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The Effectiveness of Smart Traffic Management system in Indonesia: Systematic Literature Review

Hendi Sama[1], Andik Yulianto[2], Kevin Lius[3*]
[1,2,3]Prodi sistem Informasi,Fakultas Ilmu Komuter, Universitas Internasional Batam, Indonesia
Baloi-Sei Ladi, Jl. Gajah Mada, Tiban Indah, Kec. Sekupang, Kota Batam, Kepulauan Riau 29426
Email: [1]hendi@uib.ac.id, [2]andik@uib.ac.id, [3]2231020.kevin@uib.edu
**Corresponding Author*

A B S T R A C T

Traffic congestion in Indonesia causes significant economic losses and impacts the quality of life of the community. The Smart Traffic Management System (STMS) emerges as a technology-based solution that integrates the Internet of Things (IoT), Artificial Intelligence (AI), and big data to manage vehicle flow adaptively. This research employs the Systematic Literature Review (SLR) method with the PRISMA approach to analyze the effectiveness of STMS in reducing congestion and carbon emissions, both in Indonesia and in other countries. The reviewed articles indicate that STMS can reduce vehicle travel time by 8-15%, improve traffic flow smoothness by up to 50%, and decrease carbon emissions by 30-40% per year. Trials in Jakarta demonstrate a 15% increase in traffic smoothness and a reduction in travel time during peak hours. These findings confirm that the implementation of STMS has tremendous potential to realize a more efficient, safe, environmentally friendly, and sustainable urban transportation system.

Keywords: *Smart Traffic Management System; Internet of Things (IoT); Artificial Intellingence; Big Data; Emisi Carbon.*

1. INTRODUCTION

Indonesia is the fourth most populous country in the world, after India, China, and the United States, and its population continues to grow every year. This growth presents serious challenges in managing transportation facilities, especially in major cities such as Jakarta, Surabaya, and Bandung, which often experience chronic traffic congestion. Such congestion causes significant losses, both economic and non-economic, including reduced productivity, increased logistics costs, and health problems resulting from air pollution caused by vehicles. In the development of smart city technologies, the role of the Internet of Things (IoT) is crucial as the backbone for real-time data collection. For example, the article titled The Potential of the Internet of Things (IoT) for the Future of Smart Cities [1] The article discusses how IoT enables devices, sensors, and systems to connect and exchange information through the internet, supporting smart city services such as transportation, public safety, and environmental monitoring with real-time data. The research also shows that the use of IoT offers tremendous potential to improve the efficiency of public assets and enhance data-driven decision-making in densely populated cities. This includes smoother traffic flow and faster responses to sudden situations such as accidents or congestion.

Traffic congestion in Jakarta alone is estimated to cause losses of up to Rp 65 trillion per year, resulting from wasted fuel, lost time, and increased vehicle operating costs. In other major cities such as Bandung, Surabaya, and Makassar, the losses are estimated to reach around Rp 12 trillion annually. This highlights the urgent need for technological innovation in traffic management across Indonesia, especially in large urban areas. One potential solution is the Smart Traffic Management System (STMS), which integrates Internet of Things (IoT), Artificial Intelligence (AI), and Big Data to manage traffic data in real time. This system aims to optimize traffic flow, minimize waiting times, reduce vehicle emissions, and enhance overall road safety. A study found that the implementation of AI in traffic control systems can improve travel efficiency by up to 30%, while also reducing energy consumption and carbon emissions in densely populated urban area [2]. In the city of Medan, a study titled Traffic Congestion Detection Using Deep Learning YOLOv4, and Euclidean Distance Tracker demonstrated that real-time congestion detection can reduce waiting times and provide quantitative data on losses caused by traffic jams. Such data can serve as a valuable input when integrated with adaptive traffic light systems [3]. The implementation of a real-time vehicle detection system in Denpasar using AI supports an analytical dashboard for transportation agencies, enabling faster responses to ongoing traffic conditions [4]. On the technical side, the study titled Enhancing Traffic Counting in Rainy Conditions: A Deep Learning Super Sampling and Multi-ROI Area Approach demonstrates improved accuracy and reliability in vehicle counting under adverse weather conditions. This factor is often overlooked in studies on the implementation of Smart Traffic Management Systems (STMS), yet it is crucial for ensuring system effectiveness across Indonesia's diverse weather conditions.[5].

