International Journal of Computing and Digital Systems
ISSN (2210-142X)
Int. J. Com. Dig. Sys. #, No.# (Mon-20..)

Advancements in Artificial Intelligence and RFID for Enhancing Smart City Traffic Monitoring

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Received ## Mon. 20##, Revised ## Mon. 20##, Accepted ## Mon. 20##, Published ## Mon. 20##

Abstract: This study explores the advancement and deployment of sophisticated traffic monitoring systems within smart city frameworks, utilizing cutting-edge technologies. It delves into the synergistic use of RFID, artificial intelligence (AI), and machine learning (ML) to enhance traffic management capabilities and predictive analytics. Initially, the research underscores the critical nature of traffic monitoring in urban settings and situates it within the expansive realm of smart city endeavors.
A thorough review of existing scholarly articles on smart city infrastructure is conducted, particularly emphasizing the contributions of RFID, AI, and ML to the efficacy of traffic management systems. The paper describes a comprehensive architectural framework that amalgamates these technologies to facilitate robust data acquisition, transmission, and analytical processes.
Further, the paper illuminates the advantages of employing RFID for vehicle identification alongside the diverse implementations of AI and ML algorithms for traffic predictions, vehicle classification, anomaly detection, and system optimization. The concluding sections summarize key insights, underscore the study's contributions, and outline prospective avenues for fortifying and expanding traffic monitoring systems in smart cities. The integration of these technologies plays a pivotal role not only in traffic management but also in enhancing communication, transportation efficiency, healthcare services, environmental sustainability, and energy management within smart cities.

Keywords: Smart city, Traffic monitoring, RFID, IoT, Artificial intelligence.

1. INTRODUCTION

In the context of smart cities, evaluating their "intelligence" involves more than merely assessing technological capabilities. This comprehensive evaluation covers various critical aspects of urban life including quality of life, healthcare, safety, disaster management, and environmental sustainability [1]. Traffic monitoring is a pivotal component within this broader framework, where the integration of sophisticated Information and Communication Technologies (ICT), Artificial Intelligence (AI), and robotics is reshaping urban areas into interconnected hubs of intelligence. Various studies underscore the importance of merging smart services with ICT solutions to enhance the attributes of smart cities. The recent advancements in Internet of Things (IoT) technology are propelling the transformation of smart cities, permeating civilian sectors such as communication, transportation, agriculture, surveillance, disaster response, and environmental conservation [2].

The convergence of IoT with AI as autonomous systems significantly improves civilian life across various domains—including communication, transportation, and surveillance. This integration transcends mere traffic optimization, extending to applications like pollution control, firefighting, parcel delivery, and support for emergency responders. Additionally, technologies like Wireless Sensor Networks (WSNs) and Radio-Frequency Identification (RFID) not only aid in traffic monitoring but also facilitate resource conservation and enhance emergency preparedness, thereby increasing the cost-efficiency of smart city infrastructures.

This paper explores the collaborative potential of RFID, AI, Machine Learning (ML), and IoT devices in enhancing smart city ecosystems. This partnership spans

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from extensive surveillance to efficient disaster management, underscoring their vital roles in data acquisition for energy management, air quality prediction, security enhancements, and real-time service provisioning.

This review article emphasizes the crucial role of RFID, AI, and ML in improving traffic monitoring within smart city frameworks. It discusses how their combined use helps urban planners develop adaptive, efficient transportation systems that alleviate congestion, enhance safety, and promote more interconnected, habitable urban spaces. By delving into their collaborative dynamics within the larger smart city context, the paper aims to reveal the transformative impact of these technologies in shaping future urban landscapes.

The paper is organized into six sections: Section 2 discusses the application of AI in smart cities; Section 3 reviews the literature on traffic management within these cities; Section 4 details the various technologies deployed in smart city traffic monitoring; Section 5 investigates the AI and ML algorithms designed for data processing and analysis; and Section 6 concludes with a summary of key findings, contributions, and suggestions for future research to enhance and expand traffic monitoring systems in smart cities.

