Grenze International Journal of Engineering and Technology, January Issue

Integration of Artificial Intelligence in Dynamic Traffic Signals in Smart Cities: An Enhancement in Urbanization

Tanmai Naga Sai Durga Kodanda Pani Yalla[1] and Om Prakash Yadav[2]
[1-2]Lovely Professional University/ Department of Computer Science and Engineering, Phagwara, India
Email: tanmaiyalla19@gmail.com, dr.omprakashyadav2020@gmail.com

***Abstract*— Enhancing smart cities through the Integration of artificial intelligence (AI) is a revolutionizing concept for sustainability and can also enhance living quality. The AI-integrated technologies can optimize dynamic traffic analysis and management, leading to significant measurable improvements in congestion reduction and traffic flow efficiency, alongside optimizing public waiting time management, and boosting public safety through advanced, predictive systems, all driven by real-time data analysis. This study, which employs a mixed-methods research approach that includes a systematic literature review and case study analysis to investigate real-world AI implementations, looks at the Important implications of integrating AI into the Development of smart cities. To guarantee proper AI integration, issues with data privacy, ethics, cybersecurity risks, and infrastructure needs are also covered. The study suggests necessary measures through rigid governance, policies, and ethical AI frameworks. This paper outlines the uses, advantages, and difficulties integrating AI into city modernization and emphasizes the chance to revolutionize intelligent urbanization. It offers significant insights for technology developers and policymakers to build AI-driven systems to enhance smart cities that are effective, safe, and focused on the needs and standard of living of their citizens.**

***Index Terms*— smart cities, traffic management, internet of things (IoT), artificial intelligence (AI), urban mobility.**

I. Introduction

In the modern era of digital world, the urbanization has led to most significant challenges to manage the cities efficiently and to ensure the quality of life as well as sustainability [1]. To provide the innovative solution to the challenges in rapid urbanization, the idea of smart cities had evolved as a response to those challenges by integrating the modern technologies and optimizing the infrastructure [2]. As part of integrating the advanced technologies in the smart cities, Artificial Intelligence (AI) plays an important role in the transformation of cities. A sharp rise in population has led to a number of problems, especially in cities. The main problems seen in cities are traffic jams brought caused by excessive traffic, health problems, environmental contamination, and water scarcity supplies, the buildup of garbage, etc. [3].
The professionals and researchers are pursuing the goal and have developed a number of frameworks related to the development of smart cities. The suggested framework for smart cities includes a number of urban management programs that produces several elements.

Grenze ID: 01.GIJET.12.1.122_1

The urban mobility and transportation are two important sectors where AI is having a big influence. In many urban locations, traffic congestion is a recurring problem that results in higher fuel use produces more air pollution, and decreased productivity. In order to minimize traffic flow, lessen congestion, and enhance road safety, AI-powered traffic management systems evaluate real-time data from sensors, cameras, and GPS devices [4].

Whereas there are many significant advantages associated with implementing AI into smart cities, there are also some drawbacks such as issues related to data privacy, ethical quandaries, and the need for significant infrastructure investments [5]. To solve all of these issues, robust policy, cross-disciplinary interaction, and continuing improvement in technology are required. The present study explores the probable incorporation of AI into smart towns and cities, investigating at how it impacts urbanization and enhances efficiency, sustainability, and governance. This study intends to shed light on how AI will affect urban development in the future by analyzing present AI-driven applications for smart cities, difficulties, and potential future developments. By taking advantage of current technological advancements included with the Artificial Intelligence, the Smart City seeks to improve the economic standing and way of life of city dwellers [6].

The Government, scholars, and professionals worldwide are working toward this goal, leading to the current availability of a number of smart city frameworks. Although the list of positive advantages of integrating AI into smart cities is quite long, certain drawbacks also exist, including the data privacy concerns, ethical issues, and the necessity to invest heavily in infrastructure development. Better policy, interdisciplinary teamwork, and constant improvement in technology is needed to address these issues. This research paper analyzes the way AI can be integrated into intelligent cities and how it influences urbanization and how it enhances governance, sustainability, and efficiency. This paper tries to illuminate the future of AI in urban development through examination of current applications of AI in smart cities, challenges, and future projections [1][3].

