Center for Management Science Research
ISSN: 3006-5291 3006-5283 Volume 3, Issue 4, 2025

A IOT BASED SMART TRAFFIC MANAGEMENT SYSTEMS: ENHANCING URBAN MOBILITY

Chaudhry Abu Bakar Imran

NUST Institute of Civil Engineering, School of Civil and Environmental Engineering, National University of Sciences and Technology

chabubakar2001@outlook.com

DOI: https://doi.org/10.5281/zenodo.16265038

Keywords
Internet of things, IoT sensor, Intelligent Transportation System, Smart Traffic Management, Urban Cities, Sustainability

Article History
Received: 19 April, 2025
Accepted: 29 June, 2025
Published: 21 July, 2025

Corresponding Author: *
Chaudhry Abu Bakar Imran

Abstract
Smart cities have solved a number of big problems that have come up with traditional urbanization around the world. Nevertheless, sustainable traffic management in smart cities has garnered insufficient attention from academics owing to its intricate and varied characteristics, which directly impact the transportation systems of smart cities. The research sought to tackle traffic-related challenges in smart cities by developing a sustainable framework utilizing Internet of Things (IoT) and Intelligent Transportation System (ITS) technologies. Furthermore, the two methodologies employed real-time traffic data and gathered information about vehicles and road users using AI sensors and ITS-based devices. The data may be analyzed and communicated via machine learning techniques and cloud computing for traffic management, decision-making policies and future documentation. The proposed framework indicates that implementing such systems in smart city transport could significantly enhance traffic outcome prediction, traffic forecasting, traffic decongestion, reduction of road users' lost hours, provision of alternative routes and simplification of urban transport for residents. The proposed integrated framework may effectively tackle pollution concerns in smart cities by enhancing public transit and supporting low-carbon emission zones. The implementation of these solutions help smart cities to attain sustainable traffic management and diminish their carbon impact, becoming them habitable and ecologically sound.

INTRODUCTION

In recent decades, urbanization has intensified significantly resulting in a variety of intricate difficulties that require inventive and sustainable solutions. Urban traffic management is among the most pressing issues significantly influencing urban sustainability, economic performance and public welfare (Vellela et al., 2025). The congested roads also have a major negative impact on the environment by increasing air pollution and greenhouse gas emissions in addition to costing businesses money because of delays and inefficiency. The social circumstances such as heightened stress and diminished quality of life underscore the imperative of tackling congestion in contemporary urban areas (Khang and Singh, 2025). A smart city framework has emerged as an effective approach to addressing these challenges, utilizing technologies such as the Internet of Things (IoT), artificial intelligence (AI) and sophisticated data analytics (Sreelekha., 2025). In this ecosystem, intelligent traffic management is acknowledged for its ability to improve mobility, alleviate congestion, and diminish the environmental impact of transportation. Cities may now employ diverse technologies to gather real-time data on traffic flow, vehicle counts, and travel durations via embedded IoT sensors situated at junctions and high-density corridors. This data is utilized to optimize signal timing, redirect traffic, and provide dynamic rather than static traffic management (Shvedenko et al., 2024).

A paradigm shifts from conventional schedule-driven systems to data-driven adaptive alternatives that react dynamically to real-time circumstances is represented by such advancements (Mutambik., 2025). Although IoT-enabled systems have significant potential, their implementation presents several technological and ethical challenges. Foremost among these is data governance: IoT devices consistently gather sensitive information such vehicle location and travel history which necessitates protection against abuse or cyber-attacks (Abduljabbar et al., 2025). Furthermore, system dependability depends on the quality of the receiving data. Defective sensors or network interruptions might generate inaccuracies compromising traffic control choices (Zamri et al., 2022). This research also investigates the infrastructural and regulatory prerequisites for effective deployment emphasizing optimal practices in system resilience and data management. The success of its execution is fundamentally dependent on stakeholder interaction outside the technical domain. The efficient intelligent traffic systems need cooperation among municipal authorities, transportation agencies, private-sector technology companies, and the general populace. Public acceptance is crucial in systems that are inadequately comprehended or regarded as invasive may elicit opposition.

