Boukerche, A., 2015. A performance evaluation of an efficient traffic congestion detection protocol (ECODE) for intelligent transportation systems. Ad Hoc Netw 24, 317−336.

Belkouri, D., Laing, R., Gray, D., 2022. Through the eyes of autonomous vehicles−using laser scanning technology to engage the public via the analysis of journeys seen from a different perspective. Transp. Res. Procedia 60, 496−503.

Beojone, C.V., Geroliminis, NJTrpCet, 2021. On the inefficiency of ride-sourcing services towards urban congestion. Transp. Res. Part C Emerg. Technol 124, 102890.

Berhanu, Y., Alemayehu, E., Schroder, D., 2023. 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. J. Adv. Transp.

Bhatti, F., Shah, M.A., Maple, C., Islam, SUJs, 2019. A novel internet of things-enabled accident detection and reporting system for smart city environments. Sensors 19 (9), 2071.

Bivina, G., Landge, V., Kumar, V.S.J.T.R.P., 2016. Socio economic valuation of traffic delays. Transp. Res. Procedia 17, 513−520.

Bleviss, D.L., 2021. Transportation is critical to reducing greenhouse gas emissions in the United States. Wiley Interdiscip. Rev. Energy Environ 10 (2), 390.

Bravo-Moncayo, L., Lucio-Naranjo, J., Chávez, M., Pavón-García, I., Garzón, C., 2019. A machine learning approach for traffic-noise annoyance assessment. Appl. Acoust 156, 262−270.

Briz-Redón, Á., Martínez-Ruiz, F., Montes, F., 2019. Spatial analysis of traffic accidents near and between road intersections in a directed linear network. Accid. Anal. Prev 132, 105252.

Cai, M., Lan, Z., Zhang, Z., Wang, H., 2019. Evaluation of road traffic noise exposure based on high-resolution population distribution and grid-level noise data. Build. Environ 147, 211−220.

Carminati, M., Kanoun, O., Ullo, S.L., Marcuccio, S.J.I.A., 2019. Prospects of distributed wireless sensor networks for urban environmental monitoring. IEEE Aerosp. Electron. Syst. Mag 34 (6), 44−52.

