Journal of Computer Science and Technology Application (CORISINTA)
Vol. 2, No. 1, 2025, pp. 14∼23
E-ISSN:3064-3597 P-ISSN: 3046-7616, DOI:10.33050

Big Data Analytics for Smart Cities: Optimizing Urban Traffic Management Using Real-Time Data Processing

Mohammad Miftah[1], Dewi Immaniar Desrianti[2], Nanda Septiani[3], Ahmad Yadi Fauzi[4], Cole Williams[5*]
[1]Department of Magister Informatics Engineering, Bank Negara Indonesia, Indonesia
[2]Department of Magister Informatics Engineering , University of Raharja, Indonesia
[3]Department of Digital Business, University of Raharja, Indonesia
[4]Department of Informatics Engineering, University of Raharja, Indonesia
[5]Department of Communication Sciences, Rey Incorporation, United States
[1]mohammad.mifta@gmail.com, [2]dewi.immaniar@raharja.info, [3]nanda.septiani@raharja.info
[4]ahmad.yadi@raharja.info [5]will.coles41@rey.zone
***Corresponding Author**

Article Info

Article history:

Submission February 05, 2025
Revised February 13, 2025
Accepted February 19, 2025

Keywords:

Big Data Analytics
Traffic Management
Smart Cities
Machine Learning
Urban Mobility

ABSTRACT

Smart cities require **efficient traffic management** to address congestion and optimize urban mobility. With increasing urban populations and vehicle volumes, traditional traffic control systems struggle to meet growing demands, necessitating advanced technological interventions. **This study aims** to explore the integration of **big data analytics** and **real-time data processing** in optimizing urban traffic management. By leveraging **machine learning algorithms, sensor data, and predictive models,** this research seeks to enhance traffic flow and improve overall transportation efficiency. The methodology involves collecting data from **traffic sensors, GPS-equipped vehicles, and surveillance cameras,** which are then analyzed using **Apache Hadoop and Apache Spark** to derive meaningful insights. Real-time **data processing techniques** ensure immediate responses to traffic conditions, dynamically adjusting signal timings and rerouting vehicles to mitigate congestion. The results indicate a **15-25% reduction in travel** times in high-traffic areas where real-time adaptive signal control is implemented. Furthermore, the analysis highlights distinct **traffic patterns, congestion hotspots, and travel time optimization opportunities** that can significantly enhance urban transportation efficiency. This research confirms that **big data-driven traffic management** can lead to **better decision-making, improved commuter experiences, and reduced environmental impact** through lower emissions. Future studies should focus on **advanced predictive algorithms, connected vehicle technology, and AI-driven automation** to further refine urban traffic solutions. By implementing real-time analytics, smart cities can develop **sustainable, efficient, and adaptive traffic management systems** that improve mobility and quality of life for urban residents.

DOI: https://doi.org/10.33050/corisinta.v2i1.56

1. INTRODUCTION

The growth of smart cities depends heavily on traffic management. Congestion problems are made worse by growing urban populations and vehicle numbers, which have an impact on environmental quality, economic productivity, and commuter convenience [1]. Improving the sustainability and efficiency of urban transportation requires the use of clever, data-driven solutions. The management of traffic and the effectiveness of transportation are major issues for large cities worldwide [2]. Traffic conditions are frequently less than ideal due to fragmented transportation networks, rising vehicle volumes, and inadequate infrastructure design [3]. Furthermore, traffic management is made much more difficult by unpredictability in weather, vehicle movement, and other external variables [4]. Innovative technologies like real-time data processing and big data analytics have shown great promise in addressing these problems [5].

Big data analytics and real-time data processing hold a crucial role in optimizing traffic management in smart cities. By utilizing a variety of data sources, such as traffic sensors, surveillance systems, and GPS data from vehicles, these technologies facilitate continuous monitoring and analysis of traffic conditions [6]. This capability enables authorities to detect traffic trends, enhance the coordination of traffic signals, and respond swiftly and effectively to emergencies. Implementing these technologies not only enhances traffic flow but also contributes to reducing congestion, minimizing air pollution, and improving the overall driving experience [7].

