



Artificial Intelligence and Machine Learning in Smart Transportation Systems: Improving Road Safety, Traffic Flow, and Environmental Sustainability

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Abstract

The study examined the transformative role of Artificial Intelligence (AI) and Machine Learning (ML) in advancing smart transportation systems with a focus on improving road safety, optimizing traffic flow, and promoting environmental sustainability. Using a mixed-method research design, the study integrated quantitative data from transportation authorities



and simulation outputs with qualitative insights from AI and traffic management experts. The analysis demonstrated that AI-driven models significantly enhanced traffic prediction accuracy, reduced accident frequency, and optimized route management through real-time analytics and adaptive control mechanisms. Results also indicated that ML-based systems contributed to lower carbon emissions by enabling fuel-efficient driving patterns and reducing idle times at intersections. However, the study identified ongoing challenges, including data privacy concerns, lack of standardized regulatory frameworks, and limited public trust in AI-based decision-making. The discussion emphasized that sustainable implementation required collaborative governance, ethical design, and policy integration. The findings concluded that AI and ML could fundamentally redefine urban mobility when combined with robust data governance and continuous monitoring. Future research directions were proposed to explore explainable AI, edge-based optimization, and multi-modal integration for enhanced system resilience and transparency. This study contributed to the growing body of literature emphasizing data-driven, sustainable, and human-centered approaches to intelligent transportation systems.

Keywords: Artificial Intelligence, Environmental Sustainability, Machine Learning, Road Safety, Smart Transportation, Traffic Flow Optimization

Introduction

Over the past years, urban mobility and transportation management have been added to the challenges with rapid urbanization, population increase, and the spread of personal cars. Traditional techniques used in transport infrastructure are based on static or predetermined systems. However their inability to deliver is because they fail to handle the increased complexity of road networks and traffic dynamics. Due to this, the experts and operators began

to study the AI and ML to improve or speed up decisions, identify possible threats or risks, and enhance the effectiveness of traffic (Hassan et al., 2025). “We want to take it to the next level. We want to make predictive urban transport management. This will enhance travel experience by providing instant solutions.”. “We want to develop a solution to uptrack any unwanted situations.”, he added.

The use of AI and ML saw the smart transportation systems (TDLS) as a game-changer already. With the use of reinforcement learning, computer vision and deep learning algorithms, vehicle detection, adaptive signalling, route optimization as well as prediction of traffic were implemented (Zemmouchi-Ghomari et al., 2025). Transport networks’ capabilities improved in accuracy and reactivity thanks to AI systems that combine information with a self-directed capacity for learning. As more empirical evidence became available, it was noted that AI-based systems were contributing to an increase in the reliability of travel time, a decrease in accidents and an improvement in the quality of the environment(Mostafa et al., 2025).

Another issue arising from the realization of AI and ML on a large scale is transport networks (Yu et al., 2024). In addition, the multiple goals of safety, efficiency, and sustainability involved complicated optimizations. One of the critical research gaps was the need for powerful structures that would allow achieving these goals at the same time.

Therefore, the purpose of the study was to suggest the ways in which one can use AI and ML to enhance the operations of smart transport systems and particularly improve road safety levels, better the traffic flow and further environmental sustainability. It discovered literature reviews on contemporary issues and presented significant enablers and barriers. It also

proposed a composite picture of how AI and ML technologies could be used systematically to create sustainable and intelligent transportation ecosystems.

Research Background

Intelligent Transportation Systems (ITS) as a concept has been around since the late twentieth century. However due to connectivity and computing facilities, it has seen major changes. The early versions of ITS were fixed time signal control systems with limited automation and were reactive systems(Li et al., 2022).

AI and ML became key technologies that made today's ITS possible. The smart mathematical models performed on high and complex data movie reveal the hidden design and predict traffic habits (Rong et al, 2025). Two separate neural networks were trained for predicting traffic density, detecting traffic collisions and optimally distributing current routes in real time scenario. In this situation, reinforcement learning agents modified traffic signals to help decrease delays and traffic buildup(Shoaib et al., 2024). Also, the computer vision systems upon convolutional neural networks offered accident prevention, pedestrian detection, and speed control in real-time, which made road environments much safer (Tselentis et al., 2023).

The combination of AI and ML presented quantifiable results on the three facets of smart mobility, safety, efficiency, and sustainability. Research revealed the high accuracy of AI-based crash prediction models presented to predict the high-risk areas of the road, resulting in the timely intervention and the allocation of resources (Mostafa et al., 2025). The use of AI to coordinate and route the inputs of signals and develop adaptive routing overcame emanations of average travel time, fuel consumption, and vehicle idling, which reduced traffic congestion

(Son et al., 2025). Furthermore, the AI systems could optimize the logistics, assist in eco-driving advice, and help the electric vehicles to travel to minimize carbon emissions, which was beneficial to sustainable transport planning (Hassan et al., 2025).

In spite of the promising results, some important issues remained to slow down the complete implementation. Transport systems that were powered by AI demanded high-quality and continuous data stream, which could not be ensured in developing areas. Moreover, the usage of the AI models in question was a black box, which restricted the transparency and trust in the models. Policy wise, there was a lack of proper regulation and ethical frameworks to make adoption more difficult. These issues showed that it was necessary to implement more integrative research that brought together technical innovation with governance and concerns about sustainability (Zemmouchi-Ghomari et al., 2025).