2. AI IN SMART CITY

In recent years, smart cities have leveraged the power of artificial intelligence (AI) to enhance urban functionality, sustainability, and livability. The integration of AI into the fabric of urban management enables sophisticated data analysis and automated decision-making processes, leading to more efficient resource utilization and improved public services [3]. AI technologies, including machine learning and deep learning, are central to these improvements, particularly in traffic monitoring and management.

Section 2 of this paper delves into how AI technologies are being applied to transform smart city infrastructure, with a special focus on traffic systems. By utilizing AI, cities can overcome the traditional limitations of traffic management systems and improve the accuracy of traffic flow predictions, congestion detection, and traffic management responsiveness. For example, machine learning algorithms analyze vast datasets generated by city-wide IoT sensors to optimize traffic light sequences, reduce congestion, and enhance road safety.

Moreover, the integration of AI extends to broader smart city applications, such as environmental monitoring and public safety, where predictive analytics can forecast pollution levels and optimize emergency response strategies. The real-time data processing capabilities of AI enable cities to become more adaptive and responsive to the needs of their citizens.

This section also discusses the practical implications of AI in smart cities, showcasing successful deployments and the resultant benefits in urban centers around the world. The insights drawn from these applications illustrate the transformative potential of AI in making cities smarter and more sustainable.

By emphasizing the synergy between AI and other technologies like RFID and IoT, this section highlights the layered complexity of smart city ecosystems and the multifaceted roles AI plays within them. It underscores the importance of continuing innovation and integration of technology to maintain and enhance the efficiency and quality of urban life.

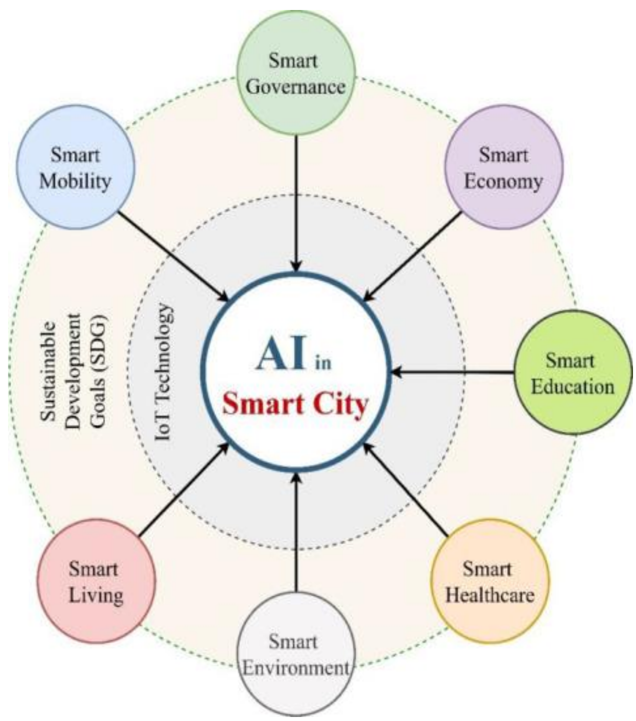

Figure 1. AI in the different domains in smart cities.

3. SMART CITY INFRASTRUCTURE AND TRAFFIC MANAGEMENT SYSTEMS

Recently a smart city in combination with IoT has the potential to improve a city's infrastructure [4]. Also, recently have witnessed a colossal increase of vehicles on the roads, but the road infrastructure and traffic systems have not kept pace with this growth, resulting in inefficient traffic management.

Interest in artificial intelligence and smart cities has increased. For example, Figure 2 illustrates the trend of the keywords “Smart City” and “Artificial Intelligence” in Google Trends since 2014. [4] It shows that the interest in artificial intelligence and smart cities has increased over time.