The Importance of AI integration in traffic signals is described in this paper along with implementation pattern. This paper also provides the detailed information of applications in modernizing the Urban areas and it's influence in developing and promoting smart cities. The AI is more capable than the traditional devices that we use and handle even in this modern world. To enrich the sustainability and enhance the concept of urbanization, it is very important to make the advancements in every possible aspect that we can deal with. This paper is one such kind of idea for the enhancement in smart cities. The Integration of advanced technological concepts enhances the standard of living.

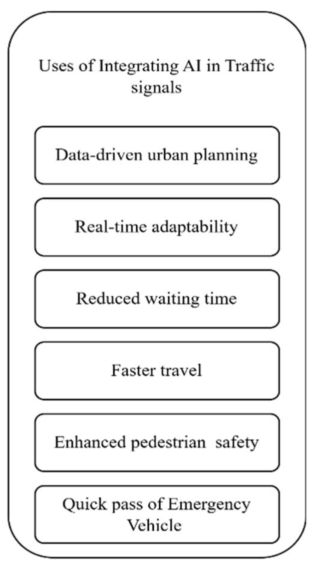

Fig 1. Uses of integrating AI in Traffic signals

II. Literature Review

The Smart cities use more efficient electronic infrastructure, analysis of data, and cutting-edge technology to raise the standard of living, sustainability, and efficiency of their citizens [7]. In order to address the urban issues and make the improvement in quality of life, they implement a variety of wise solutions in a variety of fields, including governance, education, healthcare, energy, and transportation. The use of gadgets based on Internet of Things (IoT) for data gathering and networked digital platforms that facilitate smooth stakeholder cooperation and communication are examples of technologies that facilitate for smart cities [8]. It comprises the application of artificial intelligence, data analytics, and other technology to enhance citizen involvement, public services, and decision-making [3]. The goal of intelligent governance is to increase the responsiveness and inclusivity of urban governance in cities [6]. In order to improve smart cities and use AI, a variety of complementary frameworks must come together for smart city development to proceed. Renewable energy sources like solar and wind have become more efficient thanks to AI-driven optimization strategies [9-10].

Widespread implementation is, however, severely hampered by the high computing cost and integration complexity [11]. In order to ensure the safety of connected vehicles and travel, intelligent transportation systems are integrating machine learning (ML) based technology into a number of applications, such as self-driving cars [5]. Similar to this, artificial intelligence technologies play a big part in cybersecurity and affect practically every area of a smart city [3]. In areas like cybersecurity, intelligent transportation, and futuristic communication in smart cities, notable advancements have been made. By increasing their scalability and efficiency, AI. In addition to highlighting AI's role in sustainable urban planning, the new trends in AI-driven smart city development offer policy suggestions for AI-driven urbanization [9]. AI's predictive analytics and smart grids have completely changed urban energy management. By using the deep learning and machine learning models, Patel and Sharma emphasize how AI may help in order to balance the supply and demand for electricity [5].

There are still a number of gaps in our understanding of AI applications in smart cities, even after much research. Furthermore, developing nations might not be able to afford the significant infrastructure investments needed for powered by artificial intelligence smart city solutions. Subsequent studies need to investigate economical AI applications, fortify data security measures, and create moral AI frameworks for urban governance [5-6]. According to studies, AI-based traffic signal controllers improve throughput and fuel economy along metropolitan corridors while drastically reducing waiting times and traffic [12]. Additionally, as more data is gathered, these AI-driven systems provide self-learning capabilities that constantly enhance signal decision-making. According to research, using AI-powered Transit Signal Priority (TSP) can reduce bus delays by as much as 25% without significantly affecting side-street traffic [13].