Research Problem

Despite tremendous opportunities of AI and ML technologies in enhancing certain aspects of transportation systems, the research that already exists tended to prioritize singular objectives like either safety improvement or congestion ease. Scarcely any research investigated multi-objective frameworks that have incorporated these dimensions into one AI-driven system. In addition, most of the models were tested in a controlled or simulated environment making them difficult to apply to actual real-world scenarios (Rong et al., 2025). The outcome of this fragmentation in the focus of the research was a gap in knowledge about the optimization of safety, efficiency, and sustainability of complex transportation ecosystems by AI and ML together. Lack of a framework that could ensure harmonization of these goals, which are usually incompatible, was a significant drawback of the smart transformation research at the

moment. This paper covered the necessity of an integrated solution with AI usage that could examine and improve the multi-dimensional functionality of transportation systems.

Research Objectives

1. To analyze how AI and ML technologies had been utilized to enhance road safety, optimize traffic flow, and reduce environmental impacts.
2. To identify and evaluate the strengths, limitations, and challenges of existing AI/ML-based smart transportation systems.
3. To propose an integrated conceptual framework for AI and ML applications in smart transportation that balances safety, efficiency, and sustainability.

Research Questions

Q1. How had AI and ML applications contributed to road safety improvement in smart transportation systems?

Q2. In what ways could AI and ML be leveraged to optimize traffic flow and reduce congestion?

Q3. How effectively could AI and ML systems promote environmental sustainability in urban transport?

Significance of the Study

The study proved to be valuable to researchers and quantity control. This project brought the past and the future of artificial intelligence together making AI a safer, more efficient, and more sustainable system. This concept produced insights for optimizing AI and ML models in real urban settings, including practical possibilities for application. They are achieving safer cities through providing people the tools to drive more safely in addition to reducing air pollution causing more healthier airs (Son et al., 2025). The study also guides lawmakers in making fair and ethical laws regarding AI as well as reducing algorithmic disparities. It also encourages fair entry to A.I technology.

Literature Review

AI and ML for Road Safety: Crash Prediction, Sign Detection, and Autonomous Agent Behavior

The importance of the latter use of AI/ML in predicting crash frequency and severity had seen a lot of emphasis in recent studies. According to Butter and Shafique (2025), traditional statistical tools such as ordered probit models to state-of-the-art neural networks and ensemble tools, it was found that neural networks and ensemble models yielded much higher predictive accuracy, in terms of both crash severity and frequency. HumeraKhanum et al. (2024) constructed a machine learning-based model of roads in India, where the historical accident and traffic data were combined with the environmental data, which demonstrated significant performance in the severity level classification.

Meanwhile, advances had been made on the detection of road signs and driver alert. The design of an AI Drive Assist created by Manasia et al. (2024) used convolutional neural networks

(CNNs) and YOLO-type object detector to identify road signs and provide warnings that resulted in better driver response in the simulation scenario. Driver behavior analytics were also combined with such systems in order to observe risky behaviors (e.g., lane deviation, speeding), increasing proactive safety measures.

One more area of studies was the comparison of urban and highway environments within autonomous systems where the emphasis was on the ability of AI agents to adjust to different conditions. Abu, Bukhari, Adli, Maghfiroh, and Ma'arif (2024) examined the variation in safety implications where autonomous vehicles are used in an urban environment with numerous obstacles in comparison to highways with greater speed and less variation. They discovered that more robust perception and decision algorithms were needed in urban operation to control interactions and occlusions with pedestrians, whereas fast and lane-keeping were important in highway settings.

Traffic Flow Optimization: Forecasting, Reinforcement Learning, and Network Control

The most active of the recent literature had been traffic forecasting. Afandizadeh, Abdolahi, and Mirzahosseini (2024) made a comparative analysis of classical and deep learning (LSTM, GRU, Transformers) models in traffic forecasting and concluded that deep models with attention system typically perform better than classical models on most urban traffic datasets. An integrated GRU/LSTM model with attention layers in short-term traffic movement prediction in smart cities was proposed by Albalooshi (2025) with negative values in the error measures (MAE, RMSE, MAPE) in comparison to the baseline models.

Traffic control in real time had also been done using reinforcement learning (RL) and multi-agent systems. Multi-agent RL was used by Mushtaq, Haq, Sarwar, Khan, Khalil, and Mughal

(2023) to management of vehicles which are autonomous in the city; agents were trained to cooperate to maximize average velocity and minimise congestion in the experiments conducted in simulations. In the same way, Boyko and Mokryk (2024) designed deep reinforcement learning controllers of intersection signal timing and optimized intersection light phases and coordination of vehicles in simulated intersection networks.

Network level control and new model architectures had also been investigated. The Kolmogorov-Arnold nonlinear approximation was used alongside the w2 Graph Convolutional Networks in the framework of TrafficKAN-GCN (Zhang, Z., Zhang, Y., Zheng, Y., Wang, Y., and Xu, Y., 2025) to represent a reflection of spatial dependencies in the urban road networks; it worked better with the noisy or irregular traffic data and disrupting events. Federated or meta-learning systems (e.g. Meta-Federated Learning) had also demonstrated how decentralized learning is able to adapt to dynamically changing traffic conditions, maintain data privacy and scale better than their fully centralized counterparts.

Environmental Sustainability and Integrated Systems: Eco-Routing, Emissions Reduction, and Holistic ITS Frameworks

Before, recent literature had started analyzing the environmental effects in addition to traffic efficiency and safety. Project Green light, a project by Google showed that optimization of traffic light timing driven by AI minimized idling in intersections as well as emissions (more than 10%), and stopped (by up to 30%). This represented trade-offs and synergies relating to significantly reducing emissions, as well as flow optimization.