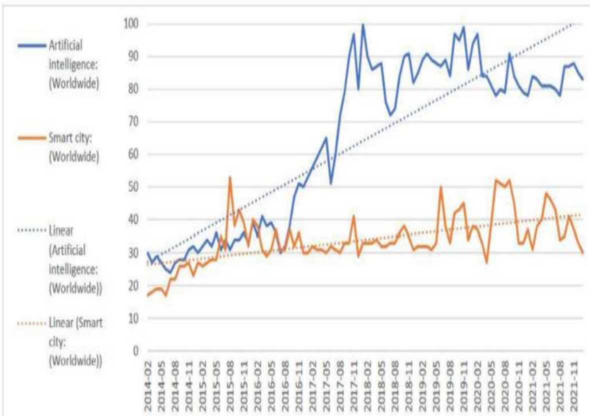

Figure 2. Keywords “Smart City” and “Artificial Intelligence [3]

In this section, we give some reviews related to work on smart cities and traffic management by dividing this part into two sections: features of smart cities and traffic management systems.

A. Features of smart cities

A smart city comprises several attributes, themes, and infrastructures, each playing a crucial role in its development (Figure 3). The characteristics of a smart city, often referred to as its attributes, form the basis on which it progresses. These characteristics are also known as the pillars supporting a smart city's ongoing development.

Furthermore, infrastructure is a crucial component that gives each smart city its fundamental operating foundation [3][5]. These essential characteristics for the implementation of a general smart city are covered in this section.

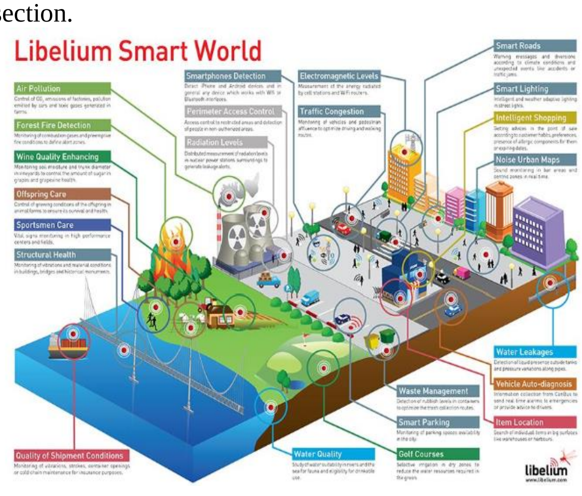

Figure 3. The labellum model of smart cities [5]

A smart city's foundation is built upon several characteristics. A significant number of smart city concepts, focus on four key elements: intelligence, urbanization, sustainability, and quality of life [6]. These qualities are composed of many sub-attributes. Infrastructure and governance, waste and pollution, energy and climate change, social concerns, economics, and health are among the sub-attributes in the framework of sustainability. Sustainability is essentially the capacity of a city to successfully manage its activities while preserving environmental balance across various dimensions [7].

The idea of a "smart city" is complex and includes several important components. Quality of life (QoL), urbanization, intelligence, and sustainability are the four primary characteristics that Monhanty and colleagues identified as essential to the majority of smart city ideas[7]. These characteristics are composed of many sub-elements. For instance, infrastructure, governance, pollution, energy, climate change, social concerns, economics, and health are all taken into account while discussing sustainability. Achieving sustainability in a city requires effective management of municipal operations along with the maintenance of an ecological balance between these many factors. The citizens ' emotional and financial well-being are important factors in their pursuit of quality of life. Conversely, urbanization centers on the technical, economic, infrastructure, and governance facets associated with the shift from a rural to an urban setting. The desire to better the city and its residents' social, environmental, and economic circumstances is referred to as intelligence.

As the perfect response to the problems brought on by increasing urbanization, smart cities are currently viewed as the next urban enchanted world. Smart cities aim to efficiently handle a variety of difficulties, including resource shortages, waste management, pollution, congestion, health implications, and aging infrastructure [8][9] [10].