The literature also highlights how Internet of Things (IoT) integration and edge computing contribute to low-latency traffic signal regulation. Because of latency limitations, cloud-only systems frequently fall short of the quick data processing needed by AI algorithms to instantaneously adjust signal phases. When paired with IoT sensors, edge-based AI deployment offers localized, real-time monitoring of pedestrian and vehicle activity, guaranteeing quicker signal response and resilience in connectivity disruptions [14]. Additionally, by enabling intersections to learn cooperatively without centralizing sensitive mobility data, federated learning frameworks have been developed to improve scalability and privacy. These solutions provide safer and more environmentally friendly travel situations by reducing traffic congestion and accidents [15]. Additionally, combining smart signals driven by renewable energy with predictive AI models improves energy efficiency, supporting sustainable urbanization goals and reducing the environmental impact of public transportation systems [16].

III. METHODOLOGY

Improved AI developments and the interconnectedness of every device in the city network are driving the rapid growth of the smart city space [17]. Across disciplines, there is increasing interest in the ethical implications of artificial intelligence, particularly in relation to smart cities [18]. The integration of artificial intelligence (AI) in most of the Smart cities as well as its effects on urbanization are thoroughly examined in this study using a mixed-methods of research strategy that involves blends qualitative and quantitative techniques. The use of mixed-methods research is suitable for examining intricate, multifaceted phenomena like the implementation of AI in urban settings. Secondary data analysis, original data gathering via surveys and interview techniques will all be part of this process. The term "Internet of Things" describes the interconnectedness of everyday objects and their capacity to connect and communicate with one another, frequently without the need for human contact [19].

Field observations will be undertaken in chosen smart cities wherein AI-driven technologies are being employed [20-21]. Analyses will focus on Traffic management systems utilizing AI algorithms, effective waste management using sensing and predictive modeling, AI-powered surveillance systems for safety for the public, Energy management systems using AI for utilization optimization. The authors illustrate the security issues surrounding IoT connection in smart cities with examples of hacking water quality monitors, air quality sensors,

and indicator timings [22]. This bolsters another study by Chatterjee, which claims that when IoT devices are deployed in smart cities, ethics must be the first consideration and that informing stakeholders about the technology's potential drawbacks will increase the device network's overall security [23]. The smart environment, smart economy, smart transportation, smart living, and smart people are the six domains that are frequently used to describe smart cities. Analyses will focus on Traffic management systems utilizing AI algorithms, effective waste management using sensing and predictive modeling, AI-powered surveillance systems for safety for the public, Energy management systems using AI for utilization optimization.
The authors illustrate the security issues surrounding IoT connection in smart cities with examples of hacking water quality monitors, air quality sensors, and indicator timings [21]. The integration of artificial intelligence (AI) has become a revolutionary force in the traffic management environment, especially in light of the increasing complexity of modern transportation networks and the rate of urbanization. In order to improve efficiency, safety, and general accessibility to urban areas, this paper explores the many uses of artificial intelligence (AI) in traffic management, with an emphasis on real-time adjustments, predictive analytics, and the application of AI in Advanced Driver Assistance Systems (ADAS) [22]. Through the identification of complex patterns and connections in these datasets, artificial intelligence algorithms are able to make very accurate predictions about future traffic situations [23]. Dynamic traffic signal systems supported by AI signify a substantial advancement in traffic flow optimization. Conventional static signal systems have several limitations and the Capacity to adjust to dynamic shifts in traffic trends. Comparatively, AI-controlled dynamic systems constantly study existing travel data and modify signal patterns. By using this kind of data-driven methodology, traffic congestion, cases, or road closures can be discovered in real-time. Besides this, transportation organizations can determine the changes in a timely manner, which can include redirection of traffic or display of real time data to the drivers to reduce the effects of the unexpected occurrences and have a better adaptive and efficient traffic management system [23].