The study titled Adaptive Light Signal Control Using Fuzzy Logic Based on Real-Time Vehicle Data from Video Surveillance, conducted in Banten, utilized the YOLO algorithm and demonstrated that the system was able to reduce vehicle waiting time by approximately 21% compared to a fixed-time system, while also improving efficiency by around 18% [6]. Such studies demonstrate that the integration of video surveillance, AI, and fuzzy logic can serve as key components in the implementation of Smart Traffic Management Systems (STMS) in Indonesia, particularly at congested intersections. Beyond traffic light control, infrastructure maintenance is also essential to ensure the system's proper functionality. For instance, the study Monitoring System for Traffic Light Lamp Damage Using BLYNK Application Based on IoT ESP32 noted that unrepaired traffic light failures can worsen congestion, as even a single malfunctioning light can lead to long queues and imbalanced traffic flow on other lanes [7]. By utilizing IoT to automatically detect damages and send notifications, this system can help traffic authorities reduce traffic light downtime and maintain the continuity of smart traffic signal operations.

In both developing and developed countries**,** Smart Traffic Management Systems (STMS) have shown significant results in addressing traffic congestion. For example, one study discussed the development of an intelligent traffic monitoring system based on a Wireless

Sensor Network (WSN) integrated with a cloud-based central control system. This system is capable of detecting the number of vehicles on a particular road segment and adjusting traffic light phases in real time according to traffic density. The technology has proven effective in improving traffic flow, reducing vehicle waiting times, and assisting traffic authorities in making data-driven decisions. In Indonesia, the study titled Development of Automatic Traffic Light Based on Wireless Sensor Networks with Star Topologies successfully utilized a star topology to detect vehicle queues and adaptively control traffic lights based on queue length[8].

Unfortunately, in Indonesia, the adoption of similar technologies remains relatively low and uneven. The implementation of Smart Traffic Management Systems (STMS) has so far been mostly limited to pilot projects in major cities such as Jakarta and Surabaya. Factors such as a lack of inter-agency integration, limited budgets for digital transportation technologies, and infrastructure unpreparedness have become major obstacles to broader implementation.

One study in Indonesia developed a traffic monitoring system based on computer vision and deep learning to automatically detect traffic violations, count vehicles, and classify vehicle types using CCTV cameras. The system was also tested under low-light conditions and supported real-time decision-making. The results showed a significant improvement in traffic safety, a reduction in road user violations, and greater efficiency in traffic flow.

The impact of an inefficient traffic system is not only reflected in congestion and wasted time but also in public safety and health. Data from the World Health Organization (WHO) indicate that countries with poorly managed traffic systems tend to have high rates of fatal accidents and Indonesia is no exception. In this context, Smart Traffic Management Systems (STMS) that integrate cameras, sensors, and artificial intelligence can serve as a long-term solution. For instance, studies have shown that sensor and AI-based systems are capable of detecting traffic violations, regulating vehicle speeds, and providing early warnings of potential accidents. These systems can also be integrated with weather alerts and road condition monitoring, further enhancing road safety. Moreover, from an environmental perspective, such systems have proven effective in reducing fuel consumption and carbon emissions, as vehicles spend less time idling at crowded intersections or in heavy traffic.

Considering the complexity of traffic issues in Indonesia and the vast potential of Smart Traffic Management Systems (STMS), it is time to conduct a comprehensive analysis of the effectiveness of implementing such systems within the country. This study adopts a Systematic Literature Review (SLR) approach to summarize findings from previous research conducted both in Indonesia and other relevant countries, thereby providing a scientific foundation for future transportation technology policy planning. The results of this research are expected not only to offer an overview of the trends and effectiveness of the technologies used but also to provide practical insights regarding key success factors, implementation challenges, and adaptation strategies suited to Indonesia’s unique geographical, social, and infrastructural conditions. Thus, this study has the potential to contribute to the acceleration of Indonesia’s digital transportation transformation, making it more adaptive, safe, efficient, and sustainable.

This study aims: A) To analyze the effectiveness and efficiency of implementing Smart Traffic Management Systems (STMS) in addressing traffic congestion problems in Indonesia;

B) To provide policy recommendations and implementation strategies for Smart Traffic Management Systems (STMS) that are relevant and aligned with the conditions in Indonesia.

This study is expected to provide the following benefits: A) To contribute to the academic literature on technology-based traffic management in developing countries, particularly in Indonesia; B) To serve as a reference for policymakers, government agencies, and transportation practitioners in developing more effective smart transportation systems; C) To help create urban environments that are more comfortable, safe, and environmentally friendly through the reduction of traffic congestion and greenhouse gas emissions.