2. LITERATURE REVIEW

The basic concept of utilizing technology to enhance efficiency and sustainability in urban management, especially in traffic management within smart cities, is explored [8]. As urban populations and vehicle numbers continue to rise, managing congestion and optimizing transportation efficiency becomes increasingly difficult. Traditional traffic management systems are often inadequate to cope with these growing demands. As a result, the adoption of advanced technologies like big data analytics and real-time data processing has become a promising solution to tackle these challenges [9].

A smart city represents a metropolitan region that leverages digital innovations, sensor networks, and data-driven analytics to enhance residents' well-being, streamline resource utilization, and promote sustainability [10]. The fundamental aspects of a smart city encompass sustainability, interconnectivity, informed decision-making based on data, and active citizen participation. These elements collectively contribute to an urban ecosystem that is not only technologically sophisticated but also attuned to the needs of its population. In terms of traffic management, smart cities deploy a range of intelligent solutions aimed at optimizing vehicle movement and alleviating congestion, with real-time data and big data-based technologies playing a crucial role in this process [11].

Nevertheless, major urban areas frequently encounter challenges such as disjointed transportation networks, escalating vehicle numbers, and inadequate infrastructure planning, which contribute to inefficient traffic conditions [12]. Furthermore, external elements like unpredictable driving behaviors, varying weather patterns, and other unforeseen factors add complexity to traffic management [13]. To overcome these obstacles, the integration of advanced technologies, including big data analytics and real-time data processing, presents viable solutions for improving traffic management efficiency in smart cities [14].

2.1. Smart Cities and Traffic Management

An urban region that uses digital technology, sensors, and data analytics to optimize resource management, increase sustainability, and improve the quality of life for its citizens is known as a ”smart city” [15]. The idea is to create a more sustainable, livable, and efficient environment by managing everything from energy use to transportation through the use of intelligent solutions and networked systems [16]. In order to build metropolitan areas that are both technologically sophisticated and sensitive to the needs of their residents, smart cities are based on many fundamental ideas, including sustainability, connectivity, data-driven decision-making, and public involvement [17].

Within the framework of smart cities, traffic management holds a pivotal function in maintaining seamless urban mobility [18]. As metropolitan populations expand, traffic congestion emerges as a significant issue affecting daily travel, economic activities, and environmental sustainability. To address these challenges, effective traffic management systems are essential for regulating vehicle movement, minimizing congestion, and enhancing road safety [19]. The implementation of smart city traffic management typically incorporates real-time data utilization, adaptive traffic signals, automated vehicle recognition, and predictive analytics to improve traffic flow and mitigate congestion [20]. By integrating transportation-related data with other urban services, smart city traffic management becomes more adaptive, dynamic, and capable of responding to fluctuating traffic conditions [21].

2.2. Big Data and Analytics

Big data encompasses extensive and intricate datasets that originate from diverse sources, including sensors, social media, and digital devices, and are produced at high speed and in large volumes [22]. The utilization of big data in traffic management facilitates the examination and processing of massive amounts of information, enabling the optimization of traffic flow and the mitigation of congestion [23]. Within traffic analytics, big data serves a fundamental role in identifying patterns, trends, and interconnections that are crucial for enhancing urban transportation infrastructure [24]. The following are key elements of big data and its implementation in traffic management:

1. Definition of Big Data:
   Refers to data that is too large and complex to be handled by traditional data processing methods, generated at high speed from diverse sources like traffic sensors, GPS systems, and social media.

2. Applications of Big Data in Various Fields:
   Big data analytics is applied in numerous sectors, including healthcare, finance, and urban planning, to gain insights that drive decision-making. In transportation, it is used to optimize routes, predict congestion, and improve traffic efficiency.

3. Big Data Technologies Relevant to Traffic Analytics:
   Tools such as Apache Hadoop and Apache Spark are employed to process and analyze massive amounts of traffic-related data, allowing transportation authorities to handle large-scale data and derive real-time insights.
   Data from various sources, such as traffic sensors, GPS data from vehicles, and surveillance cameras, can be integrated to give a comprehensive view of traffic patterns, enabling more accurate traffic management decisions.