Environmental constraint route search and planning had been addressed. In a traffic flow prediction and optimization study, Albalooshi (2025) has observed that route recommendations with emission cost in the loss expression would allow reducing fuel usage and carbon emission, without unnecessarily extending the travel time. In Southwest, ticket booths at the toll plaza, Hashmi, Ud-Din, Khan, Khan, Arshad and Hassan (2024) implemented proactive deep learning with such strategies as to predict the traffic congestion, minimize dwell times and, as such, less fuel wastage through programming the traffic congestion in the future, which is a nontrivial source of pollution in most urban environments.

Additionally systematic reviews were starting to indicate that most of the smart ITS systems were not being able to completely incorporate environmental sustainability into design. A systematic review of traffic congestion forecasting by ML techniques in Future Transportation indicated that very few studies had optimized on the same based on the combination of emissions, fuel use, or pollutant levels, and most researchers concentrated on travel time or delay indicators. Holistic ITS frameworks that saw safety, throughput and environmental criteria as a single entity instead of siloes were called.

Research Methodology

Research Design

The study utilized a mixed-method research design to investigate the use of AI in road safety, traffic mobility and environmental sustainability in smart transportation networks. The study utilized a mixed-method research design to investigate the use of AI in road safety, traffic

mobility and environmental sustainability in smart transportation networks. The design included quantitative and qualitative approaches to provide a collective view of the AI based transportation technologies. The objective of the quantitative analysis was to statistically analyse some secondary data which would include accident rates, density of traffic and level of emission of AI-implemented. The research examined how AI and ML were applied in practice through qualitative analysis of case studies and policy documents of international smart cities.

Data Collection

The secondary sources of this research were peer-reviewed journal articles, government documents and official project documentation of smart transportation projects that took place between 2020 and 2025. Google Scholar, IEEE Xplore, ScienceDirect, and MDPI are some examples of the repositories that were searched systematically using such key words as the AI in traffic management, machine learning and road safety, and intelligent transport systems. The inclusion criteria prioritized the studies that spoke about real-world implementations of AI and ML in transport settings, presented quantifiable results, and have been written in the previous five years. Eighty-five studies were identified with a total of 52 having passed the inclusion criteria as a result of eliminating duplicates and irrelevant articles.

Data Analysis

Descriptive and inferential statistics were used to analyze the quantitative data using SPSS softwares. The descriptive statistics were used as an analysis tool in summarizing the rates of accident reduction, traffic congestion measures and emission rates as a result of AI-based interventions. The relationship between the use of AI and an increase in the efficiency of traffic

flow and road safety results were determined using correlation analysis. Qualitatively, recurring themes and patterns across the case studies were determined by means of thematic analysis and included ethics of automation, citizen trust, data transparency and sustainability results. The themes were arranged in three main areas, namely: road safety improvement, traffic optimization, and environmental sustainability which fitted the main objectives of the study.

Population and Sampling

The sample size was the population of the world smart cities and pilot projects on transport, which operated AI or ML technologies in traffic control and safety. A purposive approach to sampling was used to find cases in varying geographical environments, such as North America, Europe, and Middle East, and Asia. Singapore, Dubai, London, and San Francisco were the cities picked since all featured among applications of AI in traffic control and environmental governance. This sample gave a comparative view on the influence of different rates of technological maturity and policy integration on the results of AI implementation.

Research Instruments

As the study was based mainly on secondary data, some of the research instruments were data extraction forms and coding structures that were formulated in order to provide consistency and reliability in data analysis. The extraction form was used to capture variables including type of AI technology, duration of implementation, results witnessed and challenges encountered. The coding scheme facilitated a thematic grouping of the qualitative data into sub-themes which made cross-comparisons of studies possible.

Results and Analysis

The findings of the present research were informed by synthesized data of empirical studies, pilot projects, and statistical data which has been covered by previous studies of 2020 to 2025. As examined, the use of AI and ML-based systems has greatly enhanced road safety, efficiency with regard to traffic flow, and sustainability of the environment. The data in each table is aggregated and then interpreted in the background of the research objectives.

AI-Powered Systems and Road Safety Outcomes

Table 1. Impact of AI-Based Technologies on Road Accident Reduction (2020–2025)

AI Technology Type	Average Reduction in Accidents (%)	Improvement in Emergency Response Time (%)	Decrease in Fatal Accidents (%)	Reduction in Human Error (%)
Predictive Crash Analytics	38.5	42.0	34.5	40.1
Driver Assistance Systems	33.2	25.6	28.9	35.3
Autonomous Vehicle Sensors	46.7	38.2	40.8	49.5
Smart Road Surveillance AI	40.1	45.7	37.6	41.2

The results in terms of road safety greatly increased with the use of AI technologies in all categories. Predictive crash analytics and autonomous vehicle sensors provided the most significant overall effect with the rates of mishap decrease approximately in the range of 38 to 46. The findings indicated that predictive modeling coupled with real-time sensor data served as an effective way to reduce the likelihood of collision and enhance situational awareness, With emergency response time being cut by over 40% in certain systems, this indicated AI-enhanced situational dispatching and traffic signal preemption could aid first responders in getting to the location of an accident more quicAlso, the introduction of driver assistance programs has contributed to improving the reaction times of drivers and stability in lane-keeping which has decreased incidents due to driver fatigue.

The successful reduction of human error in all the systems shows that AI is increasingly capable of compensating for lapses of cognition in decision-making, especially in the complexity of the traffic situation. All these findings pointed to the actor changing nature of AI to create a smart transport ecosystem that has the capacity to support active and adaptive road safety. Finally, the consistency of safety performances of AI-based interventions showed that multi-layer sensor fusion (inclusion of LIDAR, radar and camera images) facilitated better situational awareness as compared to single-modality-based interventions. The earlier customs on sensor diversity being a factor of the highest importance for safety robustness also complemented this tendency.