2. LITERATURE REVIEW

Smart Traffic Management Systems (STMS) have been widely adopted in both developed and developing countries to address complex traffic challenges arising from urbanization, vehicle growth, and limited road infrastructure. In Saudi Arabia, the implementation of IoT- and AI-based STMS has proven effective in reducing vehicle travel time by up to 25% in major cities. The system relies on the integration of road sensors, real-time data processing, and adaptive algorithms to dynamically control traffic signals according to actual on-site conditions.

The main causes of congestion at urban intersections in Batam were identified through direct field surveys and traffic data analysis. The study found that high vehicle volume, poor coordination between traffic lights, and suboptimal road infrastructure were significant factors contributing to congestion at intersections. To address these issues, several strategies were proposed, including improving traffic light synchronization patterns, adjusting traffic signal phase timings, and enhancing coordination among road management agencies. The implementation of these strategies is expected to significantly improve vehicle mobility at major intersections in Batam[9].

In India, the implementation of similar technologies has also shown a positive impact on vehicle safety. For example, one study developed a predictive model to project the severity of traffic accidents based on factors such as vehicle speed, weather conditions, traffic volume, and road characteristics. This model can support accident prevention by providing early warnings about potentially hazardous situations [10]. Meanwhile, in China, the study Big-Data Empowered Traffic Control in China found that the use of adaptive traffic light systems powered by big data can significantly reduce carbon emissions in densely populated cities. For instance, across the 100 most populated cities in China, the system successfully reduced annual CO_2 emissions by approximately 31.73 million tons through shorter peak travel times and optimized traffic light operations.[11].

However, in developing countries such as Indonesia, the implementation of Smart Traffic Management Systems (STMS) still faces several challenges. These include limited digital infrastructure, insufficient development funding, and resistance to change from local stakeholders. Nevertheless, several studies have shown significant potential for STMS adoption in Indonesia. For instance, a pilot project on sensor-based traffic signal control conducted in Jakarta in 2021 by the Badan Pengelola Transportasi Jabodetabek (BPTJ) demonstrated that vehicle waiting times at intersections could be reduced by up to 20%.

A Smart Traffic Management System (STMS) is an information and communication technology-based traffic management system designed to collect, process, and analyze traffic data in real-time with the aim of optimizing vehicle flow, enhancing road safety, and reducing environmental impact. This system typically utilizes IoT sensors, visual sensing cameras, as well as artificial intelligence (AI) and big data analytics algorithms to detect road congestion, predict traffic patterns, and adjust traffic signal phases dynamically in accordance with changing road conditions [12] In practical implementation, an effective Smart Traffic Management System (STMS) is capable of optimizing the duration of traffic signals based on vehicle queues, prioritizing emergency vehicles and public transportation, and even integrating external data such as weather conditions and road status to support adaptive decision-making. Studies have shown that the integration of deep learning with Internet of Things (IoT) in traffic control can significantly improve traffic flow efficiency and reduce congestion levels.[13]. Likewise, studies have shown that an IoT-based multi-agent framework integrated with vehicle-to-infrastructure (V2I) communication is capable of reducing travel time and CO_2 emissions through the optimization of adaptive traffic signal control [14].

Several key components of the Smart Traffic Management System (STMS) are as follows: A) IoT Sensors: These include traffic cameras, speed sensors, and loop detectors embedded in roads to monitor vehicle volume, traffic density, and weather conditions. The data collected from these sensors is used to detect traffic patterns, predict congestion, and provide early warnings; B) Artificial Intelligence (AI): AI plays a crucial role in analyzing traffic data and making automated decisions. For instance, machine learning algorithms are applied to adaptively control traffic signal timing, predict potential accidents, and suggest the fastest routes for road users; C) Big Data Analytics: Big data enables large-scale data processing to identify traffic trends, plan infrastructure, and simulate transportation management scenarios. Data is collected from various sources such as CCTV, GPS, and public navigation applications to provide a holistic, real-time view of traffic conditions; D) Real-Time Communication System: Technologies such as 5G, Dedicated Short-Range Communications (DSRC), and other IoT networks enable fast and accurate data exchange between sensors, servers, and road users; E) System Integration: An effective STMS integrates data and systems from various sources, such as public transportation networks, road infrastructure, and navigation applications, to create seamless and efficient user experience.