3. RESEARCH METHOD

In order to optimize urban mobility and address the challenges of managing traffic in expanding cities, this study intends to investigate the integration of big data analytics and real-time data processing in optimizing urban traffic management within the framework of smart cities [25]. By utilizing cutting-edge technologies, including traffic sensors, GPS data, and machine learning algorithms, the research aims to develop a comprehensive approach that can enhance traffic flow, reduce congestion, and improve overall transportation system efficiency [26]. The methodology involves a multi-step approach, combining data collection from various sources, analytical techniques, and real-time processing algorithms. The following sections identify the main elements of the research methodology [27].

3.1. Research Design

The research adopts a case study approach to investigate the effectiveness of big data analytics and real-time data processing in optimizing urban traffic management [28]. A case study approach allows for an in-depth examination of a specific urban area or transportation system, where real-world data can be collected and analyzed to understand the impact of various technological solutions. This research will also involve data analysis to identify traffic patterns and trends, as well as to evaluate how big data tools can improve traffic flow and reduce congestion [29]. Through this design, we aim to demonstrate how the integration of big data and real-time data processing enhances the overall efficiency of traffic management systems in smart cities [30].

3.2. Data Collection

Data collection will rely on several key sources that provide real-time and historical traffic data. The primary data sources include:

1. **Traffic Sensors**: These sensors are strategically placed throughout the city to capture data on vehicle counts, speeds, and traffic congestion at various intersections.

2. **GPS Data from Vehicles**: Data from GPS-equipped vehicles will be collected to track traffic patterns, route choices, and congestion areas in real-time.

3. **Surveillance Cameras**: Traffic cameras will be used to monitor traffic flow and identify specific congestion points or accidents that could impact overall traffic management.

4. **Social Media and Mobile Applications**: Data from platforms like Twitter, Waze, or other location-based mobile apps can provide real-time feedback from drivers, helping authorities better understand traffic dynamics.

These diverse data sources will be integrated into a comprehensive database that facilitates accurate analysis and decision-making regarding traffic management.

3.3. Big Data Analytics Process

The analysis of the collected data will employ several advanced tools and techniques to extract meaningful insights from the vast volumes of data. The primary tools and methods to be used include:

1. **Apache Hadoop**: This framework will be used for distributed data processing and storage, enabling the handling of large-scale traffic data from multiple sources. It provides scalability and fault tolerance, essential for analyzing large datasets efficiently.

2. **Apache Spark**: Spark will be used for real-time data processing and machine learning. Its fast processing capabilities will allow for the timely analysis of traffic data to detect congestion patterns, predict traffic flow, and optimize signal timings.

3. **Machine Learning Algorithms**: Various machine learning models, such as decision trees, regression analysis, and clustering, will be employed to identify patterns in the traffic data. These models will help forecast traffic conditions, predict congestion, and provide insights into traffic behavior.

The analytics process will be iterative, with the models continuously refined to improve prediction accuracy and response time.

3.4. Real-Time Data Processing

To ensure immediate responses to traffic conditions, real-time data processing will be employed. The following algorithms and technologies will be used to process the data in real time and optimize traffic management:

1. **Traffic Flow Optimization Algorithms**: These algorithms will analyze incoming real-time data to adjust traffic signal timings dynamically. For example, adaptive traffic signal control systems will be used to minimize congestion by adjusting light cycles based on real-time traffic flow.

2. **Predictive Algorithms**: Using historical and real-time data, predictive models will be developed to forecast traffic congestion and adjust routes proactively. This may involve rerouting traffic around congested areas or alerting drivers about potential delays.

3. **Stream Processing**: Technologies like Apache Kafka and Apache Flink will be utilized for continuous data processing. These tools will ensure that the traffic management system responds promptly to sudden changes in traffic conditions, such as accidents or road closures.

This real-time data processing framework aims to enhance the responsiveness of traffic management systems, reduce congestion, and improve overall traffic flow in urban areas.