The study emphasizes the significance of public education and clear communication of system advantages, data utilization and expected effects on everyday travel behaviors (Mutambik., 2023). An inclusive methodology for system design and deployment is crucial for guaranteeing its sustained sustainability. Traffic congestion is a significant impediment to transportation and it continue to escalate in tandem with urban expansion directly impacting socio-economic activity. The economic and social activities predominantly depend on integrated and sustainable transportation. Hence, when urban areas expand due to various activities like transportation systems that must be enhanced to include and support anticipated increases. The integration of transportation management with sophisticated technology will significantly aid in achieving the goals of smart cities (Troutbeck., 2016). Traffic congestion is recognized as a major global issue in metropolitan regions. The issue is more pronounced in smart cities where population growth and vehicle proliferation are escalating. Global cities are encountering difficulties due to heterogeneous traffic flow exacerbated by a rapid increase in traffic that exceeds road capacity. These have required the regulation and management of cars to provide sufficient traffic flow. Traffic congestion is unavoidable but can be reduced to a minimal level. It is essential to integrate general activities with efficient and sustainable transportation systems for a smart city to be livable which can be enhanced through collaboration with Intelligent Transportation Systems (Khallouk et al., 2018).

The swiftly and markedly growing urban population is the primary driver of air pollution from traffic emissions. The data shows that over 50% of global fuel production is utilized by the transportation sector which substantially contributes to environmental pollution. This percentage is expected to rise in the coming years due to the unprecedented and ongoing increase in vehicle ownership worldwide (Musa et al., 2023). The release of harmful gaseous substances by vehicles, such as carbon dioxide, carbon monoxide, nitrogen oxide, volatile organic compounds, particulate matter, etc., can lead to both non-current traffic congestions which are typically caused by malfunctioning traffic signals, accidents, sudden damage to road infrastructures like bridge failures, etc. The recurrent traffic congestions which are caused by consistent and higher volumes of traffic at certain hours within specific sections of a road. Failure to address these issues could defeat the goals of sustainable transportation (Othman et al., 2019).

Literature Review

The development of smart traffic management (STM) systems has been facilitated by swift progress in IoT infrastructure and real-time traffic monitoring technology. A fundamental element of these systems is the installation of IoT-enabled sensors at key urban sites such as junctions, major thoroughfares and pedestrian crossings. These sensors gather detailed data on vehicle flow, congestion levels, average speeds, and travel lengths, allowing dynamic signal management tactics and data-informed decision-making. (Jiang et al., 2022). As an illustration, in the United Kingdom IoT-based systems have been demonstrated to mitigate delays by rerouting vehicles around congestion points in real time Grag et al., 2024). These sensor networks facilitate a transition from static, schedule-dependent traffic signal operations to dynamic, condition-responsive systems. The gathered data is frequently analyzed using edge computing or transmitted to centralized traffic management centers where algorithms modify signal timing to minimize idle time and enhance throughput. These systems can include feedback loops that identify unforeseen congestion or problems and promptly undertake remedial measures frequently without human interaction.

This real-time optimization mechanism is a critical component of enhancing sustainability and efficiency as cities become more congested and environmental pressures intensify (Peráček et al., 2025). Simultaneously, new data analytics especially predictive modeling and machine learning have broadened the operational capabilities of IoT-based frameworks. These techniques enable cities to forecast future congestion patterns, allowing proactive management measures instead of reactive reactions. The application of neural networks to traffic flow forecasting has yielded promising results in the reduction of peak-hour congestion and the normalization of traffic distribution. Additionally, these solutions provide real-time driving direction through rerouting algorithms, which alleviates commuter stress and optimizes the distribution of traffic on road networks (Tiwari., 2024).