The Smart Traffic Management System (STMS) offers various benefits such as reduced travel time, improved fuel efficiency, enhanced road safety, and support for the development of sustainable smart cities. These advantages align with the Sustainable Development Goals (SDGs) and the global commitment to carbon emission reduction as outlined by the UNFCCC (2020).

Although most of the references used in this study are from publications between 2020 and 2025, several references prior to 2020 have been retained because they make a fundamenta contribution to explaining the basic concepts, system architecture, and working principles of the Smart Traffic Management System (STMS), which are still relevant today and are widely cited in recent studies.

3. RESEARCH METHODS

This research employs a qualitative approach using the Systematic Literature Review (SLR) method. This method was chosen because it provides a comprehensive overview of the development, effectiveness, and challenges in implementing the Smart Traffic Management System (STMS) in Indonesia. The SLR aims to identify, evaluate, and interpret all relevant studies related to the research questions, thereby offering a stronger theoretical foundation and empirical evidence.

The approach follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, which ensure transparency, consistency, and research replicability. By adhering to PRISMA, each stage from literature search and selection to analysis—is conducted systematically, ensuring that the findings are credible, accountable, and academically valid.

The data used in this study are secondary data obtained from various literature sources. Secondary data were chosen as they provide a solid theoretical foundation and allow comparison of STMS implementation practices across different countries with the actual conditions in Indonesia. The data sources include: a) Case studies of STMS implementation in both developed and developing countries that have applied this technology in their transportation systems; b) Research on supporting technologies, such as the Internet of Things (IoT), Artificial Intelligence (AI), and big data, in the context of traffic management; c) STMS implementation data in Indonesia, at both national and local levels, derived from government publications, official reports, and academic research studies.

All data were collected from both international and national databases such as Scopus, IEEE Xplore, SpringerLink, Publish or Perish, and Google Scholar, focusing on publications from the 2020–2025 period to ensure the relevance of the findings with the latest technological developments.

The data collection process was carried out in several systematic stages as follows: A) Identification of Research Questions:

The first stage involved formulating the main research question, namely: “What is the impact of implementing Smart Traffic Management Systems (STMS) on reducing urban carbon emissions, and to what extent are these systems effective and efficient in addressing traffic congestion in Indonesia?”; B) Literature Search: The search was conducted through Google Scholar and Publish or Perish using keywords such as “Traffic Management,” “Intelligent Traffic Systems,” and “Traffic Solutions.” The publication period was limited to 2020–2025. Each article identified was screened based on its title, abstract, and keywords to ensure its relevance to the research topic; C) Literature Selection: The selection process was carried out in two stages: a) Initial screening, which eliminated irrelevant articles for instance, those not focusing on STMS or unrelated to traffic management; b) Advanced screening, which selected articles based on specific criteria, including: 1) Publications from 2020–2025; 2) Research focusing on STMS, particularly regarding traffic congestion and carbon emission reduction; D) Quality Assessment of Literature : The selected literature was then evaluated using the Critical Appraisal Skills Programme (CASP) framework. The evaluation considered: a) Clarity of research objectives; b) Alignment between methods and objectives; c) Methodological validity and strength of argumentation; d) Contribution of the study to the development of STMS

Articles meeting high-quality research standards were subsequently chosen for in-depth analysis.

The data analysis in this study employed a qualitative approach through the following steps: A) Data Reduction: The collected data were extracted and then categorized based on specific themes such as the technologies used (IoT, AI, Big Data), implementation challenges (technical, regulatory, financial), and STMS implementation outcomes across various countries, including Indonesia; B) Data Presentation: The results of the analysis were presented in the form of comparison tables, flow diagrams, charts, and descriptive narratives. This stage aimed to facilitate understanding and illustrate the interrelationships among different findings; C) Conclusion and Verification: Conclusions were drawn based on the synthesized data, followed by verification to ensure the validity and reliability of the interpretations. This step confirmed that the conclusions were consistent with the data patterns obtained during the analysis.

Based on the analyzed data, conclusions were drawn to address the main research questions. The validity of these conclusions was strengthened through literature triangulation, which involved comparing findings from multiple sources to ensure the accuracy and consistency of the results.