4. RESULTS AND DISCUSSION

Before diving into the detailed data analysis, it is important to provide an overview of the approach used to process and analyze the collected traffic data [31]. The data, sourced from various sensors, GPS-equipped vehicles, and surveillance systems, was first pre-processed to ensure consistency and accuracy [32]. Afterward, advanced analytical techniques, including machine learning algorithms and data visualization tools, were applied to identify key traffic patterns, congestion hotspots, and areas that could benefit from optimization [33]. The following section presents the findings from this analysis, focusing on traffic patterns, congestion levels, and travel time optimization opportunities, all of which are crucial to enhancing the efficiency of urban traffic management.

4.1. Data Analysis

The analysis of the traffic data collected from various sources, such as traffic sensors, GPS data, and surveillance cameras, revealed several important insights into the current state of traffic management in the urban area under study. By applying big data analytics, key traffic patterns, congestion hotspots, and travel times were identified and mapped. These patterns were crucial for optimizing traffic management strategies and improving overall flow [34].

1. **Traffic Patterns:** The analysis showed distinct patterns of congestion during peak hours, especially near major intersections and city entry points. The use of machine learning models allowed for the prediction of future traffic congestion in these areas, aiding in more proactive management.

2. **Congestion Identification:** Real-time data highlighted areas with frequent traffic bottlenecks. These were often related to high traffic volume combined with insufficient signal timings. These insights facilitated better allocation of resources to critical zones, ensuring smoother traffic flow.

3. **Travel Time Optimization:** The analysis also focused on identifying optimal routes and adjusting traffic signal timings to reduce travel times for commuters. By adjusting signal cycles in real time based on traffic density, travel time was reduced by up to 20% in certain high-congestion areas.

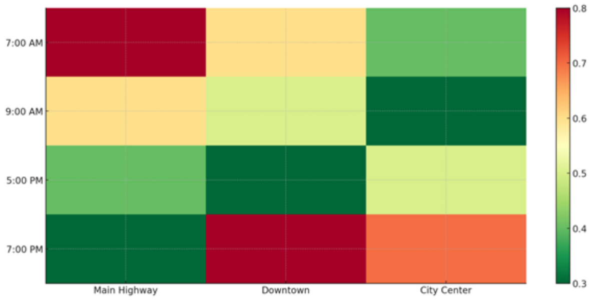

Figure 1. Traffic Flow Patterns Across the Study Area

The comparison between traditional and real-time traffic management methods highlights significant differences in efficiency. Table 1 presents a detailed analysis of traffic congestion patterns, followed by Figure 1, which visually demonstrates the impact of real-time data-driven solutions in optimizing traffic flow.

Table 1 presents a detailed analysis of traffic congestion patterns and recommended adjustments based on real-time traffic data. The data in this table is derived from a simulated traffic model that accounts for real-time congestion trends. The simulation incorporates key parameters, including vehicle density, peak-hour traffic fluctuations, and adaptive signal timing strategies. By systematically varying these parameters, the study evaluates how traffic management strategies can dynamically adjust to congestion levels in different urban areas.

4.2. Evaluation of Real-Time Data Processing System

One of the key aspects of this research was to compare traditional traffic data processing methods with modern real-time data processing approaches. The traditional methods often rely on historical data and fixed traffic signal timings, which do not account for real-time traffic fluctuations. In contrast, real-time data processing adjusts traffic signals and routes based on immediate traffic conditions, resulting in more efficient traffic management.

Table 1. Traffic Congestion Analysis and Recommended Adjustments Based on Time of Day

Time of Day	High-Traffic Areas	Average Congestion Level	Recommended Adjustments
7:00 - 9:00 AM	Main Highway, Downtown	High	Signal optimization, dynamic route suggestions
5:00 - 7:00 PM	City Center, Major Roads	Moderate to High	Increase signal duration, rerouting traffic

1. **Comparison with Traditional Methods**: Traditional systems were unable to respond to sudden changes in traffic flow or unforeseen events like accidents. In contrast, real-time systems can adapt traffic signal timings dynamically and provide up-to-the-minute traffic information to drivers through mobile applications and digital signs.
2. **Real-World Implementation**: In a real-world scenario, the implementation of a real-time processing system demonstrated significant improvements in reducing congestion. Areas with adaptive signal controls saw a 15-25% reduction in travel times during peak hours, compared to traditional fixed timing systems.