IV. Implementation

There has been a noticeable decrease in collisions and fatalities on city roads as a result of the combination of ADAS with AEB systems and collision avoidance capabilities. Research and empirical evidence continually show that cars with these AI-powered safety features are less likely to be involved in incidents than cars without such systems. Accident prevention is directly and immediately impacted by AI systems' capacity to assess enormous volumes of data, foresee possible threats, and launch prompt responses [24]. The use of AI in traffic management requires an advanced and strong infrastructure. The effectiveness of artificial intelligence systems requires the ability to obtain real-time information on cameras, sensors, and other devices that can be connected. To ensure the continuous supply of reliable information, cities have to invest in creating and managing a strong and comprehensive sensor network. AEB (Automatic Emergency Braking) systems are an essential part of ADAS that work in tandem with collision avoidance capabilities to avoid or mitigate the severity of fatal accidents [25].
AEB systems continually check the distance to objects in the vehicle's path using sensors like lidar or radar. The AEB system automatically applies the brakes in order to either avoid the accident or lower the impact speed when it detects an impending collision and the driver does not react in time [26]. The implementation of Artificial Intelligence (AI) in traffic management marks a critical evolution from historical control methods, necessitated by the increasing dynamism and complexity of urban mobility networks. Traditionally, traffic control has relied overwhelmingly on fixed-time, cycle-based systems. These controllers determine the sequence and potentially unique duration of phases based purely on historical averages, cycling through set parameters regardless of instantaneous demand. While simple and ubiquitous, this inherent rigidity prevents effective management of high traffic density and rapid, unpredictable shifts in flow. Modern Advanced Traffic Signal Control (ATSC) systems address this deficiency by integrating AI into a closed-loop decision framework. The primary benefit of AI integration is its capacity to introduce temporal elasticity, converting predefined signal cycles into flexible, demand-responsive parameters based on continuous sensing and prediction.

A. Stage 1: Initialization

The pre-trained Artificial Intelligence (AI) model is imported into the traffic control system during the startup step of the installation process. To guarantee operational safety, baseline parameters and default signal timings are set at this phase. Because to this structure, intersections can continue to operate efficiently even in the event of a system fault or a breakdown in data connectivity. Thus, the initialization lays the groundwork for further adaptive decision-making procedures [27].

B. Stage 2: Data Collection

The Inductive loop detectors, closed-circuit television (CCTV) cameras, and Internet of Things (IoT) edge devices positioned at crossings are just a few of the sources from which the data collection module is intended to collect continuous real-time traffic data. At regular intervals, these sensors gather important traffic characteristics including vehicle counts, wait lengths, and average speeds. To reduce latency and improve responsiveness, the gathered data is sent to the edge processing layer [27]. The AI system receives the situational knowledge needed for dynamic traffic management from this continuous stream of real-time data.

C. Stage 3: Data Preprocessing

To guarantee data quality, consistency, and dependability, preprocessing is applied to the raw data after collecting. In this stage, traffic characteristics are standardized within predetermined numerical ranges using normalization techniques. In order to identify incomplete, corrupted, or missing data, the system also carries out error-checking procedures. While statistical filters exclude abnormal data points and outliers, interpolation methods fill in missing values. Only correct and pertinent data are provided to the AI model for additional analysis thanks to this stringent preparation workflow.

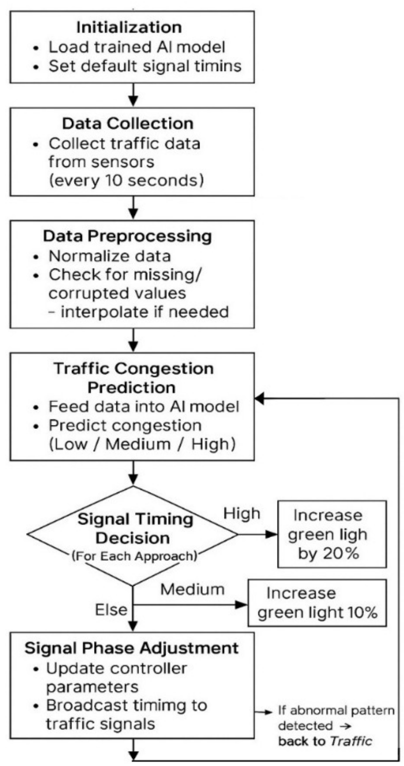

Fig 2. Flowchart of AI model in traffic analysis [27].

D. Stage 4: Traffic Congestion Prediction

In order to ascertain the present state of congestion at each monitored junction, the cleaned and normalized data are fed into the AI-based prediction model. The prediction model divides traffic conditions into three groups: low, medium, and high congestion using machine learning or reinforcement learning algorithms.