To provide robust management and promote economic growth, the notion of urbanization is separated into two categories: industrialization-based and entrepreneurship-based. Modern views on urbanization have been profoundly impacted by technological advancements, with research concentrating on the connection between urbanization and the idea of the smart city.

The global objective of urban intelligence is to improve living standards in the economic, social, and environmental fields. Studies evaluating smart city initiatives have assessed a variety of indicators, including human capital, e-government, and transportation networks, to measure a city's intelligence.

Researchers have explored the correlations between ICT infrastructure and economic growth, while case studies have been conducted to evaluate the intelligence cities [11]. These efforts collectively contribute to understanding and defining the attributes of an intelligent city.

B. Traffic management systems

Traffic flow prediction is a crucial task in transportation management, as it allows for better planning, optimization, and decision-making in transportation systems. With the increasing availability of data and the development of Artificial Intelligence (AI) techniques, there has been a growing interest in using AI for traffic flow prediction. Figure 2 gives a smart town traffic management system using LoRa and a machine learning mechanism [12].

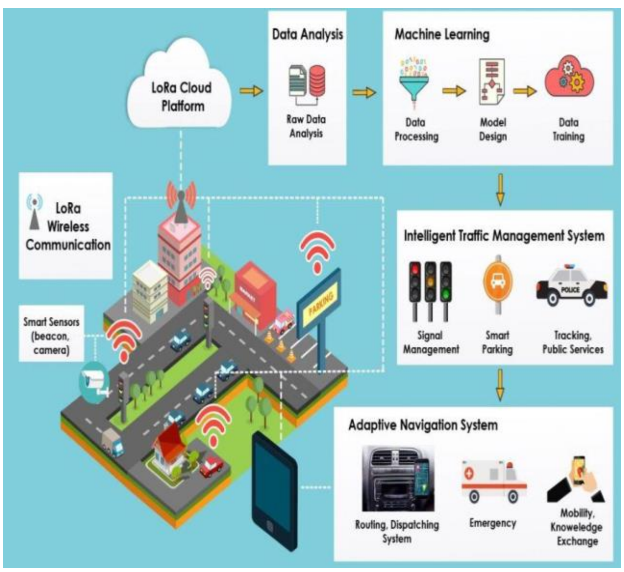

Figure 4. Smart Town Traffic Management System Using LoRa and Machine Learning Mechanism [12].

In this literature review, we will summarize some of the key research papers that have used AI techniques for traffic flow prediction. These papers cover a range of AI techniques, including machine learning, deep learning, and neural networks.

One study used a deep learning approach to predict traffic flow using historical data from sensors on highways [13]. The study found that their model was able to accurately predict traffic flow with high accuracy and outperformed other traditional forecasting models [14].

Another research paper used machine learning algorithms to predict traffic flow on freeways and found that a Random Forest model performed best in terms of accuracy and computation time [15].

Table 1 provides a comprehensive review of research efforts in the field of traffic management systems. These studies explore the complex field of traffic flow prediction, an essential aspect of successful traffic management and city planning. Each paper examines distinct methodologies, ranging from traditional statistical and machine learning models to cutting-edge hybrid and deep learning approaches, aimed at predicting traffic patterns. The discussions within these articles focus on assessing model performance on criteria such as accuracy, robustness, and computational efficiency, illuminating their applicability in real-world scenarios. In addition, considerations of sustainability, environmental impact, and complex spatial and temporal dependencies in traffic data are central themes explored in this work. Collectively, these ideas open the door to improved traffic forecasting methodologies that promise to increase the efficiency of traffic management systems and city infrastructure planning [16].

Smart city architecture represents the roadmap, infrastructure, and interconnected systems designed to use technology in urban environments to enhance efficiency, sustainability, and quality of life. It is a holistic framework that combines a variety of components, including sensors, data networks, and applications, to enable cities to operate smarter and more efficiently.