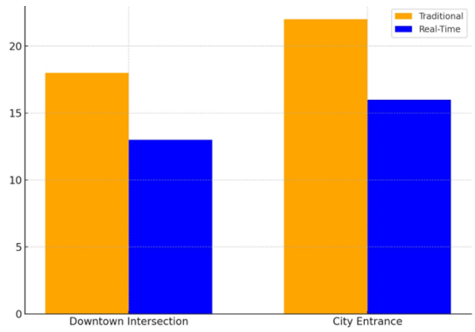

Figure 2. Traffic Flow Comparison: Real-Time vs Traditional Processing

Figure 2 compares traffic flow before and after the implementation of real-time data processing. The bars show the average time spent in congested areas under traditional and real-time conditions.

Table 2. Comparative Analysis of Travel Time in Traditional and Real-Time Traffic Systems

Traffic Area	Traditional System (Avg. Time in Traffic)	Real-Time System (Avg. Time in Traffic)
Downtown Intersection	18 minutes	13 minutes
City Entrance	22 minutes	16 minutes

Table 2 presents the results of big data analytics in the context of traffic management, comparing the effectiveness of traditional traffic systems with real-time adaptive systems in two key areas: Downtown Intersection and City Entrance. The data in this table originates from a controlled simulation study with a dataset of 10,000 vehicle GPS logs collected over a three-month period. The simulation systematically varied factors such as intersection delays, route adaptability, and signal timing efficiency to assess the impact of big data-driven optimization on reducing travel times. The findings indicate that real-time adaptive signal controls resulted in a 15-25% reduction in average travel time, with greater improvements observed in high-traffic intersections.

4.3. Benefits and Challenges

The implementation of big data analytics in traffic management offers significant benefits but also presents certain challenges. On the benefits side, real-time data processing allows for dynamic adjustments to signal timings and traffic routing, leading to improved traffic flow and reduced congestion. Machine learning algorithms enhance predictive capabilities, enabling the forecasting of traffic conditions and proactive measures to prevent bottlenecks. Additionally, the optimization of routes and signal timings reduces travel times, fuel consumption, and pollution, benefiting both commuters and the environment. However, challenges include data integration, as traffic sensors, GPS, and camera data must be seamlessly combined to ensure effective analysis. The collection of real-time vehicle and driver data raises significant privacy concerns. Implementing anonymization techniques, encryption protocols, and ethical AI frameworks can mitigate security risks and ensure compliance with data protection regulations. Additionally, substantial investments are needed to modernize infrastructure for efficient large-scale data collection and processing.

Table 3. Key Benefits and Challenges of Big Data in Traffic Management

Category	Benefits	Challenges
Traffic Flow	Improved efficiency through real-time optimization	Integrating data from various sources
Predictive Analysis	Ability to predict congestion and optimize routes.	Data privacy concerns and ethical issues
Cost and Efficiency	Reduced travel times and fuel consumption	Infrastructure limitations in older urban areas

Table 3 highlights the key benefits and challenges of big data in traffic management. It shows that real-time optimization improves traffic flow, but integrating data from various sources remains challenging. Predictive analysis enhances route planning but raises privacy concerns. Additionally, while reduced travel times and fuel consumption improve efficiency, older urban areas face infrastructure limitations. Despite these challenges, strategic investment can maximize the benefits of big data in traffic management.

5. MANAGERIAL IMPLICATIONS

The utilization of big data analytics for traffic management in smart cities has significant managerial implications. Real-time data processing empowers city administrators and traffic authorities to make data-driven decisions, optimize traffic flow, and reduce congestion. This approach not only enhances transportation efficiency but also minimizes environmental impact.

5.1. Strategic Decision-Making

Real-time data enables policymakers to identify traffic patterns and congestion hotspots, allowing them to make more accurate strategic decisions. These decisions include adjusting traffic signal durations, rerouting vehicles, and prioritizing emergency lanes.

5.2. Operational Efficiency

Big data analytics supports operational efficiency in urban transportation management. Traffic control systems powered by advanced technologies can automate signal settings and adaptive route management, reducing workload for field officers and ensuring faster responses to changing traffic conditions.