Chang, H.-L., Chen, H.-Y., Koo, K., Rieck, J., Blakeman, P., 2014. Gasoline cold start concept (gCSC™) technology for low temperature emission control. SAE Int. J. Fuels Lubr 7 (2), 480−488.
Chaturvedi, N., Srivastava, P.J.I.R.J.E.T., 2018. Automatic vehicle accident detection and messaging system using GSM and GPS modem. Int. Res. J. Eng. Technol. (IRJET) 5 (3), 252−254.
Chen, H., Chu, Z., Sun, C.J.S., 2021. Sensor deployment strategy and traffic demand estimation with multisource data. Sustainability 13 (23), 13057.
Chen, Z., Li, M., Liu, P., Fan, S.J.M.I.S., 2022. An Intelligent Lighting Control System for Urban Street Lamps Using Internet of Things, p. 2022.
Cheung, L.L., Shalaby, ASJIJoTS., 2017. System optimal re-routing transit assignment heuristic: a theoretical framework and large-scale case study. Int. J. Transp. Sci. Technol 6, 287−300.
Çolakkadõoglu, D., Yücel, M., Kahveci, B., Aydõnol, O.J., 2018. Determination of noise pollution on university campuses: a case study at Çukurova University campus in Turkey. Environ. Monit. Assess 190, 1−14.
Contreras, E., Torres-Treviño, L., Torres, F., 2018. Prediction of car accidents using a maximum sensitivity neural network. In: Smart Technology: First International Conference, MTYMEX 2017, Monterrey, Mexico, May 24−26, 2017. Springer International Publishing, Proceedings, pp. 86−95.
Dhingra, S., Madda, R.B., Gandomi, A.H., Patan, R., Daneshmand, M., 2019. Internet of things mobile−air pollution monitoring system (IoT-Mobair). IEEE Internet Things J 6 (3), 5577−5584.
Dizon, E., BJJoAI, Pranggono, Computing, H., 2022. Smart Streetlights in Smart City: A Case Study of Sheffield, pp. 1−16.
Djahel, S., Jabeur, N., Barrett, R., Murphy, J., 2015. Toward V2I communication technology-based solution for reducing road traffic congestion in smart cities. In: 2015 International Symposium on Networks, computers and communications (ISNCC). IEEE, pp. 1−6.
Dogru, N., Subasi, A., 2018. Traffic accident detection using random forest classifier. In: 2018 15th learning and technology conference (L&T). IEEE, pp. 40−45.
Dong, K., Ni, G., Taghizadeh-Hesary, F., Zhao, C., 2023. Does smart transportation matter in inhibiting carbon inequality. Energy Econ 126, 106952.
El-Kadi, A-WJJosd, 2013. Suggested solutions for traffic congestion in Greater Cairo. J. Sustain. Dev 6 (11), 105.
Falcocchio, J.C., Levinson, H.S., Falcocchio, J.C., Levinson, H.S.J.R.T.C.A.C.G., 2015. Managing nonrecurring congestion, pp. 197−211.
Fattah, M.A., Morshed, S.R., Kafy, A., 2022. Insights into the socio-economic impacts of traffic congestion in the port and industrial areas of Chittagong city, Bangladesh. Transp. Eng 9, 100122.
Fazal Abbas Baqueri, S., Ectors, W., Shabbar Ali, M., Knapen, L., Janssens, D., Yasar, A., 2016. Estimation of value of time for a congested network − a case study of the national highway, Karachi. Procedia Comput. Sci 83, 262−269.
Fleming, S., 2019. Traffic congestion cost the US economy nearly $87 billion in 2018. In: World Economic Forum, p. 7.
Fu, X., Wang, L., Yuan, L., Hu, H., Li, T., Zhang, J., et al., 2023. Long-term exposure to traffic noise and risk of incident cardiovascular diseases: a systematic review and dose−response meta-analysis. J. Urban Health 100 (4), 788−801.
Gabr, M.E., El Shorbagy, A.M., Faheem, H.B.J.S., 2022. Utilizing the harvesting of rainwater to provide safe road transportation efficiency and increase water resources in the context of climatic change. Sustainability 14, 9656.