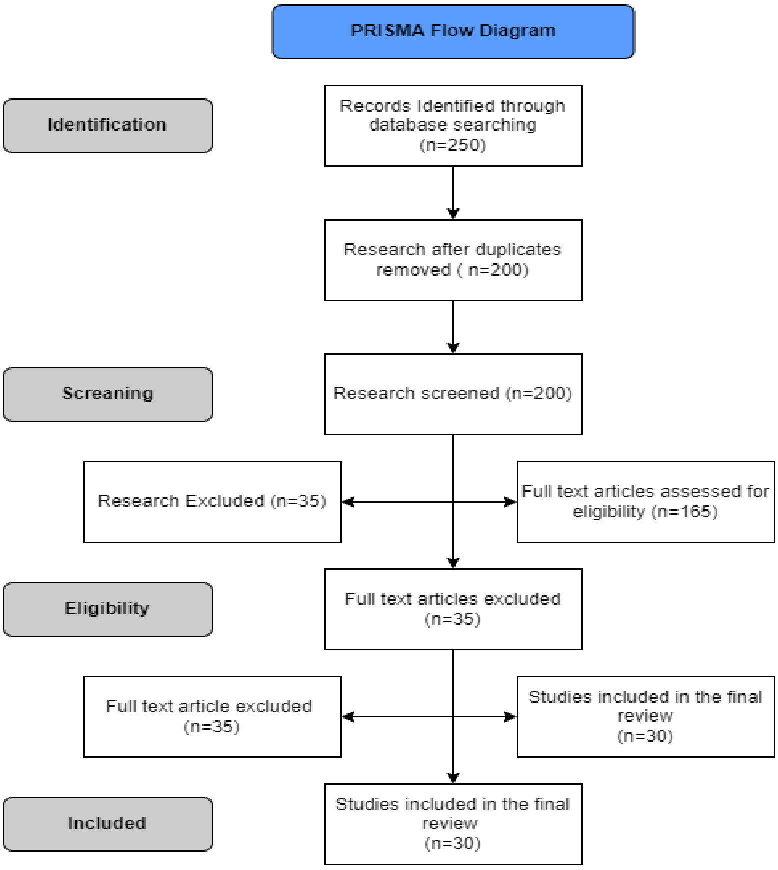
Table 1. Inclusion and exclusion criteria used identify journals relevant to the research topic

	Inclusion	Exclusion
By File	Journals written in English within a five-year period (2020-2025)	Books, proceedings, theses, dissertation, or literature articles that are not in English or published outside the 2020-2025
By Title	Journals with titles discussing the effectiveness of management system implementation in smart traffic system	Journals with titles discussing the effectiveness of management system implementation in smart traffic system
By Abstract	Journals with abstracts focusing on the effectiveness of management system implementation in smart traffic system	Journal with abstracts not addressing the effectiveness of management system implementation in smart traffic system
By Full Paper	Journals whose full papers discuss the effectiveness of management system implementation in smart traffic system	Journals whose full papers do not discuss the effectiveness of management system implementation in smart traffic system

During the literature identification process, the researcher initially collected 250 articles from databases such as Google Scholar, Scopus, Publish or Perish, and IEEE Xplore using the keywords “Traffic Management”, “Intelligent Traffic Systems”, and “Traffic Solutions”. After the initial elimination stage, 50 articles were excluded due to irrelevance to the research topic. The next step involved screening the remaining 200 articles, focusing on abstract relevance, topic alignment, and DOI availability. As a result, 165 articles were eliminated for not meeting the inclusion criteria, primarily because they contained only titles/abstracts without full content or lacked verifiable DOIs. Ultimately, 30 final articles were selected for further analysis. These articles were chosen based on their direct relevance to the effectiveness of Smart Traffic Management System (STMS) implementation, particularly concerning traffic congestion reduction and carbon emission mitigation.

The articles that were eliminated did not meet the inclusion criteria due to their lack of alignment with the research focus or because they primarily discussed the implementation of

Big Data, IoT, and AI in general traffic management contexts rather than specifically addressing the effectiveness of Smart Traffic Management Systems (STMS).



Picture 1. PRISMA Flow Diagram

4. RESULT AND DISCUSSION

Based on 30 journal articles that met the inclusion criteria, the research results are as follows.