Traffic Management in Smart Cities:

Traffic congestion is a societal and environmental detriment that directly and indirectly affects a nation's GDP. A research indicates that on average individuals in the United States lose 338 hours annually due to traffic congestion. This phenomenon mirrors conditions in many urban centers globally where the demand for increased traffic surpasses the capacity of existing road infrastructure resulting in complexities in traffic management (Schrank and Eisele, 2021). The establishment of rigorous and robust transportation predictive approaches and decision-making tools that are compatible with the anticipated nature of the traffic is essential in order to prevent the occurrence of such a phenomenon while developing smart cities (Pu et al., 2017). The significant increase in population and other activities diminishes the effectiveness of conventional traffic lights. Therefore, modernizing these outdated systems to meet contemporary standards necessitates integrating traffic management with powerful AI technologies (Muse et al., 2023). The study was one of the notable contributions that emphasized the development of strong automated platforms for traffic management.

The system utilizes real-time traffic data encompassing vehicle speed and volume which is transmitted to a server equipped with IoT-configured devices to execute computations and display signals in alignment with lane capacity and traffic volume. This has facilitated the automation of traffic in a smooth manner. These techniques are associated with sensitive and costly devices, including video image processing, microwave radar, laser radar, passive infrared, ultrasonic, and passive acoustic arrays. These may pose maintenance challenges and be susceptible to adverse weather and environmental disturbances. There are numerous methodologies that are primarily automated for controlling urban traffic are advancing with enhanced functionalities (Imran., 2025).

Implications for Traffic Management:

The incorporation of specific vehicle fleet data into the simulation framework for a thorough assessment of traffic management solutions tackling the distinct issues presented by London's varied road users (Mutambik., 2025). As an illustration, comprehending the constitution of the vehicle fleet will enable the following details as mentioned in Table 1.

Table 1: *The implications for Traffic Management.*

Factors	Role in Traffic Management
Signal optimization	Traffic signals are adjusted to priorities buses and emergency vehicles, reducing the delays for high-priority users.
Congestion mitigation	By identifying areas with high commercial vehicle density, targeted rerouting strategies are implemented to minimize bottlenecks.
Safety enhancements	Dedicated lanes and signal timing for cyclists improve road safety and reduce conflicts with motorized vehicles.

Internet of Things (IoT)-Based Intelligent Transportation System:

The Intelligent Transportation Systems (ITS) was originally designed to assist cities in addressing road traffic challenges. Nevertheless, because to its adaptability the system has expanded to encompass autonomous toll fare collecting, freight and fleet management, the application of GIS, and advanced satellite technologies particularly in structured urban areas. Artificial intelligence is a vital element in the administration of transportation inside smart cities. The implementation will facilitate uninterrupted vehicular flow, traffic monitoring, accident prevention, real-time data acquisition regarding vehicles and other road users, improved security, increased system efficiency by eliminating human error, and prompt safety and assistance for drivers. The aim of the previously disclosed concept of sustainable traffic management utilizing the ITS framework in smart cities is to create resilient transportation systems that ensure dependable and efficient networks, optimize overall travel duration, reduce fuel consumption, and alleviate pollution in vulnerable environments. This may be accomplished by the systematic and dependable gathering, organization, and analysis of data hence facilitating accurate and rapid traffic decision-making processes. These novel methods must align with the multifaceted characteristics of smart cities (Collotta et al., 2018).

Models for Analysis of Traffic in Smart Cities:

The rapidly increasing trend of multidisciplinary research has facilitated the integration of AI techniques in transportation engineering. The conventional and classical statistical tools such as linear regression have been utilized to address real-world issues yet they are nearing obsolescence due to their limitations in resolving specific problems (Correia et al., 2013). However, with technological advancements, complex and predominantly non-linear problems are emerging particularly in traffic engineering which necessite specialized approaches. It is necessary to fully comprehend the properties of data before beginning any modeling. A study has provided a general explanation of the steps required for the execution of data mining and analysis (Musa et al., 2023). The steps were categorized and designated as the Knowledge Discovery in Database KDD.