The architecture of a smart city is based on the collection, analysis, and processing of data. Sensors and Internet of Things (IoT) devices are strategically deployed around the city to collect real-time data on various aspects such as traffic flow, energy consumption, air quality, waste management, and so on. This data is then transmitted via communication networks to centralized systems for processing and analysis [17][18].

TABLE I. SOME METHODS FOR TRAFFIC FLOW MONITORING

Study/Year	Key Points
[19]/2018	Reviews AI methods in traffic flow prediction: traditional (statistical, ML) & newer (deep learning, hybrids). Evaluate performance on accuracy, robustness, scalability, and efficiency. Discusses strengths, limitations, and future research directions. Useful for the transportation industry.
[20]/2018	Introduces a sustainable traffic prediction model using ARIMA with a sustainability index. Validates Delhi traffic data improves accuracy, and considers environmental and social impacts. Relevant for urban transportation planning.
[21]/2020	Proposes a deep learning (LSTM-based) approach for traffic flow prediction in metropolitan networks. Emphasizes the importance of communication systems, showcases preprocessing techniques for better accuracy, and demonstrates superior performance over traditional ML algorithms.
[22]/2022	Addresses the challenge of accurate traffic flow prediction by combining CNNs and LSTMs. Shows better accuracy than traditional methods, captures spatial and temporal dependencies effectively, and

	offers insights into factors affecting traffic flow. Applicable in real-time traffic management systems.
[23]/23	Provides a comprehensive review of the literature on safety in traffic management systems and discusses the different safety issues that arise in traffic management systems.
[24]/2022	Gives an instrumentation based on low-cost cameras and a vehicle recognition and counting methodology using modern machine learning techniques, compliant with the requirements of the CNOSSOS-EU noise assessment model.
[25]/2021	Gives a wireless traffic flow detection system focused on conditions in which the traffic flow is slow or stopped, which increases the risk of highway accidents using a Low Power Wide Area Network based on LoRa.
[26]/2016	Gives a system based on a PIC microcontroller that evaluates the traffic density using IR sensors and accomplishes dynamic timing slots with different levels.
[27]/2014	Presents a data fusion method that provides information about traffic states at all crucial locations of urban road networks. This is mainly based on FCD based on the collection of localization data, speed, direction of travel, and time information from GPS in vehicles that are being driven.
[28]/2022	Introduces machine learning concepts to predict traffic flow in an earlier manner by applying "Deep Autoencoder (DAN)", "Deep Belief Network (DBN)", and "Random Forest (RF)".
[29]/2018	Compares the different methods for managing traffic, Traffic Light Systems (TLS): Static and Dynamic TLS, Radio Frequency Identification (RFID), and Internet of Things (IoT).
[30]/2022	Gives some works in deep learning for traffic flow prediction: Convolutional Neural Network (CNN), Recurrent Neural Network (RNN), Long Short-Term Memory (LSTM), Restricted Boltzmann Machines (RBM), and Stacked Auto Encoder (SAE).
[31]/2020	Presents a novel approach to automatically monitor real-time traffic images using deep convolutional neural networks and a standalone graphical user interface and describes research results received in the process of developing models that serve as a framework integrated for artificial intelligence-enabled traffic monitoring. system. This system deploys several cutting-edge deep learning algorithms to automate different traffic monitoring needs.

The synthesis of the review table on methods for traffic flow monitoring reveals a variety of approaches, each with unique strengths and challenges in application to smart city environments. Notably, traditional methods like triangulation, which employs mobile phones within vehicles to transmit information for traffic analysis, though useful for traffic flow analysis, suffer from data distortion and limited applicability. Meanwhile, the utilization of GPS for traffic monitoring provides accurate vehicle location and communication capabilities, but it is dependent on vehicles being equipped with GPS, presenting cost and implementation barriers.