Table 2. The research results based on 30 journal articles that met the inclusion criteria

No.	Researcher & Year	Research Results
1	Arindam Chaudhuri (2024)	The implementation of the Faster R-CNN method optimized with Topological Active Nets has proven to deliver higher accuracy in vehicle segmentation, density estimation, and tracking compared to previously used methods[15].
2	Mamoona Humayun, Sadia Afsar, Maram Fahaad Almufareh, Mashayel ALSuwailem (2022)	A study developed an IoT-, Cloud-, Big Data-, and 5G-based architecture, which effectively helped to significantly reduce traffic congestion in Riyadh by providing real-time traffic information through Google Maps and an integrated dashboard[16].
3	Mohammed Sarrab, Supriya Pulparambil, Medhat Awadalla (2020)	The developed IoT system demonstrated a positive impact on real-time traffic updates through roadside message units without the need for smart devices, offering high accuracy in vehicle detection and traffic density estimation[17].

4	Alzahraa Elsayed, Khalil Mohamed, Hany Harb (2023)	A FOG Computing-based system was found to outperform IoV and STL models, achieving lower latency, higher throughput, and better traffic efficiency[18].
5	Ahmed Mahmoud Elbasha, Mohammad M. Abdellatif (2025)	The implementation of a solar-powered IoT-5G system improved traffic efficiency, reduced fuel consumption, and enhanced road safety through dynamic light control and inter-device communication[19].
6	Christofel Rio Geonawan (2024)	The deployment of an ASTM system integrating CNN YOLOv5 and RNN-LSTM increased traffic flow by 50% and reduced waiting time by up to 70% based on CARLA simulation results[20].
7	Samah Adel Gamel, Ahmed Ibrahim Saleh, Hesham Arafat Ali (2021)	Research identified that IoT is effective in traffic management, although it faces major challenges related to scalability, security, interoperability, and infrastructure costs[21].
8	Asma Ait Ouallane, Ayoub Bahnasse, Assia Bakali, Mohamed Talea (2022)	A literature review revealed that AI-, IoT-, and Big Data-based solutions are effective for adaptive traffic management, offering great potential for further research in urban transportation management[22].
9	Shima Damadam, Mojtaba Zourbakhsh, Reza Javidan, Azadeh Faroughi (2022)	The application of the Multi-Agent Reinforcement Learning (MARL) algorithm successfully reduced queue lengths and waiting times at intersections in Shiraz compared to static traffic light systems[23].
10	Rana Ahmed, Radwa Ahmed Osman, Motaz Amer (2024)	Lastly, the implementation of AI-based CCTV systems improved traffic efficiency by up to 34% compared to static light systems, without requiring any additional hardware[24].

Research on smart traffic management systems indicates that the integration of modern technologies such as IoT, AI, big data, cloud computing, 5G, deep learning, and fog computing can significantly reduce traffic congestion levels in major urban areas. Several studies have demonstrated the effectiveness of sensor-based, camera-based, reinforcement learning, and image analysis systems in optimizing traffic light durations, accurately detecting vehicles, and providing real-time information through dashboards, mobile applications, or roadside message units. These implementations have resulted in reduced waiting times due to congestion, smoother traffic flow of up to 50%, improved energy efficiency, and decreased fuel consumption. On the other hand, some studies highlight the importance of evaluating IoT- and AI-based solutions and identifying key challenges such as the need for large-scale infrastructure, robust data security, device interoperability, and implementation costs. Nevertheless, the overall findings consistently indicate that technology-driven traffic management systems have a positive impact on urban mobility, road safety, and the long-term sustainability of smart cities.

Table 3. The research results based on 30 journal articles that met the inclusion criteria (continued)

11	Jamiu Adeniyi Yusuf (2024)	The implementation of smart traffic management systems has been proven to significantly reduce fuel consumption, travel time, and greenhouse gas emissions. Economic analysis indicates that the benefits outweigh the investment costs, making the system financially feasible and supportive of future sustainable urban transportation[25].
12	Osvaldo Santos, Fernando Ribeiro, Jose Metrolho, Rogerio Dionisio (2024)	Simulation results at an intersection in a small city in Portugal show that smart traffic lights can reduce CO_2 emissions by 32–40%, increase average speeds by 60–101%, and decrease waiting times by 53–95%[26].