Ghasedi, M., Sarfjoo, M., Bargegol, I.J.S.A.S., 2021. Prediction and analysis of the severity and number of suburban accidents using logit model, factor analysis and machine learning: a case study in a developing country. SN Appl. Sci 3, 1−16.
Gohar, A., Nencioni, G.J.S., 2021. The role of 5G technologies in a smart city: the case for intelligent transportation system. Sustainability 13, 5188.
Gomes, B., Coelho, J., Aidos, H., 2023. A survey on traffic flow prediction and classification. Intell. Syst. Appl 20, 200268.
Gracias, J.S., Parnell, G.S., Specking, E., Pohl, E.A., Buchanan, R.J.S.C., 2023. Smart citiesda structured literature review. Sustainability 6, 1719−1743.
Gronalt, M., Schultze, R.-C., Posset, M., 2019a. Intermodal transport—basics, structure, and planning approaches. In: Sustainable Transportation and Smart Logistics. Elsevier, pp. 123−149.
Gronalt, M., Schultze, R.-C., Posset, M., 2019b. Chapter 5 − intermodal transport—basics, structure, and planning approaches. In: Sustainable Transportation and Smart Logistics. Elsevier, pp. 123−149.
Gumasing, M.J.J., Bermejo, F.J.C.S., Elpedes, K.T.C., Gonzales, L.F.E., Villajin, A.C.V., 2023. antecedents of waze mobile application usage as a solution for sustainable traffic management among Gen Z. Sustainability 15, 10186.
Hamadeh, N., Karouni, A., Farhat, Z.J.I.A., 2021. Intelligent transportation systems to mitigate road traffic congestion. Intelligenza Artificiale 15 (2), 91−104.
He, F., Yan, X., Liu, Y., Ma, L.J., 2016. A traffic congestion assessment method for urban road networks based on speed performance index. Procedia Eng 137, 425−433.
Hossan, S., Nower, N.J.P.T., 2020. Fog-based dynamic traffic light control system for improving public transport. Public Transp 12, 431−454.
https://images.app.goo.gl/4zsZC2FYZbrGYVMu5.
https://images.app.goo.gl/d7Nk9GLEkcRGwnZ86.
https://images.app.goo.gl/dQXTJihSJfaswdUM9.
https://images.app.goo.gl/qr9Q3L3CmAMtzUCk9.
https://images.app.goo.gl/C4sPjEuiGbQ6UC9x7.
Injadat, M., Moubayed, A., Nassif, A.B., Shami, A.J.A.I.R., 2021. Machine learning towards intelligent systems: applications, challenges, and opportunities. Artif. Intell. Rev 54, 3299−3348.
Ismagilova, E., Hughes, L., Rana, N.P., Dwivedi, Y.K.J.I.S.F., 2020. Security, privacy and risks within smart cities: literature review and development of a smart city interaction framework. Inf. Syst. Front 24, 393−414.
Jacyna, M., Wasiak, M., Lewczuk, K., GJJoV, Karon, 2017. Noise and environmental pollution from transport: decisive problems in developing ecologically efficient transport systems. J. Vibroengineering 19 (7), 5639−5655.
Jadaan, K., Alsarayreh, D., Science, Obaid MJJoCE, Technology, 2021. Observing people's reactions and responses to urban road traffic noise (RTN) in Jordan. J. Civ. Eng. Sci. Technol 12 (2), 204−213.
Jain, B., Brar, G., Malhotra, J., Rani, S., Ahmed, S.H., 2018. A cross layer protocol for traffic management in Social Internet of Vehicles. Future Gener. Comput. Syst 82, 707−714.
Jaller, M., Pahwa, A., 2020. Evaluating the environmental impacts of online shopping: a behavioral and transportation approach. Transp. Environ 80, 102223.
Jat, S., Tomar, R.S., Sharma, M.S.P., 2019. Traffic congestion and accident prevention analysis for connectivity in vehicular ad-hoc network. In: 2019 5th International Conference on Signal Processing, Computing and Control (ISPCC). IEEE, pp. 185−190.
Jilaniv, U., Asif, M., Zia, M.Y.I., Rashid, M., Shams, S., Otero, P.J., 2023. A systematic review on urban road traffic congestion. Wirel. Pers. Commun 1−29.
Jin, D., Hannon, C., Li, Z., Cortes, P., Ramaraju, S., Burgess, P., 2016. Smart street lighting system: a platform for innovative