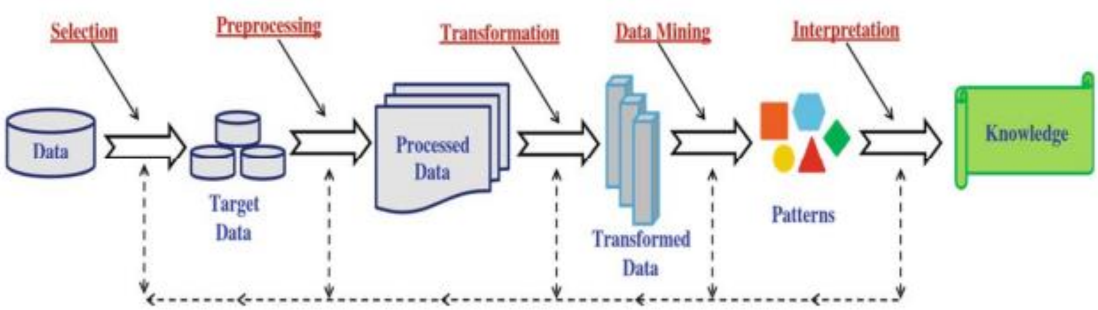

Figure 1: *Architectural workflow of the KDD process (Musa et al., 2023)*

The traffic analysis categorizes traffic models into microscopic, macroscopic, and mesoscopic as seen in Figures 1 and 2.

- The microscopic models for traffic management often establish a compelling correlation among cars, commuters and road networks mostly contingent upon the reliability of the available data.
- The macroscopic models establish a framework for traffic analysis. This formulate a mathematical relationship by utilizing the density and flow of traffic streams, integrating tiny traffic flow models and transforming entity attributes.
- The mesoscopic models operate on probability distributions by elucidating details and characterizing the type of traffic. They were categorized into cluster and kinetics models. The models created for hybridized traffic simulation are growing analytical and simulation tools with several researchers having built several software applications to analyze such traffic behavior that anticipated to be prevalent in the ongoing trend of smart city development (Sheikh and Peng, 2022).

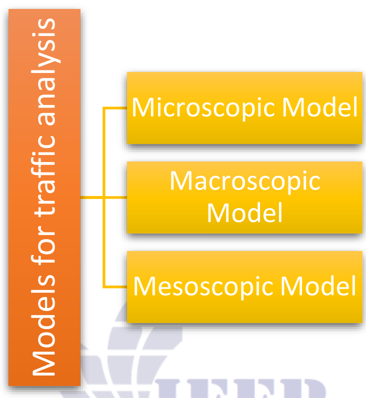

Figure 2: ***Models for Traffic Analysis.***

The recent trend of modern technology has proliferated throughout all professional domains including transportation where linked cars are swiftly growing. The integration of developing technologies will provide an unparalleled benefit to residents of smart cities as the majority of their infrastructure development is digital. Consequently, transportation systems must be enhanced to align with the standards for smart city development. Nevertheless, the ongoing accumulation of such cars would provide atypical challenges in traffic management potentially complicating resolution due to the presence of diverse and hybrid vehicle types (Musa et al., 2023).

The stream of traffic is becoming more diverse due to the rapid evolution of connected automated vehicles (CAVs) in industrialized nations, which include both linked automated cars and human-driven vehicles (HDVs). Consequently, a smart city will facilitate hybrid traffic comprising both categories of cars (Wu et al., 2022). A stochastic model was employed to examine the impact of CAVs on conventional traffic. The findings suggest that integrating CAVs into the flow of HDVs will enhance traffic congestion dynamics and significantly mitigate associated uncertainties regarding HDVs (Qian et al., 2017). A heterogeneous mixed model was built to understand the characteristics of traffic consisting of HDVs and CAVs.