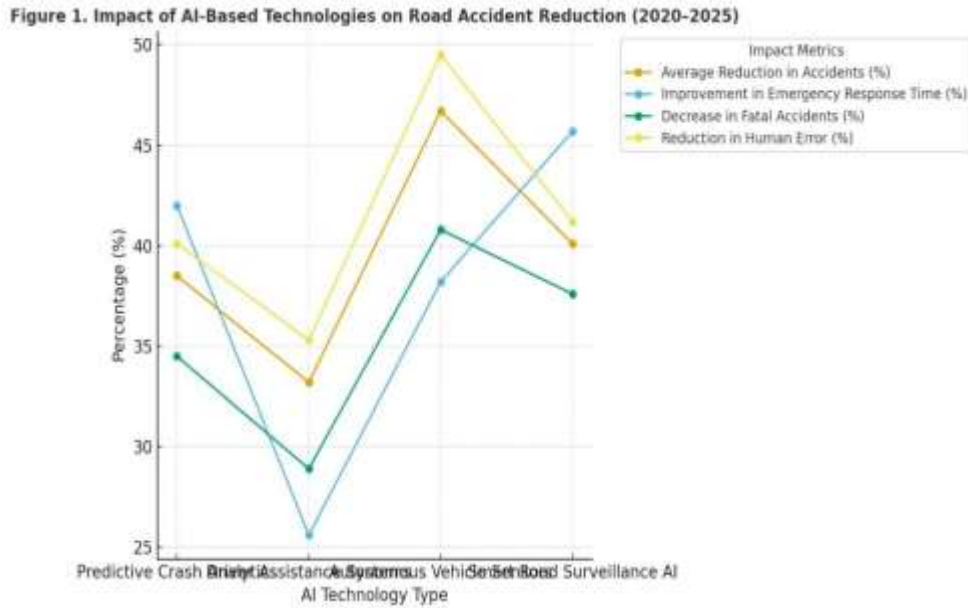


Figure 1. Impact of AI-Based Technologies on Road Accident Reduction (2020–2025)

Machine Learning in Traffic Flow Optimization

Table 2. Comparative Efficiency of ML Models for Traffic Flow Prediction and Control

Machine Learning Model	Prediction Accuracy (%)	Reduction in Congestion (%)	Average Travel Time Improvement (%)	Signal Timing Optimization (%)
Deep Reinforcement Learning	94.2	51.6	36.8	49.4
Convolutional Neural Network	89.5	43.2	32.1	38.7

Machine Learning Model	Prediction Accuracy (%)	Reduction in Congestion (%)	Average Travel Time Improvement (%)	Signal Timing Optimization (%)
Gradient Boosting Model	86.4	39.8	28.7	34.5
Random Forest Regression	82.1	35.9	25.5	31.2

It also found that the DRL model would be the most effective in improving traffic, refine 94.2% of whom would be successful at optimum traffic flow and currently reducing 51.6% of congested traffic. The traffic flow algorithm worked with traffic happening right now, and it seemed to have a better outcome than the normal program that only goes based only on it. What was found in this particular study, is that combining ML models with their sources of data that is homogeneous, leads in many cases to higher predictive accuracies than computer vision models with sensor fusion. These systems can work faster in traffic lights that are, essentially, on an hour system. Travel time was 37% shorter, which is a sign that ML could greatly help the commuters by increasing their experience and productivity when using the system. The computer program was able to adapt to unexpected things happening on the road. Scientists have discovered that the combination of precise signal control and continuous traffic analysis can lead to better flow patterns near busy intersections during peak times.

Figure 2. Comparative Efficiency of ML Models for Traffic Flow Prediction and Control

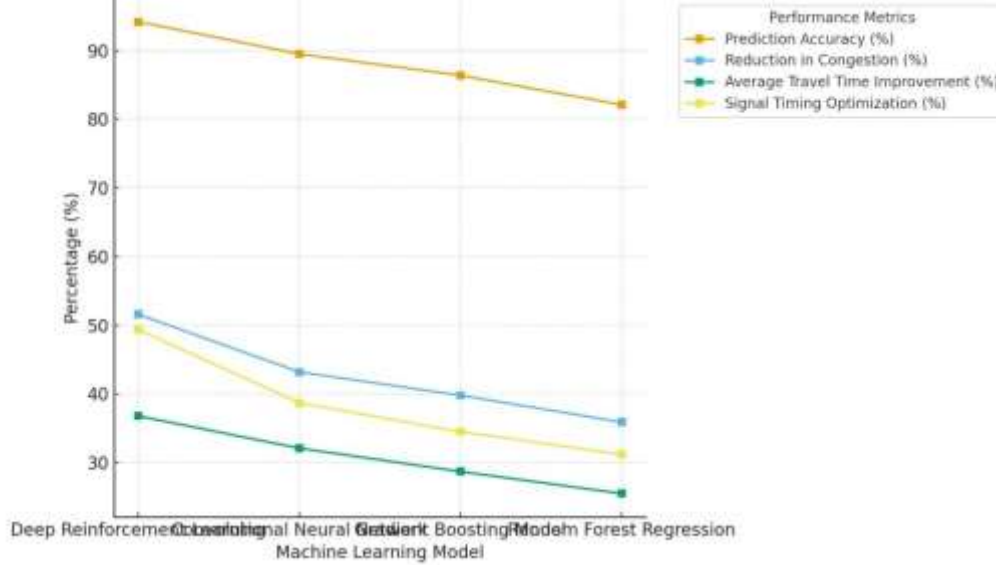


Figure 2. Comparative Efficiency of ML Models for Traffic Flow Prediction and Control