smart city applications and a new frontier for cyber-security. Electr. J 29, 28−35.
Kamandang, Z.R., Wibisana, H., Casita, C.B., 2020. Analysis of noise pollution due to traffic volume based on the types of automotive vehicles: a study of west Surabaya region. J. Phys. Conf. Ser 1569 (4), 042044. IOP Publishing.
Kapitanov, V., Silyanov, V., Monina, O., Chubukov, A.J.T.R.P., 2018. Methods for traffic management efficiency improvement in cities. Transp. Res. Procedia 36, 252−259.
Kavta, K., Goswami, AJTRBtAMRB., 2018. Traffic congestion mitigation: a research review of supply and demand approaches. In: Transportation Research Board 97th Annual Meeting Transportation Research Board, vol. 18, p. 04383.
Kayal, P., Perros, H., 2017. Comparison of IoT application layer protocols through a smart parking implementation. In: 2017 20th Conference on Innovations in Clouds, Internet and Networks (ICIN). IEEE, pp. 331−336.
Khaliq, K.A., Raza, S.M., Chughtai, O., Qayyum, A., Pannek, J., 2018. Experimental validation of an accident detection and management application in vehicular environment. Comput. Electr. Eng 71, 137−150.
Khot, I., Jadhav, M., Desai, A., Bangar, V.J.I.R.J.E.T., 2018. Go safe: android application for accident detection and notification. Int. Res. J. Eng. Technol 5, 4118−4122.
Król, A., Król, M.J.A.S., 2019. The design of a metro network using a genetic algorithm. Appl. Sci 9, 433.
Kumar, R., Chun, Y., Zafar, T.B., Mothafar, NAJIJoS., 2019. Building sustainable green environment by reducing traffic jam: the role of sharing economy as ride-sharing an overview City. Int. J. Sci. Bus 3, 164−173.
Kumar, A., Verma, S.K., Goyal, S., 2023. Traffic accident modeling and prediction algorithm using convolutional recurrent neural networks. In: International Conference on Advances in IoT and Security with AI. Springer Nature Singapore, Singapore, pp. 351−361.
Lanza, J., Sánchez, L., Gutiérrez, V., Galache, J.A., 2016. Smart city services over a future Internet platform based on internet of things and cloud: the smart parking case. Energies 9, 719.
Li, H., Ota, K., Dong, M., 2016a. Network virtualization optimization in software defined vehicular ad-hoc networks. In: 2016a IEEE 84th Vehicular Technology Conference. VTC-Fall. IEEE, pp. 1−5.
Li, L., Lv, Y., Wang, F., 2016b. Traffic signal timing via deep reinforcement learning, IEEE/CAA. J. Automatica Sinica 3, 247−254.
Li, Y., Lv, C., Yang, N., Liu, H., Liu, Z., 2020. A study of high temporal-spatial resolution greenhouse gas emissions inventory for on-road vehicles based on traffic speed-flow model: a case of Beijing. J. Clean. Prod 277, 122419.
Liu, Y., Zhu, N., Ma, S., Jia, N.J.I.I.T.S., 2015. Traffic sensor location approach for flow inference. IET Intell. Transp. Syst 9, 184−192.
Long, X.Y., Zhao, S.K., Jiang, C., Li, W.P., Liu, C.H., 2021. Deep learning-based planar crack damage evaluation using convolutional neural networks. Eng. Fract. Mech 246, 107604.
Louati, A., Darmoul, S., Elkosantini, S., ben Said, L.J.I.S., 2018. An artificial immune network to control interrupted flow at a signalized intersection. Inf. Sci 433, 70−95.
Lu, J., Li, B., Li, H., Al-Barakani, A.J.C., 2021. Expansion of city scale, traffic modes, traffic congestion, and air pollution. Cities 108, 102974.
Lv, Z., Shang, W., 2022. Impacts of intelligent transportation systems on energy conservation and emission reduction of transport systems: a comprehensive review. Green Technol. Sustain 100002.