The model evaluates essential factors pertinent to traffic analysis including speed, acceleration and distribution of the ratio of CAVs inside the normal traffic flow. The results provided insight into the benefits of creating CAVs which will improve traffic flow, increase stability, and diminish accident risks owing to organized human activities (Zheng et al., 2020). The transmission model was developed to address these drawbacks by employing a microscopic model in the analysis of mixed traffic. This model was found to be more effective in predicting congestion and speed thanks to the Cell Transmission Model (CTM) (Wu et al., 2022). It functions as a promising instrument for dependable, efficient and effective modeling of traffic flow and characteristic analysis.

The mixed traffic model created using PTV VISSIM software which examined mixed traffic through response time analysis that enabled the development of a fundamental diagram illustrating mixed traffic flow and the penetration impact of connected and automated vehicles (CAVs) within the conventional traffic stream (Xu et al., 2020). A control vehicle formulation was proposed to enhance vehicle-to-vehicle (V2V) communication in smart cities utilizing a control variable while maintaining a constant speed in the traffic stream (Yang et al., 2014). They employed frequency domain analysis to properly assess the stability of traffic situations while considering the safety criteria of autonomous cars (Wu et al., 2018). Although these connected automobile vehicles were designed with vehicle-to-vehicle (V2V) communication capabilities the proper integration of these capabilities into other smart infrastructures of smart cities may still present a difficult challenge. This potentially result in challenges in the decision-making process for traffic in smart cities (Jiang et al., 2021).

The ultrasonic controller system model was employed for traffic simulation at junctions and for identifying road law violators (Kavitha and Ravikumar,2021). An IoT-based intelligent traffic controller was created utilizing both centralized and decentralized servers for the management of real-time traffic (Park et al., 2019). The traffic surveillance and prioritization scheduling IoT-based surveillance systems were created for traffic control at signalized junctions. The data gathered from IoT devices will be transmitted to the subsequent signal and subsequently to the server for adjustments and suggestions (Kuppusamy et al., 2018).

Applications of the Intelligent Transportation System in Smart Cities:

Intelligent Transportation Systems (ITS) are crucial for improving mobility, safety, efficiency and environmental sustainability in smart cities. These systems amalgamate sophisticated communication, control and information technology to enhance transportation networks. The principal uses of Intelligent Transportation Systems (ITS) in smart cities are outlined below.

Detecting Transportation Incidences:

Comprehensive transportation systems are susceptible to inevitable incidents resulting from human-machine interactions. ITS can be utilized as a supplementary instrument for identifying such occurrences. Real-time data and position may be transmitted to the control center for efficient management. These incidents may involve accidents, traffic congestion or security threats. The identified information can provide road users with an alternate path (Sharma et al., 2018). The Swedish tram system in Gothenburg used a similar idea to determine the ITS's detection capabilities demonstrating how these sensors and incident detection devices have greatly aided in energy conservation, rerouting and traffic management. Consequently, implementing this in smart cities will function as dependable instruments for traffic management (Sun and Song, 2017).

Automated Ramp Control System:

In smart cities, operations are predominantly automated, utilizing an Intelligent Transportation System (ITS) based Internet of Things (IoT) framework for traffic management. This system employs sensing devices to monitor traffic density, speed and volume in specific road segments. The data collected by monitoring the appropriate levels and gaps between traffic streams will be processed and the resultant output will swiftly determine the anticipated volume and speed limits based on traffic flow through ramp control mechanisms (Jacobsen et al., 2017).

Traffic Signal Management:

The majority of ITS devices function as detectors and the equilibrium between traffic supply and road network capacity presents a formidable challenge that cannot be simply managed manually. Nevertheless, with ITS-based inductive detectors embedded in the road surface, traffic volume, velocity and queues may be monitored, providing automated solutions via connection with the central computer of the primary control center (Mukti and Prambudia, 2018).