RFID technology, another method listed, shows significant promise due to its resilience to weather and compact size, making it ideal for use in robust urban traffic systems. However, the expense and potential security vulnerabilities associated with active RFID systems could pose concerns. Similarly, advanced AI methods such as machine learning models (including deep learning and neural networks) offer superior traffic prediction capabilities by effectively analyzing vast amounts of data from urban sensors. These models outperform traditional methods by capturing complex spatial and temporal traffic patterns, thus enhancing traffic management systems' accuracy and efficiency.

Each method's contribution to the traffic management ecosystem underscores the necessity of integrating multiple technologies to address the multifaceted challenges of urban traffic flow. The discussions in the table highlight not only the technological capabilities but also the broader impacts on environmental sustainability and urban planning. This comprehensive understanding facilitates smarter, more responsive traffic management solutions that are crucial for the evolving demands of smart cities.

The processed data is transformed into useful information using technologies such as artificial intelligence and analysis systems. This information is used to make informed decisions, allowing city managers and stakeholders to optimize resource allocation, improve service delivery, and tackle urban development projects more efficiently.

Security and privacy are primordial in smart city architecture, with measures in place to protect sensitive data and ensure system integrity. In many cases, citizen engagement is also an integral part of the architecture, with platforms and applications enabling residents to participate, provide feedback, and access information, supporting a more included and more reactive urban environment.

Ultimately, smart city architecture aims to create more connected, sustainable, and livable cities by capitalizing on technology to improve infrastructure, services, and the overall urban experience for residents and visitors.

4. TRAFFIC MANAGEMENT TECHNOLOGIES

Traffic flow monitoring is a permanent, dynamic process designed to supervise, analyze, and improve the movement of vehicles on roads. Its main aim is to efficiently monitor traffic using a variety of methods and technologies that facilitate the collection of real-time data and the prediction of future traffic patterns.

This management involves constant monitoring and evaluation of traffic conditions using a wide range of techniques and tools. These include video cameras, sensors (such as inductive loop detectors, IR sensors, and RFID systems), as well as manual observations by specialist operators. The data collected by these methods enables us to understand traffic density, vehicle speed, road occupation, and general traffic behavior.

A. Traffic Monitoring Methods

In traffic management, a wide range of advanced technologies work together to optimize effectiveness. Video data is analyzed using continuous monitoring of cameras, which transmit compressed video images to a central station. This enables real-time calculation of traffic data and supports crime reduction initiatives. However, difficulties persist due to considerable investment and operating costs, as well as reduced reliability in unfavorable weather conditions and at night - problems attenuated somewhat by the integration of expensive infrared cameras.

Adaptive traffic control strategically redirects traffic away from congested main roads, although it often willfully increases congestion in residential areas.

Another cutting-edge technology for traffic management is wireless sensor networks, which rely on sensors detecting environmental changes, and relaying data via gateways such as Ethernet or cellular networks. These networks are structured in ad hoc, infrastructural, and hybrid architectures, enabling different models of communication between sensors and facilitating advances in traffic control techniques.

Specific sensor technologies play a crucial role in traffic monitoring. Inductive loop sensors, despite their effectiveness in detecting the presence of vehicles and keeping count of passing vehicles through voltage changes induced in insulated wire loops, face reliability problems in areas subject to frequent disturbances. Load cells, based on piezoelectric technology, transform the gravitational force of vehicles into electrical signals. They can be used to determine traffic density and the number of vehicles on the road, providing essential data for traffic management.

IR or infrared sensors, which use transmitter-receiver configurations to emit and detect infrared waves, excel in collision avoidance by detecting nearby objects. Integrated into vehicles, they improve safety by alerting drivers to the presence of nearby obstacles.

Radiofrequency identification (RFID) uses radio waves to identify multiple objects, employing RFID readers and tags [25]. This versatile technology has applications in traffic monitoring, parking management, and toll collection. Passive tags are powered by the waves emitted by the reader, storing information in non-volatile memory and enabling a whole range of traffic-related functions [26] [27].