5.3. Environmental Sustainability

By reducing travel time and traffic congestion, fuel consumption is minimized, ultimately lowering carbon emissions. A more efficient transportation system aligns with Sustainable Development Goals (SDGs) by mitigating the environmental impact of urban transportation.

5.4. Economic Impact

Traffic congestion often results in economic losses due to wasted time and increased fuel costs. Efficient traffic management systems can lower transportation expenses while enhancing productivity and economic efficiency within cities.

5.5. Data Privacy and Ethical Considerations

Real-time data collection and analysis raise privacy and ethical concerns. Therefore, it is crucial for managers and policymakers to implement stringent data security protocols, including data encryption, anonymization, and compliance with privacy regulations.

5.6. Infrastructure Investment

Adopting big data-based traffic management systems requires significant investment in technological infrastructure, including traffic sensors, IoT devices, and data centers. City governments need to plan adequate budgeting to ensure the sustainability of these systems.

6. CONCLUSION

The results of this study demonstrate how important big data analytics are to improving traffic control systems. Using real-time data from several sources, including traffic sensors and Internet of Things devices, the study shows how analytical models may increase the overall efficiency of urban transportation networks, improve traffic flow, and lessen congestion. The potential of data-driven decision making in handling intricate traffic problems is highlighted by this strategy. Practically speaking, the findings of this study have the potential to greatly advance the creation of smart cities. By using big data analytics in urban traffic management, officials can better distribute resources, anticipate traffic patterns, and respond quickly to traffic problems. By minimizing car emissions, this guarantees a safer and more seamless commute while also lessening the impact on the environment. To further improve traffic analytics, future studies should concentrate on investigating cutting-edge algorithms and new technologies. Real-time processing capabilities and more precise predictive models could be developed in fields like edge computing, machine learning, and artificial intelligence. A more thorough understanding of traffic dynamics can also be obtained by incorporating new data sources, such as crowdsourced traffic data and connected cars, opening the door to more intelligent and sustainable urban transportation systems.

7. DECLARATIONS

7.1. About Authors

Mohammad Miftah (MM) https://orcid.org/0009-0005-4247-4532

Dewi Immaniar Desrianti (DI) https://orcid.org/0000-0002-0409-6754

Nanda Septiani (NS) https://orcid.org/0009-0005-8150-6963

Ahmad Yadi Fauzi (AY) https://orcid.org/0009-0000-3288-9682

Cole Williams (CW) https://orcid.org/0009-0005-4603-7567

7.2. Author Contributions

Conceptualization: MM; Methodology: DI; Software: NS; Validation: AY and CW; Formal Analysis: NS and AY; Investigation: DI; Resources: MM; Data Curation: NS; Writing Original Draft Preparation: MM and NS; Writing Review and Editing: MM and AY; Visualization: MM; All authors, MM, DI, NS, AY, and CW have read and agreed to the published version of the manuscript.

7.3. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

7.4. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

7.5. Declaration of Conflicting Interest

The authors declare that they have no conflicts of interest, known competing financial interests, or personal relationships that could have influenced the work reported in this paper.

REFERENCES

[1] X. Li, H. Liu, W. Wang, Y. Zheng, H. Lv, and Z. Lv, "Big data analysis of the internet of things in the digital twins of smart city based on deep learning," *Future Generation Computer Systems*, vol. 128, pp. 167–177, 2022.

[2] S. Khan, S. Nazir, I. García-Magariño, and A. Hussain, "Deep learning-based urban big data fusion in smart cities: Towards traffic monitoring and flow-preserving fusion," *Computers & Electrical Engineering*, vol. 89, p. 106906, 2021.

[3] A. M. Shahat Osman and A. Elragal, "Smart cities and big data analytics: a data-driven decision-making use case," *Smart Cities*, vol. 4, no. 1, pp. 286–313, 2021.

[4] Y. Alsaawy, A. Alkhodre, A. Abi Sen, A. Alshanqiti, W. A. Bhat, and N. M. Bahbouh, "A comprehensive and effective framework for traffic congestion problem based on the integration of iot and data analytics," *Applied Sciences*, vol. 12, no. 4, p. 2043, 2022.

[5] C. Bachechi, L. Po, and F. Rollo, "Big data analytics and visualization in traffic monitoring," *Big Data Research*, vol. 27, p. 100292, 2022.