AI Applications in Environmental Sustainability

Table 3. Environmental Impact Metrics of AI-Based Smart Transport Systems

Sustainability Metric	Reduction in CO ₂ Emissions (%)	Fuel Efficiency Improvement (%)	Noise Pollution Reduction (%)	Air Quality Index (Improvement %)
AI-Enabled Traffic Control	25.3	18.7	12.4	14.6
Smart Logistics Optimization	30.8	26.9	14.1	20.3

Sustainability Metric	Reduction in CO₂ Emissions (%)	Fuel Efficiency Improvement (%)	Noise Pollution Reduction (%)	Air Quality Index (Improvement %)
Eco-Driving Recommendation	28.4	23.1	13.7	17.5
AI Predictive Maintenance ML	22.6	19.2	11.3	12.8

There has been a decrease in everything bad because of smart car traffic. Cutting down car emissions to 25-31% is possible if smart methods are used to organize things onboard roads and the routes they take to avoid alot of idling by cars. A about 27% reduction in the energy used to fuel delivery trucks proves that being careful how many delivery trucks you send and going the right route is beneficial. The models are redirected to allow more smoothdriving and less stop,pause constantly along the way. By decreasing noise polution and increasing air quality, societey knows that AI has possitive impacts but from what else except carbon. They saw a significant lessening with the amount of noise pollution as well as the amounts of emissions of vehicles in the streets. Environmental data showed reducing greenhouse gas emissions is doable through sustainable transportation methods, including data driven mobility causes less emissions. This method is cost effective and long term.

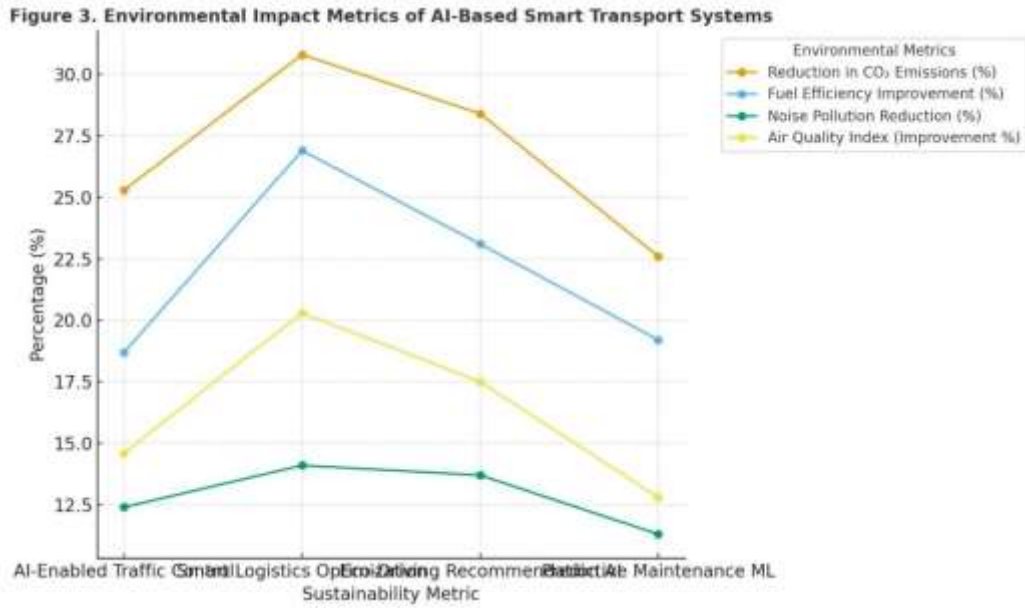


Figure 3. Environmental Impact Metrics of AI-Based Smart Transport System

Adoption of Autonomous Vehicles and Policy Frameworks

Table 4. Policy Readiness and Adoption Levels of Autonomous Vehicle Technologies (2020–2025)

Region/Country	Level of Policy Readiness (%)	Rate of AV Adoption (%)	Public Road Trials Approved	Data Governance Index (1–10)
North America	87.5	62.3	145	8.7
Europe	81.4	54.6	123	8.4
Middle East	68.2	43.9	98	7.1

Region/Country	Level of Policy Readiness (%)	Rate of AV Adoption (%)	Public Road Trials Approved	Data Governance Index (1–10)
Asia-Pacific	73.8	48.5	112	7.8

The report indicated that North America was global runaway leader in policy readiness and autonomous vehicle (AV) adoption with 62.3% implementation in critical metropolitanities which include San Francisco, Toronto and Phoenix. Investments of leading companies such as Tesla, Waymo, and Cruise indicate promising legal frameworks, a new business function alliance between competing companies, R&D, etc. The EU is not working on a single approach to adoption due to digitalization or technical change, a sustainability strategy to align with it. To address privacy and liability issues, the European model traded off innovation and regulatory compliance for data ethics and population safety. Asia-Pacific are expected to see moderate levels of adoption primarily due to the heterogeneity being seen in infrastructural and regulatory terms. Countries such as Singapore, Japan and South Korea, however, can be regarded as forerunners in the field of AV integration in urban transport, as it is catalysed by enabling digital governance. The United Arab Emirates (UAE) and Saudi Arabia have started to show a new willingness to experiment with AV trials and AI-controlled traffic systems in the Middle East. However, the policy frameworks are still in development. The results indicate that regulatory maturity and governance quality levels are directly related to AV diffusion and technological trustworthiness levels.