TABLE II. FEATURES OF TRAFFIC MANAGEMENT METHODS [21]

Methods	Descriptions	Advantages	Disadvantages
Triangulation method	Utilizes mobile phones within cars to transmit information to mobile networks for traffic flow analysis.	Circumstantial measurement of network data; Useful for traffic flow analysis	Barring data distortion; Limited applicability
GPS based method	Requires vehicles equipped with GPS for accurate location and velocity detection, enabling communication with traffic data providers.	Accurate vehicle location and velocity data; Communication capability with data providers	Dependency on GPS-enabled vehicles; Cost and implementation barriers
RFID tags	Utilizes RFID tags in ambulances, overcoming weather issues; Stores data and instructions.	Resilient to severe weather - Compact size	Expense of active RFID; Vulnerability to interception

The synthesis of various traffic management methods as detailed in Table II highlights the diverse approaches used to enhance traffic flow analysis and management in smart cities. The Triangulation method, for instance, utilizes mobile phones within cars to transmit data to mobile networks for traffic flow analysis. This method is particularly beneficial for circumstantial measurement of network data and is useful in scenarios where traditional data collection methods might fail. However, its application is somewhat limited due to potential data distortion and its dependency on mobile network coverage.

On the other hand, the GPS-based method leverages the precise location and velocity data from GPS-equipped vehicles. This method allows for direct communication with traffic data providers, offering highly accurate traffic monitoring. The main advantages of this method include its accuracy and the ability to communicate directly with central traffic management systems. However, the reliance on GPS-enabled vehicles introduces high costs and implementation barriers, which can limit its widespread adoption in regions with economic constraints.

Lastly, the use of RFID tags in traffic management, especially in critical applications such as ambulances and emergency services, demonstrates the technology's resilience to severe weather conditions and its compact size. RFID tags store essential data and instructions, which can be crucial in emergency scenarios. Despite these benefits, the expense of active RFID systems and their vulnerability to interception pose significant challenges to their broader application in traffic management systems. These methods collectively represent a significant advancement in traffic monitoring technologies, each with distinct advantages and challenges that influence their suitability for different urban environments.

5. AI AND MACHINE LEARNING IN TRAFFIC MONITORING

The rapid expansion of AI promises to transform the way cities are managed and operated. Smart cities rely on advanced technologies, including AI and ICT, to improve the functionality, efficiency, and sustainability of urban spaces. The integration of AI, including supervised and unsupervised learning, deep learning, and computer vision, into city infrastructure and management is a growing area of research and development within smart city initiatives.

In the field of smart cities, traffic prediction involves a wide range of models for anticipating and effectively managing traffic flows. Here are some of the most significant models in the field of artificial intelligence for traffic management [28][29].

- ***Regression models*** play an essential role, using simple or linear regression techniques. These models are based on historical data and provide valuable information for forecasting traffic flows. The fact that they are based on past trends means that potential traffic patterns can be understood and predicted.
- ***Time-series models*** such as ARIMA (Autoregressive Integrated Moving Average) and SARIMA (Seasonal ARIMA) play an essential role in traffic forecasting by drawing on historical traffic data. ARIMA models capture temporal patterns using autoregression, differencing, and moving average techniques to forecast traffic flows and congestion based on past trends.
- ***The SARIMA model*** goes a step further by incorporating seasonal variations, enabling more accurate forecasts for recurring patterns such as daily, weekly, or monthly traffic fluctuations. These models analyze historical data, identify patterns, and extrapolate them to predict future traffic scenarios, contributing to proactive traffic management and infrastructure planning in smart cities. Hybrid models are a synthesis of various forecasting methodologies. They integrate several models to create a more robust and comprehensive traffic forecasting system. These hybrid systems take into account a range of factors, offering a more accurate and complete understanding of traffic dynamics, and improving the efficiency of traffic management in smart cities. This diverse range of models constitutes the essential backbone of traffic forecasting in smart cities, collectively contributing to a more informed, efficient, and proactive management of urban traffic flows.
- ***Artificial Neural Networks (ANNs)*** stand out for their ability to capture complex relationships between traffic flows and various factors (Figure 1). Models such as Multilayer Perceptron (MLP) and Convolutional Neural Networks (CNN) are capable of understanding complex correlations that might not be obvious from traditional analytical approaches [30]. Their ability to process large amounts of data and identify complex patterns enables traffic prediction systems to be more efficient.
- ***Machine learning models***, which include decision trees, random forests, and support vector machines (SVMs), examine various parameters such as road conditions, weather variations, and traffic volume. These models comprehensively analyze these factors to make nuanced predictions about traffic flow, making a significant contribution to intelligent traffic management systems.