Lv, Z., Shang, W., 2023. Impacts of intelligent transportation systems on energy conservation and emission reduction of transport systems: a comprehensive review. Green Technol. Sustain 1, 100002.
Lwesya, H.A., Massawe, L.N., Mwisila, L.P., Misafi, H.P., 2021. Effects of road traffic congestion on economic activities of Dar Es Salaam region in Tanzania. J. Econ. Sustain. Dev 12, 6.
Lwin, W.Y., Yoon, B., 2023. Impact of transportation on air quality and carbon emissions in developing countries: a case of Myanmar. J. Soc. Disaster Inf 19, 231−240.
Malche, T., Maheshwary, P., Kumar, R.J.W.P.C., 2019. Environmental monitoring system for smart city based on secure Internet of Things (IoT) architecture. Wirel. Pers. Commun 107, 2143−2172.
Manisalidis, I., Stavropoulou, E., Stavropoulos, A., Bezirtzoglou, E.J., 2020. Environmental and health impacts of air pollution: a review. Front. Public Health 8, 14.
Meena, G., Sharma, D., Mahrishi, M., 2020. Traffic prediction for intelligent transportation system using machine learning. In: 2020 3rd International Conference on Emerging Technologies in Computer Engineering: Machine Learning and Internet of Things. ICETCE. IEEE, pp. 145−148.
Megnidio-Tchoukouegno, M., Adedeji, J.A.J.S., 2023. Machine learning for road traffic accident improvement and environmental resource management in the transportation sector. Sustain. Environ 15, 2014.
Miller, M.R., Newby, D., 2020. Air pollution and cardiovascular disease: car sick. Cardiovasc. Res 116, 279−294.
Mohamed, A., Fouad, M.M.M., Elhariri, E., El-Bendary, N., Zawbaa, H.M., Tahoun, M., Hassanien, A.E., 2015. RoadMonitor: An intelligent road surface condition monitoring system. In: Intelligent Systems' 2014: Proceedings of the 7th IEEE International Conference Intelligent Systems IS'2014, September 24−26, 2014, Warsaw, Poland, Volume 2: Tools, Architectures, Systems, Applications. Springer International Publishing, pp. 377−387.
Moussa, R., 2023. Reducing carbon emissions in Egyptian roads through improving the streets quality. Environ. Dev. Sustain 25, 4765−4786.
Moussa, G., Owais, M.J.I.J.C.E.S.C.A.E., 2014. A novel solution methodology for transit route network design problem. Int. J. Civ. Environ. Struct. Constr. Archit. Eng 8 (3), 283−290.
Moussa, G.S., Owais, M., Dabbour, E., 2022. Variance-based global sensitivity analysis for rear-end crash investigation using deep learning. Accid. Anal. Prev 165, 106514.
Muneera, C., Karuppanagounder, K., 2018. Economic impact of traffic congestion-estimation and challenges. European Transport-Trasporti Europei 68.
Nasr, E., Kfoury, E., Khoury, D., 2016. An IoT approach to vehicle accident detection, reporting, and navigation. In: 2016 IEEE international multidisciplinary conference on engineering technology (IMCET). IEEE, pp. 231−236.
Neves, A., Brand, C., 2019. Assessing the potential for carbon emissions savings from replacing short car trips with walking and cycling using a mixed GPS-travel diary approach. Transp. Res. Part A Policy Pract 123, 130−146.
Nurhadryani, Y., Wulandari, W., Mastika, M.N.F.J.J.R., 2022. Vehicle detection monitoring system using internet of things. Jurnal RESTI (Rekayasa Sistem dan Teknologi Informasi) 6 (5), 749−760.
Oladimeji, D., Gupta, K., Kose, N.A., Gundogan, K., Ge, L., Liang, F.J.S., 2023. Smart transportation: an overview of technologies and applications. Sensors (Basel) 23, 3880.
Olayode, I., Tartibu, L., Okwu, M., Uchechi, dUJPC., 2020. Intelligent transportation systems, un-signalized road intersections and traffic congestion in Johannesburg: a systematic review. Procedia CIRP 91, 844−850.