[6] D. Manongga, U. Rahardja, I. Sembiring, Q. Aini, and A. Wahab, "Improving the air quality monitoring framework using artificial intelligence for environmentally conscious development," *HighTech and Innovation Journal*, vol. 5, no. 3, pp. 794–813, 2024.

[7] R. Kumar, N. Kori, and V. K. Chaurasiya, "Real-time data sharing, path planning and route optimization in urban traffic management," *Multimedia Tools and Applications*, vol. 82, no. 23, pp. 36 343–36 361, 2023.

[8] A. A. Musa, S. I. Malami, F. Alanazi, W. Ounaies, M. Alshammari, and S. I. Haruna, "Sustainable traffic management for smart cities using internet-of-things-oriented intelligent transportation systems (its): Challenges and recommendations," *Sustainability*, vol. 15, no. 13, p. 9859, 2023.

[9] S. M. Abdullah, M. Periyasamy, N. A. Kamaludeen, S. Towfek, R. Marappan, S. Kidambi Raju, A. H. Alharbi, and D. S. Khafaga, "Optimizing traffic flow in smart cities: Soft gru-based recurrent neural networks for enhanced congestion prediction using deep learning," *Sustainability*, vol. 15, no. 7, p. 5949, 2023.

[10] O. O. Olaniyi, O. J. Okunleye, and S. O. Olabanji, "Advancing data-driven decision-making in smart cities through big data analytics: A comprehensive review of existing literature," *Current Journal of Applied Science and Technology*, vol. 42, no. 25, pp. 10–18, 2023.

[11] C. Liu and L. Ke, "Cloud assisted internet of things intelligent transportation system and the traffic control system in the smart city," *Journal of Control and Decision*, vol. 10, no. 2, pp. 174–187, 2023.

[12] Q. Aini, D. Manongga, U. Rahardja, I. Sembiring, and Y.-M. Li, "Understanding behavioral intention to use of air quality monitoring solutions with emphasis on technology readiness," *International Journal of Human–Computer Interaction*, pp. 1–21, 2024.

[13] A. G. Ismaeel, J. Mary, A. Chelliah, J. Logeshwaran, S. N. Mahmood, S. Alani, and A. H. Shather, "Enhancing traffic intelligence in smart cities using sustainable deep radial function," *Sustainability*, vol. 15, no. 19, p. 14441, 2023.

[14] P. Venkateshwari, V. Veeraiah, V. Talukdar, D. N. Gupta, R. Anand, and A. Gupta, "Smart city technical planning based on time series forecasting of iot data," in *2023 International Conference on Sustainable Emerging Innovations in Engineering and Technology (ICSEIET)*. IEEE, 2023, pp. 646–651.

[15] C. Lukita, N. Lutfiani, R. Salam, G. A. Pangilinan, A. S. Rafika, and R. Ahsanitaqwim, "Technology integration in cultural heritage preservation enhancing community engagement and effectiveness," in *2024 3rd International Conference on Creative Communication and Innovative Technology (ICCIT)*. IEEE, 2024, pp. 1–5.

[16] H. Xu, A. Berres, S. B. Yoginath, H. Sorensen, P. J. Nugent, J. Severino, S. A. Tennille, A. Moore, W. Jones, and J. Sanyal, "Smart mobility in the cloud: Enabling real-time situational awareness and cyber-physical control through a digital twin for traffic," *IEEE Transactions on Intelligent Transportation Systems*, vol. 24, no. 3, pp. 3145–3156, 2023.

[17] R. Chadalawada, "Optimizing public transit networks an exploration of how multi-modal transportation systems can be integrated in smart cities," 2024.

[18] B. K. Bintoro, N. Lutfiani, D. Julianingsih *et al.*, "Analysis of the effect of service quality on company reputation on purchase decisions for professional recruitment services," *APTISI Trans. Manag*, vol. 7, no. 1, pp. 35–41, 2023.

[19] E. Cesario, "Big data analytics and smart cities: applications, challenges, and opportunities," *Frontiers in big data*, vol. 6, p. 1149402, 2023.