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13	Xingyu Tao, Lan Cheng, Ruihan Zhang, W. K. Chan, Huang Chao, Jing Qin (2024)	Traffic data from Hong Kong demonstrate that vehicle flow prediction using machine learning algorithms effectively reduces congestion, fuel consumption, and carbon emissions, thereby supporting green innovation in smart cities[27].
14	Alexander Hammarl, Ravi Seshadri, Thomas Kjaer Ramussen, Otto Anker Nielsen (2025)	Simulations on urban highways reveal that Model Predictive Control (MPC) with Variable Speed Limits can significantly reduce pollutant emissions with only a slight increase in travel time, even under uncertain traffic demand conditions[28].
15	Michael Thobie Rahadian Kartono, Nuvia Kurnia Sari, Andi Trio Suroso (2024)	A pilot implementation of an IoT- and AI-based traffic management system in Jakarta shows a 15% improvement in traffic flow and a reduction in travel time during peak hours, demonstrating the potential of such intelligent systems for other major cities in Indonesia.[12]
16	Pattiasina Jefry Recky (2021)	The study also emphasizes that the adoption of a non-stop RFID-based toll system (MLFF) can reduce congestion at toll gates, minimize economic losses due to traffic jams, and enhance the efficiency of goods and service distribution in Indonesia[29].
17	Mohammed Al-Turki, Arshad Jamal, Hassan M.Ai-Ahmadi, Mohammed A. Ai-Sughaiyer, Muhammad Zahid (2020)	A case study conducted in Dhahran, Saudi Arabia, using the NSGA-II algorithm, shows improved traffic efficiency with reductions in delay, fuel consumption, and emissions by 16–23%, compared to both baseline and standard Synchro optimization[30].
18	Kan Wu, Jianrong Ding, Jingli Lin, Guanjie Zheng, Yi Sun, Jie Fang, Tu Xu, Yongdong Zhu, Baojing Gu (2025)	An analysis of the 100 most congested cities in China found that the implementation of big data–driven adaptive traffic signals reduced travel times by 8–11% and annual CO_2 emissions by up to 31.73 million tons, with economic benefits far exceeding implementation costs[11].
19	Zhaowei Wang, Le Xu, Jianxiao Ma (2023)	The D3QN algorithm for traffic signal control in mixed traffic environments (CAVs and human-driven vehicles) successfully reduced waiting times and CO_2 emissions more effectively than traditional methods, especially under low to medium traffic volumes[31].
20	Lin Duan, Hongxing Zhao (2025)	Finally, deep reinforcement learning models for traffic light optimization have shown superior performance compared to conventional approaches, with simulation results indicating reduced average waiting times and lower CO_2 emissions across various mixed-traffic scenarios[32].

Recent studies indicate that the implementation of smart traffic management systems integrating IoT, AI, machine learning, big data, and algorithmic optimization has significantly improved traffic efficiency while simultaneously reducing carbon emissions. Case studies conducted across Indonesia, Portugal, China, Hong Kong, Saudi Arabia, and various European countries consistently demonstrate positive outcomes, including a 8–15% reduction in travel time, up to 23% decrease in delays, a 15% improvement in traffic flow, and a 30–40% reduction in CO_2 emissions, reaching as high as 31 million tons annually on a large scale. The systems examined—ranging from smart traffic lights, reinforcement learning–based adaptive signals, and predictive analytics, to Variable Speed Limits using Model Predictive Control (MPC)—have all shown superior performance compared to conventional methods. Beyond environmental benefits, economic analyses also highlight a positive benefit-cost ratio, confirming that these intelligent technologies are both financially feasible and sustainable solutions for future urban transportation systems across diverse global contexts.

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Table 4. The research results based on 30 journal articles that met the inclusion criteria (continued)