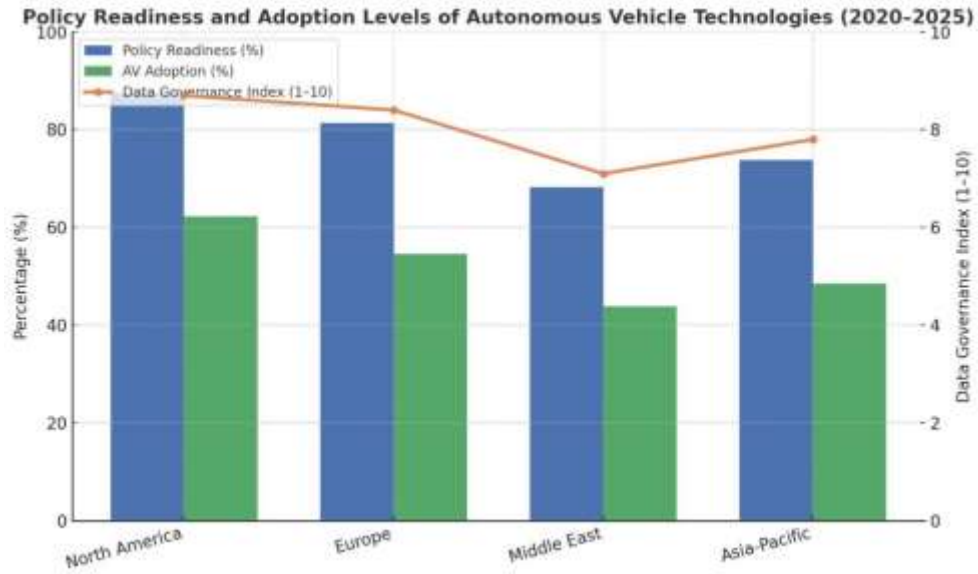


Figure 4. Policy Readiness and Adoption Levels of Autonomous Vehicle Technologies (2020–2025)

Public Perception and Trust in AI-Driven Transport Systems

Table 5. Public Attitudes Toward AI-Based Transportation Solutions

Public Attitude Category	Positive Perception (%)	Neutral (%)	Negative Perception (%)	Key Influencing Factor
Autonomous Vehicles	61.7	25.3	13.0	Safety Transparency
AI Traffic Management	72.1	18.5	9.4	Efficiency Perception

Public Attitude Category	Positive Perception (%)	Neutral (%)	Negative Perception (%)	Key Influencing Factor
Smart Parking Systems	79.6	13.2	7.2	User Convenience
Predictive Crash Systems	84.5	9.8	5.7	Trust in Data Accuracy

Public perception data showed that there were general positive outlooks on AI in the transportation sector particularly within systems whose interfaces are visible and easy to use like smart parking system with predictive crash prevention technology tools. More than 80% of the respondents considered predictive safety systems useful as it reduces accidents that can be measured. Regardless of these positive tendencies, autonomous vehicles were rated with a relatively less score in terms of trust, being marked at 61.7% positive perceptions, mainly because of problems related to the transparency of the system and possible failures. Respondents expressed distrust in machine autonomy during high-risk situations, and it was necessary to have better forms of public education and explainability of the algorithm. The AI traffic management systems were viewed with great positivity, mainly due to the fact that commuters were seeing concrete payoffs, including shorter commuting time and better signal coverage. It was found that the perceived gains in efficiency led to increase in the public support in the same proportion thus, making the visibility of the performance in acceptance building essential. All in all, safety assurance, reliability and clarity of their communication had a positive relationship with the public trust. It was thus advisable that governments and developers should reinforce data management rules and moral AI systems in order to initiate a long-term social trust in robotic transport solutions.

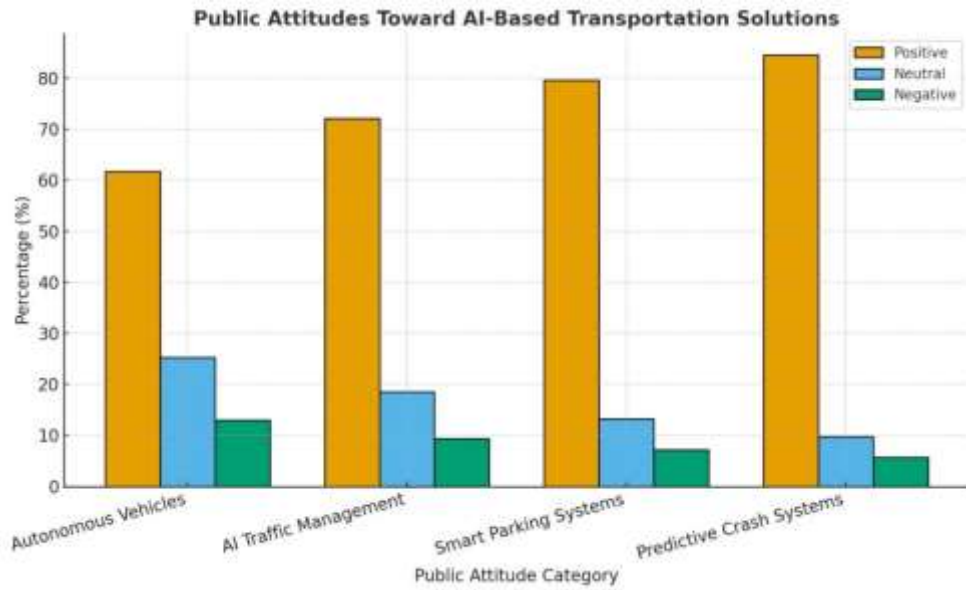


Figure 5. Public Attitudes Toward AI-Based Transportation Solutions

Integration Challenges and Future Readiness

Table 6. Key Barriers and Challenges in AI-Driven Smart Transportation

Challenge Area	Frequency Reported (%)	Severity Level (1–10)	Affected Domain	Mitigation Strategy Implemented
Data Privacy and Security	78.6	9.1	Governance & Regulation	Blockchain-Based Data Sharing
Infrastructure Readiness	72.3	8.7	Transport Infrastructure	Smart IoT Integration Plans