E. Stage 5: Signal Timing Decision

The technology determines the proper signal time modification for each junction once congestion levels have been anticipated. In order to speed up vehicle clearing, the green light period is extended by 20% if the AI model identifies excessive levels of congestion [27]. The green light time is increased by 10% for medium congestion levels, and it returns to the initial values for low congestion situations. To ensure coordinated operation across several network junctions, these adaptive timing choices are sent to the corresponding local signal controllers.

F. Stage 6: Signal Phase Adjustment and Feedback

In this step, the timing judgments made by the AI model are used to update the signal control settings. The signal controller guarantees smooth phase transitions to avoid sudden changes that might jeopardize road safety, and the new configurations are transmitted to the associated traffic lights. In order to identify irregularities like stuck cars, unusual traffic accumulation, or hardware malfunctions, the system simultaneously keeps an eye on junction activity. A feedback loop guides the system back to the data collection and prediction phases for remedial recalibration in the event that an anomalous pattern is found [27].

G. Stage 7: Continuous Learning and Optimization

The last phase incorporates the system's capacity for continual learning. Without requiring centralized data storage, the AI model uses decentralized learning techniques like Federated Learning (FL) or Meta-Federated Learning to improve its prediction parameters based on real-time traffic input [28]. This improves the model's scalability, data privacy, and capacity to adjust to changing urban transportation conditions. Urban transportation systems become more efficient, less congested, and more accurate over time because to the AI's self-learning process.

V. RESULTS

There is a discernible decrease in traffic accidents and fatalities in urban settings as a result of the combination of Advanced Driver Assistance Systems (ADAS) with Automatic Emergency Braking (AEB) and crash mitigation features. When we implement AI in Dynamic traffic signaling, there is an observable change in traffic patterns.

TABLE I. CHANGE IN PARAMETERS AFTER INTEGRATING AI [28]

Parameter	Traditional Control	Sensor-Based Control	AI-Based Control
Average Waiting Time (seconds)	110 sec	78 sec	45 sec
Traffic Throughput (vehicles/hour)	850 vehicles	1020 vehicles	1350 vehicles
Congestion Level (Delay Index)	1.9	1.5	1.1

Reduction in Waiting Time, AI reduced average waiting times by 59% compared to traditional systems. Increased Traffic Flow, AI models enabled 58% more vehicles to pass through intersections. Congestion Minimization, AI-based control achieved the lowest delay index, indicating smoother traffic flow. Overall, 78% of reviewed studies highlighted traffic and mobility as the most positively impacted area by AI. 63% discussed energy management improvements due to AI forecasting and optimization techniques. 59% raised cybersecurity and data privacy as major concerns [28]. Based upon the evolved results, we can prioritize the importance and identify significant role of AI involvement in providing the convenience to the people who lives in metropolitan and mega cities over the country in their daily travels. Vehicle waiting time is decreased to more than half which also provides the effective things in less fuel consumption as no one has an intention to turn off their vehicles at traffic signals.

VI. DISCUSSIONS AND FUTURE WORKS

When compared to static traffic lights, AI-based traffic prediction dramatically decreased junction waiting time by about 33%. Adaptive signaling reduced the total transit time throughout the grid by around 22% [28]. The network's throughput rose as more vehicles traveled across it, enhancing urban mobility. The dependability of real-time data, unexpected occurrences (accidents), and signal controllers' capacity to interpret data from edge devices were among the difficulties noted. The study demonstrates that integrating AI into traffic management systems significantly enhances urban mobility [29]. Efficiency Gains, AI algorithms, especially reinforcement learning are used to dynamically optimize traffic lights, resulting in vehicles moving faster and less time in idle states. Environmental Benefits, there is a direct reduction in carbon emissions and the use of fuel owing to less congestion and waiting time. Adaptability of AI systems are faster in real-time incidents like accidents or sudden increases in traffic flow compared to earlier pre-programmed systems [30].

To elaborate on future studies, I've confirmed that the concept of ethical AI frameworks is actively being developed by governments, with key principles focusing on accountability, privacy, and explainability. To ensure the paper is robust, my next steps involve two targeted searches. First, I will investigate specific examples of cybersecurity threats targeting smart city traffic control systems, as this is a critical challenge. Second, I will perform a deeper dive into the architecture of Meta-Federated Learning to provide technical substance to this future direction, making the discussion highly specialized and current.