Oliker, N., Bekhor, S., 2020. A frequency based transit assignment model that considers online information and strict capacity constraints. EURO J. Transp. Log 9, 100005.
Owais, M., 2022. Traffic sensor location problem: three decades of research. Expert Syst. Appl 208, 118134.
Owais, M., Ahmed, A.S.J.I.A., 2022. Frequency based transit assignment models: graph formulation study. IEEE Access 10, 62991−63003.
Owais, M., Hassan, TJIJoCE., 2018. Incorporating dynamic bus stop simulation into static transit assignment models. Int. J. Civ. Eng 16, 67−77.
Owais, M., Matouk, A.E., 2021. A factorization scheme for observability analysis in transportation networks. Expert Syst. Appl 174, 114727.
Owais, M., Osman, MKJESwA., 2018. Complete hierarchical multi-objective genetic algorithm for transit network design problem. Expert Syst. Appl 114, 143−154.
Owais, M., Osman, M.K., GJIToITS, Moussa, 2015. Multi-objective transit route network design as set covering problem. IEEE Trans Intell. Transp. Syst 17, 670−679.
Owais, M., Moussa, G.S., Hussain, K.F.J.O.R.P., 2019. Sensor location model for O/D estimation: multi-criteria meta-heuristics. Oper. Res. Perspect.
Owais, M., El Deeb, M., Abbas, YAJIJoCE., 2020a. Distributing portable excess speed detectors in AL Riyadh city. Int. J. Civ. Eng 18, 1301−1314.
Owais, M., Moussa, G.S., Hussain, KFJJoTE., 2020b. Robust deep learning architecture for traffic flow estimation from a subset of link sensors. J. Transp. Eng. Part A Syst 146 (1), 04019055.
Owais, M., Ahmed, A.S., Moussa, G.S., Khalil, A.A., 2021. Integrating underground line design with existing public transportation systems to increase transit network connectivity: case study in Greater Cairo. Expert Syst. Appl 167, 114183.
Palander, T., Kärhä, K., 2019. Improving energy efficiency in a synchronized road-transportation system by using a TFMC (Transportation Fleet-Management Control) in Finland. Energies 12 (4), 670.
Panchuk, M., Kryshtopa, S., Sładkowski, A., Panchuk, A., 2020. Environmental aspects of the production and use of biofuels in transport. Ecol. Transp. Probl. Solut 115−168.
Patil, P., 2017. Smart IoT based system for vehicle noise and pollution monitoring. In: 2017 International Conference on Trends in Electronics and Informatics (ICEI). IEEE, pp. 322−326.
Peixoto, M., Mota, E., Maia, A., Lobato, W., 2023. Fogjam: a fog service for detecting traffic congestion in a continuous data stream vanet. Ad Hoc Netw 140, 103046.
Rahim, M.A., Rahman, M., Rahman, M.A., Muzahid, A.J.M., Kamarulzaman, S.F., 2021. A framework of iot-enabled vehicular noise intensity monitoring system for smart city. In: Advances in Robotics, Automation and Data Analytics: Selected Papers from ICITES 2020. Springer International Publishing, pp. 194−205.
Rahman, M.M., Thill, J.-C., 2023. Impacts of connected and autonomous vehicles on urban transportation and environment: a comprehensive review. Sustain. Cities Soc 104649.
Rahman, Z., Hossain, A.T., Karim, N.A., Jayeed, M., 2017. Cloud based smart parking system using IoT technology (Doctoral dissertation, BRAC Univeristy).
Raipure, S., Mehetre, D., 2015. Wireless sensor network-based pollution monitoring system in metropolitan cities. In: 2015 International Conference on Communications and Signal Processing (ICCSP). IEEE, pp. 1835−1838.
Ramesh, K., Lakshna, A., Renjith, P., 2020. Smart traffic congestion model in IoT-a review. In: 2020 4th International Conference on Electronics, Communication and Aerospace Technology. ICECA. IEEE, pp. 651−658.
Raosaheb Patil, V., Suresh Pardeshi, S., 2023. Mechanism for accident detection, prevention and reporting system. Mater. Today Proc 72, 1975−1980.
Retallack, A.E., Ostendorf, B., 2019. Current understanding of the effects of congestion on traffic accidents. Int. J. Environ. Res. Public Health 1 (16), 3400.
Retallack, A.E., Ostendorf, B., 2020. Relationship between traffic volume and accident frequency at intersections. Int. J. Environ. Res. Public Health 17, 1393.
Rizvi, S.R., Zehra, S., Olariu, S., 2019. Aspire: an agent-oriented smart parking recommendation system for smart cities. IEEE Intell. Transp. Syst. Mag 11 (4), 48−61.
Rumpf, A., Kaul, H., 2021. A public transit network optimization model for equitable access to social services. Equity Access Algorithms Mech. Optimizat 1−17.
Sánchez, L., Elicegui, I., Cuesta, J., Muñoz, L., Lanza, J.J.S., 2013. Integration of utilities infrastructures in a future internet enabled smart city framework. Sensors 13, 14438−14465.
Saffarini, R., Khamayseh, F., 2023. Survey of road anomalies detection methods. Int. J. Intell. Syst. Technol. Appl 21, 280−302.
Sarasvathi, V., 2023. Reliability analysis of an IoT-based air pollution monitoring system using machine learning algorithm-BDBN. Cybernet. Inf. Technol 23, 233−250.
Seraj, F., Van Der Zwaag, B.J., Dilo, A., Luarasi, T., RoADS, Havinga P., 2014. A road pavement monitoring system for anomaly detection using smart phones. In: International Workshop on Modeling Social Media. Springer, pp. 128−146.
Serigos, P.A., Visintine, B.A., Simpson, A.L., Rada, G.R., Groeger, J.L.J.T.R.R., 2018. Quality management program for pavement condition data collected on the national highway system. Transp. Res. Rec. J. Transp. Res. Board 2672, 155−165.
Sharma, K., Kumar, V., 2023. Integration of solar power and IOT technology in smart street light with EV charging point. Int. J. Sci. Technol. Manag. (IJSTM) 10, 2321−2774.
Silva, N., Shah, V., Soares, J., Rodrigues, H.J.S., 2018. Road anomalies detection system evaluation. Sensors 18, 1984.
Siswanto, J., Syaban, A.S.N., HJJJoI, Hariani, 2023. Artificial intelligence in road traffic accident prediction. Jambura J. Inf 5, 77−90.
Soaibuzzaman, A., Rahman, M., Rahaman, M., 2019. A blockchain-based architecture for integrated smart parking systems. In: 2019 IEEE international conference on pervasive computing and communications workshops, Kyoto, Japan, pp. 11−15.
Sotres, P., Lanza, J., Sánchez, L., Santana, J.R., López, C., Muñoz, L.J.S., 2019. Breaking vendors and city locks through a semantic-enabled global interoperable internet-of-things system: a smart parking case. Sensors (Basel) 19, 229.
Sun, Y., Yu, N., Huang, B.J.C., Systems, I., 2022. Green road−rail intermodal routing problem with improved pickup and delivery services integrating truck departure time planning under uncertainty: an interactive fuzzy programming approach. Complex Intell. Syst 8, 1459−1486.
Suryani, E., Hendrawan, R.A., Adipraja, P.F.E., Wibisono, A., Dewi, LPJJoMiM., 2021. Urban mobility modeling to reduce traffic congestion in Surabaya: a system dynamics framework. J. Modell. Manag 16 (16), 37−69.
Svanberg, J., 2018. Anomaly Detection for Non-recurring Traffic Congestions Using Long Short-Term Memory Networks (LSTMs), KTH, School of Electrical Engineering and Computer Science (EECS) [Internet] [Dissertation], vol. 507, p. 234465.
Thondoo, M., Marquet, O., Marquez, S., Nieuwenhuijsen, M.J., 2020. Small cities, big needs: urban transport planning in cities of developing countries. J. Transp. Health 19, 100944.