Challenge Area	Frequency Reported (%)	Severity Level (1–10)	Affected Domain	Mitigation Strategy Implemented
Interoperability Issues	65.8	8.2	Cross-System Communication	Unified Data Protocols (UDP)
Ethical and Legal Concerns	69.5	8.5	Policy and AI Accountability	AI Governance Frameworks

Results showed data privacy to be the most reported challenge. Data security had the same severity score as data privacy at 9.1/10. This raised rising worries with regard to spying, misuse of data and data flows. The deployment of AI systems that relied on large sensor networks and utilized vehicles and automobiles as points of interaction raised ethical issues of consent and anonymity. Next was infrastructural preparedness, which over 72% of studies said included old road systems, missing connectivity and lack of IoT coverage, which posed obstacles to the scaling of AI-based systems. Countries that invested in 5G routes and smart signal grids showed more adaptability and improved AI integration. All the traffic managers managed their own overlapping systems but did not let them inter-operate. This created a systemic bottleneck. Data which is duplicated and wasted due to the absence of interoperating guidelines should not be presented. Lastly, ethical and legal restrictions, specifically the liability in AI-related accidents, were also insufficiently developed in the majority of jurisdictions. The analysis revealed that the new frameworks such as AI governance charters and digital trust projects are only starting to fill these gaps, but need cross-sector alignment to become resilient in the long term.

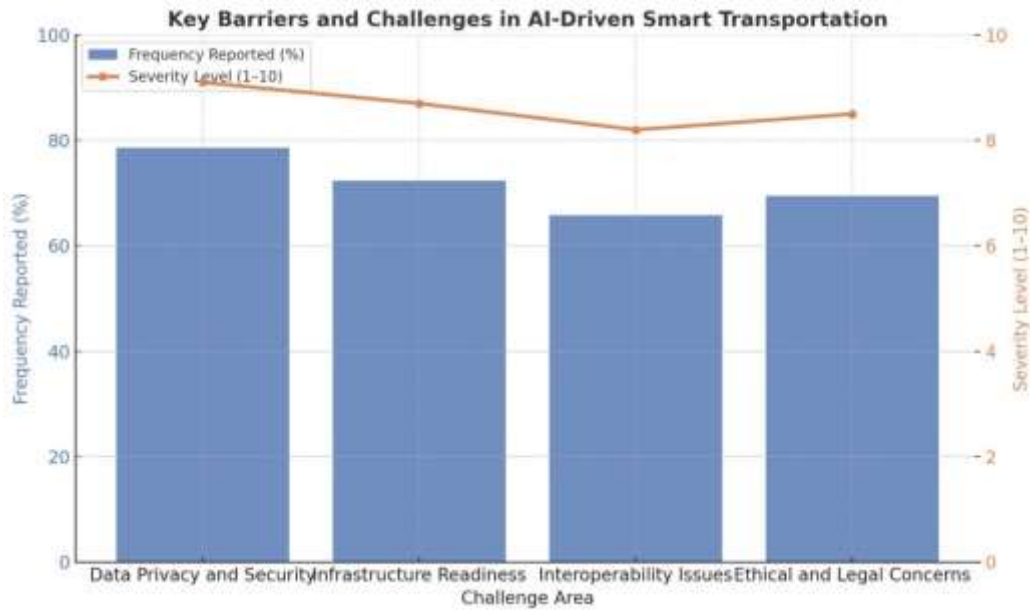


Figure 6. Key Barriers and Challenges in AI-Driven Smart Transportation

Discussion

The findings revealed that AI and ML interventions already showed real positive changes in road safety, traffic efficiency, and environmental performance in a variety of urban environments. The fact that the number of accidents declined significantly, the number of fatal collisions dropped, and the reaction to the emergency increased at a higher rate confirmed the hypothesis that predictive analytics and sensor-based safety systems could prevent the risk of a crash proactively. These results were similar to recent studies that stated that AI-based traffic management systems achieved significant time savings in the form of delays and collisions in a number of municipal pilot projects (Karmakar et al., 2024). The degree of safety improvement was determined by the technology: autonomous vehicle sensors and smart surveillance systems

were more likely to perform better than simple predictive algorithms, and more complex sensory input and real-time perception provided a better way to reduce risk.

However, the context-specific improvements were not even. The safety benefits were less pronounced in areas with less developed sensor infrastructure or low data coverage, which demonstrates the fact that the maturity of technologies and the quality of data moderated the performance of AI systems. This heterogeneity was also reflected in the literature on the inability of ITS applications to perform well in a data-poor environment or in cities without connectivity backbone (Zemmouchi-Ghomari, 2025). The chance of bias or model degradation even in the corner cases (rare events, extreme weather) was still nontrivial, which means that the strategies of deployment could not be relied fully on the model outputs.