Figure 5 gives an implementation of an automatic traffic monitoring system (AI-enabled system [31]).

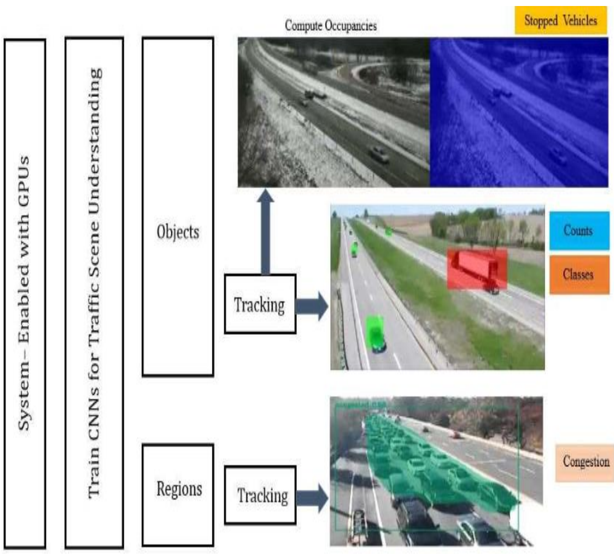

Figure 5. Visual Representation of the Proposed AI-Enabled System [31]

ANNs play crucial roles in traffic flow prediction by analyzing historical data, aiding congestion management, and routing optimization. CNNs process camera feeds, identifying and tracking vehicles, pedestrians, and road signs for efficient traffic control. Their adaptability and ability to learn intricate patterns make ANNs invaluable across various domains, empowering smarter systems in areas like traffic management within smart cities [32].

6. Conclusion

This paper takes a broader look at the use of AI, machine learning, and RFID technologies to advance traffic flow management systems in smart cities. the integration of RFID technology, sensor networks, and artificial intelligence presents considerable potential for reducing traffic jams and improving predictive capabilities. Just as healthcare systems face significant challenges due to societal change, financial constraints, and data overload, modern technologies are becoming increasingly indispensable. The adoption of these advances can potentially introduce a greater reliance on automated systems in traffic management. Also, the integration of AI, machine learning, and RFID technologies is crucial for a variety of smart city applications, including communication, transportation, traffic flow monitoring, healthcare management, environmental preservation, and energy conservation.

In the future, even trivial elements such as infrastructure-integrated traffic detectors can significantly improve overall urban mobility and potentially avoid many traffic-related incidents. The trajectory of traffic flow management is promising, given the rapid evolution of sensor technology, AI, and machine learning. Stakeholders, including municipalities, traffic control authorities, and technology providers, face not only new opportunities but also an imperative to integrate smart city solutions [33][34]. While acknowledging the challenges and risks associated with these technologies, the literature regularly emphasizes the central role of smart technologies in optimizing user experiences within smart cities [35][36]. AI and RFID technologies remain essential, propelling improvements in traffic management and enhancing the overall smart city experience [37] [38] [39][40][41].

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