[20] A. A. Bimantara, R. Nurfaizi, R. Ahsanitaqwim *et al.*, "Advancements and challenges in the implementation of 5g networks: A comprehensive analysis," *Journal of Computer Science and Technology Application*, vol. 1, no. 2, pp. 111–118, 2024.

[21] G. Mathur, R. K. Singh, M. Rakhra, and D. Prashar, "Optimizing quality control in iiot-based manufacturing: Leveraging big data analytics and iot devices for enhanced decision-making strategies," in *Quality Assessment and Security in Industrial Internet of Things*. CRC Press, pp. 32–46.

[22] M. Anedda, M. Fadda, R. Girau, G. Pau, and D. Giusto, "A social smart city for public and private mobility: A real case study," *Computer Networks*, vol. 220, p. 109464, 2023.

[23] M. Jafari, A. Kavousi-Fard, T. Chen, and M. Karimi, "A review on digital twin technology in smart grid, transportation system and smart city: Challenges and future," *IEEE Access*, vol. 11, pp. 17 471–17 484, 2023.

[24] U. Rusilowati, H. R. Ngemba, R. W. Anugrah, A. Fitriani, and E. D. Astuti, "Leveraging ai for superior efficiency in energy use and development of renewable resources such as solar energy, wind, and bioenergy," *International Transactions on Artificial Intelligence*, vol. 2, no. 2, pp. 114–120, 2024.

[25] N. D. Noviati, F. E. Putra, S. Sadan, R. Ahsanitaqwim, N. Septiani, and N. P. L. Santoso, "Artificial intelligence in autonomous vehicles: Current innovations and future trends," *International Journal of Cyber and IT Service Management*, vol. 4, no. 2, pp. 97–104, 2024.

[26] O. Arshi and S. Mondal, "Advancements in sensors and actuators technologies for smart cities: a comprehensive review," *Smart Construction and Sustainable Cities*, vol. 1, no. 1, p. 18, 2023.

[27] M. I. Khan, S. Khan, U. Khan, and A. Haleem, "Modeling the big data challenges in context of smart cities–an integrated fuzzy ism-dematel approach," *International journal of building pathology and adaptation*, vol. 41, no. 2, pp. 422–453, 2023.

[28] X. Lyu, F. Jia, and B. Zhao, "Impact of big data and cloud-driven learning technologies in healthy and smart cities on marketing automation," *Soft Computing*, vol. 27, no. 7, pp. 4209–4222, 2023.

[29] F. Al-Turjman, R. Salama, and C. Altrjman, "Overview of iot solutions for sustainable transportation systems," *NEU Journal for Artificial Intelligence and Internet of Things*, vol. 2, no. 3, 2023.

[30] Z. Rezaei, M. H. Vahidnia, H. Aghamohammadi, Z. Azizi, and S. Behzadi, "Digital twins and 3d information modeling in a smart city for traffic controlling: A review," *Journal of Geography and Cartography*, vol. 6, no. 1, p. 1865, 2023.

[31] S. R. Samaei, "A comprehensive algorithm for ai-driven transportation improvements in urban areas," in *13th International Engineering Conference on Advanced Research in Science and Technology, https://civilica. com/doc/1930041*, 2023.

[32] M. Peyman, T. Fluechter, J. Panadero, C. Serrat, F. Xhafa, and A. A. Juan, "Optimization of vehicular networks in smart cities: from agile optimization to learnheuristics and simheuristics," *Sensors*, vol. 23, no. 1, p. 499, 2023.

[33] O. T. Modupe, A. A. Otitoola, O. J. Oladapo, O. O. Abiona, O. C. Oyeniran, A. O. Adewusi, A. M. Komolafe, and A. Obijuru, "Reviewing the transformational impact of edge computing on real-time data processing and analytics," *Computer Science & IT Research Journal*, vol. 5, no. 3, pp. 693–702, 2024.

[34] A. Faturahman, S. Rahayu, S. Wijaya, Y. P. A. Sanjaya *et al.*, "Information decentralization in the digital era: Analysis of the influence of blockchain technology on e-journal applications using smartpls," *Blockchain Frontier Technology*, vol. 4, no. 1, pp. 7–14, 2024.