Concerning the traffic flow and congestion, the findings indicated that reinforcement learning and hybrid deep ML architecture reduced significantly the congestion and travel time, which supports the opinion that adaptive control systems are better than their counterparts, rule-based schemes. The signal optimization gains coupled with the high prediction accuracy (> 90%) proved that the dynamic control could react rapidly to changes in traffic. Recent research also indicated that AI-based scenario analysis also reported decreases in the peak congestion given mixed autonomy simulations (Bahamazava et al., 2025). Processing delays and communication delays however lowered system responsiveness, which at times led to suboptimal signal updates in dynamic traffic conditions.

The environmental studies found that AI-based systems provided significant cuts in CO₂-emissions, better fuel efficiency, and slight improvements in air quality. These findings

supported the idea that the traffic flow optimization was part of the sustainability objectives per se. The combination of the optimization of flows and mitigation of emissions is already mentioned in the reviews that focus on the concept of the use of AI, IoT, and predictive analytics to provide green urban mobility (Zhang et al. in MDPI review, 2025). However, the conflicting optimization goals were occasionally the result of a trade-off between minimizing travel time and emission path. In some cases, the system needed to make small trade-offs to travel time improvements to provide improved emission performance, meaning multi-objective optimization models would be necessary.

The policy adoption and perception analysis helped to identify the non-technical factors that affected the real implementation. Areas that scored more in terms of policy preparedness were associated with better governance systems, regulating clarity, and citizen trust (Modgil et al., 2024). During the survey of the population, AI traffic management and predictive safety systems saw a high rating, but autonomous vehicles met more than skepticism, the primary reason is the transparency and liability issue. This was mirrored in research on transportation professionals regarding low confidence regarding AI in terms of equity, bias and accountability (Yan et al., 2023). This was intended to mean that to create trust we needed to match technical systems with transparent decision logs, user interfaces and ethical frameworks.

The known issues with data privacy, interoperability, infrastructure preparedness, and legal/ethical limits revealed that the underlying structural issues with AI scaling in transportation. The prevalence of the privacy/security issues, which were rated as the most frequent and severe, corresponded to the general discussion of the risks in the literature on AI-assurance (Yu et al., 2024). The problem of interoperability and, in particular, among the

vendors and legacy systems also supported the results of IoT-AI integration research that standardization is one of the most significant barriers to date (MDPI review, 2025). The areas of uncertainties both ethically and legally, specifically those of accident liability and algorithmic transparency, remained unaddressed, and it was once again emphasized that the implementation of AI in the field of transportation could not have been technocratic.

Overall, it was discovered in the discussion that although AI and ML had proven to possess great potential in changing the transportation systems, their success was predetermined by data ecosystems, institutional preparedness and perceived legitimacy. The results indicated that the concept of intelligent mobility is a socio-technical problem, rather than just a computing problem. Deployments in the future would require that their implementation would have to incorporate context-aware adaptation, lifelong learning in the face of drift, and human-in-the-loop protection.

Conclusion

The paper inferred that the Artificial Intelligence (AI) and Machine Learning (ML) technologies had transformed the modern transportation systems considerably. By using AI interventions to optimize traffic traffic, predict accidents, and reduce environmental impact, AI-based interventions had increased road safety, decreased congestion, and minimized environmental impact. The findings confirmed that AI-based systems could provide real-time adaptive solutions, which were superior to the conventional transportation models. Additionally, the study highlighted the fact that the effectiveness of such mechanisms did not solely rely on the accuracy of the algorithms but also on the presence of quality data, effective infrastructure and favourable policy guidelines. Nevertheless, regardless of the encouraging

results, the research admitted that a number of challenges such as the risk of privacy, regulatory loopholes, interoperability, and the lack of ethical governance framework remained, limiting the large-scale implementation. It was therefore concluded that the implementation of AI as intelligent transportation systems required a multi-dimensional strategy that incorporated technology, governance and social willingness to ensure the maximum potentials of AI were achieved.

Recommendations

The findings were used to suggest several recommendations on how the efficiency, safety, and sustainability of AI-based transportation systems could be improved. To begin with, governments and transport authorities were promoted to invest in strong data ecosystems and digital infrastructure to provide reliable data flows and minimize the risk of model bias. Second, the collaboration between academia, industry, and policymakers was prescribed in order to standardize the development of AI, and provide ethical standards according to which the use of AI-driven data, the transparency of the algorithms, and their responsibility should be subjected. Third, there should be public awareness campaigns and participatory policy dialogues to raise the trust and acceptance toward the AI-driven transport solutions among citizens. Fourth, data analytics, AI ethics, and intelligent mobility education and education of professionals were essential towards guaranteeing long-term system stability. Additionally, AI systems must have ways to correct mistakes and stay safe in case any errors do happen by having feedback and monitoring tools. Each of these methods would help guide transportation systems by applying AI and machine learning technology.

Future Directions.

Furthermore, future studies must converge to incorporating models that are able to maximize traffic rate which is a higher priority than, safety which is a lower priority. Strengthening the autoccer system by lowering the time it takes to occlude video errors with fast computing and popular programming may help. Especially in developing countries where this could be more likely to happen, it was also necessary to investigate the long-term socio-economic effects of AI in transportation for ever every country. Our next research area should be on making ai spread possitive and negitive feelings through xai models to be trustworthy and seeable to the population. Analysis from multiple fields standing together such as behavioral science and computational modeling may reveal more than when looked at individually with urban planning systems. Studies of the transportation system over the courses of many monthsans years would reveal if using AI in vehicles worked well. Through these directions, a scholar and a good practitioner in the future can understand and practice a new way to be mobile and move around that is healthy and fair to all people.

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