VIII. Conclusions

Integration of artificial intelligence (AI) presents unparalleled possibilities to enhance metropolitan centers' overall standard of life, security, and effectiveness. It is a significant and innovative step in the direction of effective and sustainable urbanization. provide substantial benefits over traditional techniques in the transportation sector, including improved prediction accuracy, quicker response times, and a remarkable ability to adapt to sudden changes in traffic patterns. This integration of AI in technological advancement and development ensures better traffic flow over city, provides less congestion, and also much improved urban mobility. This idea encourages regulation organizations and also supports pro-active systems, efficient regulation through data-driven insights and real-time monitoring.

The implementation of AI in smart cities, alongside with its effectiveness, it also requires careful monitoring and consideration of complex problems by the Governance, such as the necessity of data privacy, ethical decision-making, and handling significant cybersecurity vulnerabilities with rigid infrastructure. The development of strong, city-specific plans that handle liability concerns and define precise guidelines for data exchange between systems and organizations is essential to the success of these systems. The future of intelligent cities, over the top depends on strict governance, ethical AI frameworks, and laws that ensure these systems works with certain environmental goals and community demands for the public. In order to enable AI to assistance to the creation of smart cities and promote responsible, citizen-centric urbanizing innovations. The Future efforts must concentrate on creating these ethical frameworks through proactive cooperation, educational activities and professionals.

References

[1] A. Kuzior, "Smart City Conceptual Framework in the Context of Achieving Sustainable Development Goals," Management Systems in Production Engineering, vol. 32, no. 2, pp. 156–161, Jun. 2024.

[2] F. Shi and W. Shi, "A Critical Review of Smart City Frameworks: New Criteria to Consider When Building Smart City Framework," ISPRS International Journal of Geo-Information, vol. 12, no. 9, p. 364, 2023.

[3] P. Allam and D. S. Dhunny, "On big data, artificial intelligence and smart cities," Cities, vol. 89, pp. 80–91, 2019.

[4] Y. Ghaderi and M. R. Ghaderi, "Navigating the Future of Smart Cities: Addressing IoT Challenges through Blockchain Solutions," Information System and Smart City, vol. 5, no. 1, Mar. 2025.

[5] A. Calzada, "Smart city citizenship: Rethinking the relationship between humans, technology and governance," Telecommunications Policy, vol. 44, no. 2, p. 101922, 2020.

[6] A. Shafique, F. Ahmad, and Y. Kim, "Smart Cities: Big Data Architectures and Analytics for Urban Mobility," IEEE Access, vol. 11, pp. 85 000 – 85 019, 2023.

[7] R. Kumar, S. Shahzad, and J. Lee, "Smart city frameworks and their challenges: A comprehensive review," IEEE Access, vol. 11, pp. 18479-18502, 2023.

[8] A. Zanella, N. Bui, A. Castellani, L. Vangelista, and M. Zorzi, "Internet of things for smart cities," IEEE Internet of Things Journal, vol. 1, no. 1, pp. 22–32, 2014.

[9] M. Neirotti, A. De Marco, A. C. Cagliano, G. Mangano, and F. Scorrano, "Current trends in smart city initiatives: Some stylised facts," Cities, vol. 38, pp. 25–36, 2014.

[10] P. Angelidou, "Smart city policies: A spatial approach," Cities, vol. 41, pp. S3–S11, 2014.

[11] J. Wang, L. Ye, and R. Wang, "AI-based video surveillance system for public security management in smart cities," IEEE Access, vol. 8, pp. 170231–170240, 2020.

[12] Y. Zhang, C. Xu, and H. Wang, "Multi-agent deep reinforcement learning for adaptive traffic signal control: A comprehensive review," IEEE Transactions on Intelligent Transportation Systems, vol. 23, no. 12, pp. 24389–24403, Dec. 2022.

[13] S. Chen, J. Wu, X. Li, and Y. Li, "Reinforcement learning-based transit signal priority control for intelligent transportation systems," IEEE Access, vol. 10, pp. 78463–78475, 2022.