The fundamental need is that the communication devices must be adaptable and possess comprehensive network coverage and processing capabilities to guarantee prompt data processing. The comprehensive implementation of IoT-based devices is crucial for traffic management. These devices equipped with robust processors that are typically programmed to optimize cycle times and green durations for each signal while the detectors are engineered to prioritize specific vehicles. The detection process is often carried out by incorporating GPS devices into the systems connected to the city's central control rooms. These devices were utilized commercially and were launched by the Sydney Coordinated Adaptive Traffic System (SCATS) and the Split Cycle Offset Optimization Technique (SCOOT). These systems were effectively implemented in Kingston, a suburb of London, UK, as a gating system (Jacobsen et al., 2015).

Effective Parking Management Tools in Smart Cities:

In smart cities, the allocation and positioning of parking facilities are essential, as improper parking might compromise the efficacy of some traffic management systems. Nonetheless, parking in smart cities may be somewhat reliant on Intelligent Transportation Systems (ITS). Integrating Intelligent Transportation Systems (ITS) with traditional parking methodologies will assist commuters by providing information on parking recommendations, payment options, designated on-street parking areas and space management. In most European towns particularly in Spain, an ITS parking fee was widely used (Ersoy and Börühan, 2015).

Demand-Responsive Transport Management (DRTM):

ITS-based IoT will be crucial in smart city applications such as Demand-Responsive Transport Management (DRTM). The majority of vehicles used for public transportation were traditionally built to run on predetermined routes, regardless of how frequently traffic conditions changed. The public transportation systems and flexible scheduling and booking systems typically overlap in order to provide passengers with real-time and precise itineraries, alternate routes, projected journey times and the number of commuters in distinct vehicles (Jacobsen et al., 2015).

Special Provision to Vulnerable Road Commuters:

In smart cities, the individuals who are at risk of accidents require special consideration and treatment when using transportation infrastructures. Conventional traffic management pays less attention to this because of negative perceptions of traffic incidents. An IoT-based Intelligent Transportation System can assist certain groups of individuals with limited mobility on the road due to its sensitive nature. These solutions are applicable in pedestrian crossing zones and various public spaces (Pau et al., 2018).

Platooning:

The transportation industry, as a primary contributor to the greenhouse gas impact, must use sustainable practices to improve operations and mitigate emissions that contribute to overall pollution. The advancement of truck platooning significantly aids this objective by optimizing fuel use, lowering air pollution, and alleviating traffic congestion (Ling et al., 2022). Nevertheless, the platooning system is hindered by the challenge of inter-vehicle spacing which is affected by the aerodynamic drag coefficient of the vehicles (Birgisson et al., 2020). There are various models that have been created and applied in smart cities to reduce the aerodynamic drag coefficient. A notable study employed a predecessor following architecture to monitor the target distance while minimizing the predicted aerodynamic drag coefficient to achieve the best value (Robertson et al., 2019). The enhanced and sophisticated truck platooning, referred to as automated truck platooning employs the Intelligent Transportation System and is vital to the expanding global freight industry.

Conclusion:

This study aimed to investigate the potential of IoT-enabled sensor-driven adaptive traffic management systems to alleviate urban congestion, improve mobility, and diminish environmental consequences in densely populated cities. This research employed a multiagent simulation framework to analyze complicated traffic scenarios and assess the efficacy of novel techniques including adaptive signal management and dynamic rerouting. This study linked real-time data from IoT sensor networks with a dynamic and multiagent-based simulation environment in contrast to conventional techniques that typically depend on static traffic models or oversimplified assumptions. This method enabled a detailed depiction of urban traffic networks illustrating the interactions among various road users such as private automobiles, buses, bicycles and emergency services. This study is distinguished from most others in the field by the integration of predictive analytics which allows proactive modifications to traffic patterns, including anticipatory signal timing and real-time rerouting, therefore improving efficiency and flexibility. Smart cities need resilient and adaptable mobility strategies coupled with cutting-edge artificial intelligence frameworks. Nevertheless, the management of traffic congestion is a multifaceted endeavor that is influenced by a variety of factors including rate and time dependency. It is essential to ascertain the sources of congestion, traffic flow, occupancy and destination to manage traffic efficiently. Smart cities were constructed utilizing AI-related equipment including physical and vision-based cameras to get necessary information.

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