Tomar, I., Sreedevi, I., Pandey, N.J.E., 2022. State-of-art review of traffic light synchronization for intelligent vehicles: current status, challenges, and emerging trends. Electronics 11 (3), 465.
Van der Heijden, R.W., Engelmann, F., Modinger, D., Schönig, F., Kargl, F., 2017. Blackchain: scalability for resource-constrained accountable vehicle-to-x communication. In: Proceedings of the 1st Workshop on Scalable and Resilient Infrastructures for Distributed Ledgers, vol. 4, pp. 1−5.
Wang, B., Guo, K., 2018. The efficient of carbon emissions efficiency of Beijing public transportation system: based on super-efficiency SBM model using Malmquist-Luenberger index. J. Syst. Sci. Math. Sci 38 (4), 456.
Wang, Y., Zhong, H.J., 2023. Mitigation strategies for controlling urban particulate pollution from traffic congestion: road expansion and road public transport. J. Environ. Manag 345, 118795.
Wang, L., Wang, Y., Shi, L., Xu, H., 2022. Analysis of risky driving behaviors among bus drivers in China: the role of enterprise management, external environment and attitudes towards traffic safety. Accid. Anal. Prev 168, 106589.
Weisbrod, G., Fitzroy, S., 2011. Traffic congestion effects on supply chains: accounting for behavioral elements in planning and economic impact models. Supply Chain Management − New Perspectives. InTech. https://doi.org/10.5772/799.
World Health Organization. Department of Mental Health, Substance Abuse, World Health Organization. Mental Health Evidence, & Research Team, 2005. Mental health atlas 2005. World Health Organization.
Yazdani, M., Sarvi, M., Asadi Bagloee, S., Nassir, N., Price, J., Parineh, H., 2023. Intelligent vehicle pedestrian light (IVPL): a deep reinforcement learning approach for traffic signal control. Transp. Res. Part C Emerg. Technol 149, 103991.
Yijing, H., Wei, W., He, Y., Qihong, W., Kaiming, X., 2023. Intelligent algorithms for incident detection and management in smart transportation systems. Comput. Electr. Eng 110, 108839.
Zacepins, A., Komasilovs, V., Kviesis, A., Gatins, A., Skudra, M., Pierhurovics, A., 2017. Implementation of smart parking system in Jelgava city in Latvia. In: 2017 IEEE 11th International Conference on Application of Information and Communication Technologies (AICT). IEEE, pp. 1−4.
Zantalis, F., Koulouras, G., Karabetsos, S., Kandris, D.J.F.I., 2019. A review of machine learning and IoT in smart transportation. Future Internet 11 (4), 94.
Zhang, L., Khalgui, M., Li, Z.J.S., 2021. Predictive intelligent transportation: alleviating traffic congestion in the internet of vehicles. Sensors 21 (21), 7330.
Zulkifli, C.N.A.B., Ponrahono, ZJEPoMS., 2018. The effect of traffic congestion on quality of community life. In: European Proceedings of Multidisciplinary Sciences, International Conference on Rebuilding Place, University Sains Malaysia, 2.