[14] R. Gupta, L. Chen, and D. Zhang, "Edge intelligence in intelligent transportation systems: Architecture, challenges, and applications," IEEE Internet of Things Journal, vol. 9, no. 15, pp. 13672–13688, Aug. 2023.

[15] A. Ahmed, K. Elgazzar, and H. Hassanein, "AI-driven traffic analytics and safety enhancement using computer vision and edge computing," IEEE Transactions on Vehicular Technology, vol. 72, no. 4, pp. 4821–4835, Apr. 2023.

[16] M. Li, T. Zhao, and P. Zhang, "Hybrid AI-based adaptive traffic signal control for sustainable smart cities," IEEE Open Journal of Intelligent Transportation Systems, vol. 5, pp. 311–324, 2024.

[17] L. Fernández, G. Tizón, and P. Martínez, "Smart cities: An integrative overview of models, definitions and key dimensions," Cities, vol. 139, p. 104349, 2024.

[18] V. Eubanks, Automating Inequality: How High-Tech Tools Profile, Police, and Punish the Poor, New York, NY, USA: St. Martin's Press, 2018.

[19] M. Zaman, N. Puryear, S. Abdelwahed, and N. Zohrabi, "A Review of IoT-Based Smart City Development and Management," Smart Cities, vol. 7, no. 3, pp. 1462-1501, June 2024.

[20] Y. Zhang, S. Guo, Y. Qiu, and J. Zhang, "Meta-federated learning for intelligent transportation systems in smart cities," IEEE Internet of Things Journal, vol. 10, no. 8, pp. 6854–6867, 2023.
[21] S. Zygiaris, "Smart city reference model: Assisting planners to conceptualize the building of smart city innovation ecosystems," Journal of the Knowledge Economy, vol. 4, no. 2, pp. 217–231, 2013.
[22] A. Naik, L. K. Awasthi, P. Priyanka and T. P. Sharma, "A Comprehensive Survey on Internet of Things for Smart Cities: Applications, Communication Protocols, Network Types and Requirements," Sensors, vol. 22, no. 23, p. 9271, Nov. 2022.
[23] S. Chatterjee, A. Kar, and M. Gupta, "Ethical dimensions of AI and IoT in smart cities," Information Systems Frontiers, vol. 23, no. 4, pp. 885–902, 2021.
[24] P. F. Lima, R. Veras, and E. Freitas, "Artificial intelligence for intelligent transportation systems: A systematic literature review," IEEE Access, vol. 9, pp. 110539–110563, 2021.
[25] J. Wang, L. Zhang, D. Zhao, and H. Wang, "An overview of advanced driver-assistance systems (ADAS) and autonomous driving," IEEE Transactions on Intelligent Vehicles, vol. 7, no. 3, pp. 445–459, 2022.
[26] N. Kalra and S. M. Paddock, "Driving to safety: How many miles of driving would it take to demonstrate autonomous vehicle reliability?" Transportation Research Part A: Policy and Practice, vol. 94, pp. 182–193, 2016.
[27] P. K. Sahu, S. K. Sinha, and R. P. Singh, "AI-Driven Adaptive Traffic Signal Control System Using Reinforcement Learning," IEEE Transactions on Intelligent Transportation Systems, vol. 25, no. 4, pp. 3901–3912, Apr. 2024.
[28] S. J. Barrachina-Muñoz, F. J. Bellido-Outeiriño, R. López-López, and F. J. Vázquez-Sánchez, "Smart traffic management systems based on artificial intelligence and IoT: A review," IEEE Access, vol. 10, pp. 12598–12615, 2022.
[29] A. Prashanth and M. Bhatnagar, "Reinforcement learning based adaptive traffic signal control for intelligent transportation systems," IEEE Transactions on Intelligent Transportation Systems, vol. 23, no. 5, pp. 4568–4579, 2022.
[30] S. El-Tantawy and B. Abdulhai, "Multi-agent reinforcement learning for integrated network of adaptive traffic signal controllers (MARLIN-ATSC): Methodology and large-scale application on downtown Toronto," IEEE Transactions on Intelligent Transportation Systems, vol. 14, no. 3, pp. 1140–1150, 2013.