21	Saravana Balaji Balasubramanian, Prasanalakshmi Balaji, Asmaa Munshi, Wafa Almukadi, T. N. Prabhu, Venkatachalam K, Mohamed Abouhawwash (2023)	A machine learning–based IoT system was developed to manage adaptive traffic signals and simultaneously detect accidents, proving to be more efficient than conventional methods while improving transportation safety[33].
22	Shailesh Shivajirao Bhise (2025)	A review study revealed that the implementation of IoT in traffic management can reduce congestion, enhance safety, and optimize traffic distribution, although cybersecurity challenges remain.[34]
23	Michael Thobie Rahadian Kartono, Nuvia Kurnia Sari, Andi Trio Suroso (2025)	The implementation of an IoT- and AI-based traffic management system in Jakarta has been shown to improve traffic flow by 15% and reduce travel times during peak hours[12].
24	Ashwani Dhar Dwivedi, Ashish Kumar Singh, Dr. Pankaj Kumar (2023)	A smart traffic management system based on image processing was developed to automatically count vehicles from video or image inputs, allowing traffic lights to adjust signal timing according to vehicle volume and thereby reduce congestion levels[35].
25	Zongyang Zhao (2024)	Through a study conducted in Manhattan using the Propensity Score Matching method, it was found that Adaptive Traffic Signals (ATS) significantly reduce peak-hour congestion and improve traffic flow[36].
26	Dex R. Aleko, Soufiene Djahel (2020)	A big data and artificial intelligence–based traffic prediction model was developed, which improved the accuracy of vehicle flow forecasting and supported more efficient urban traffic planning[37].
27	Gerald P. Rocha Filho, Rodolfo I. Meneguette, Jose R. Torres Neto, Alan Valejo, Li Weigang, Jo Ueyama, Gustavo Pessin, Leandro A. Villas (2020)	The findings also show that IoT sensor–based traffic systems can optimize urban transportation management by monitoring road conditions in real time, enabling faster responses to congestion and traffic density[38].
28	Wei-Hsun-Lee, Chi-Yi Chiu (2020)	A Smart Traffic Signal Control (STSC) system was developed to prioritize emergency and public transportation vehicles, and field tests demonstrated its effectiveness in enhancing both traffic smoothness and safety[39].
29	Ponlathep Lerworawanich, Panumas Unhasut (2021)	An intersection control system based on CO emission levels was proven to reduce carbon emissions by 7.67% compared to the Webster method, while also decreasing vehicle delays and stops[40].
30	Jingya Wei, Yongfeng Ju (2024)	A machine learning algorithm for optimizing adaptive traffic signal control was found to effectively reduce average vehicle waiting times and improve overall traffic flow[41].

Studies have shown that the integration of IoT, AI, and adaptive signal systems has proven effective in reducing traffic congestion, waiting times, and carbon emissions, while simultaneously improving traffic flow and road safety. This technology is considered a sustainable and feasible solution for urban transportation, despite ongoing challenges related to implementation costs and data security. The adoption of the Smart Traffic Management System (STMS) has demonstrated a significant positive impact on reducing carbon emissions in urban areas. The integration of IoT, AI, and big data technologies enables more adaptive traffic regulation, minimizing vehicle idling during congestion or static red-light phases.

Several international studies , such as those conducted by Kan Wu [11] and Osvaldo [26] showed a reduction in CO_2 emissions by up to 30–40% per year following the implementation of this system. This indicates that STMS not only supports smoother traffic flow but also aligns global targets for reducing urban carbon emissions.

From the perspective of effectiveness, studies conducted both in Indonesia and abroad have demonstrated that STMS can reduce vehicle travel time by 8–15% and improve traffic flow by up to 50%. For instance, trials conducted in Jakarta successfully reduced travel time during peak hours while significantly enhancing overall traffic smoothness [12]. This indicates that the implementation of STMS has the potential to be an effective solution in addressing chronic traffic congestion in major Indonesian cities, which causes economic losses amounting to trillions of rupiah each year.

Thus, it can be concluded that STMS makes a significant contribution to creating a more efficient, environmentally friendly, and sustainable urban transportation system. Although there are still challenges such as limited infrastructure and high investment costs, empirical evidence shows that the benefits of STMS—both in reducing carbon emissions and improving traffic efficiency—far outweigh the existing obstacles.

The study "Design and Implementation of a Smart Traffic Signal Control System for Smart City Applications" demonstrates how a Smart Traffic Signal Control (STSC) system that integrates adaptive control, public transport priority, and emergency vehicle preemption has been successfully implemented in the field, effectively reducing vehicle delays and improving intersection traffic flow [39]. However, the study "Implementation of Area Traffic Control System (ATCS) in Various Regions of Indonesia as an Application of Smart Mobility" reveals significant challenges in the implementation of STMS/ATCS in Indonesia, such as budget constraints, equipment malfunction, and low public compliance with traffic regulations. Although ATCS has been proven to improve traffic flow in several locations, these operational and social barriers indicate that the success of STMS depends not only on technology but also on institutional support and public readiness [42].

The development of the Smart Traffic Management System (STMS) based on the Internet of Things (IoT) and Artificial Intelligence (AI) has shown positive results in efforts to overcome congestion and improve urban transportation efficiency. This system enables real-time data collection and analysis so that traffic light settings can adapt dynamically to road conditions. The study confirms that the implementation of an IoT-based intelligent transportation system can significantly reduce carbon emissions and fuel consumption in densely populated urban areas, while also improving vehicle travel time efficiency. However, the study also highlights the importance of government policy support and digital infrastructure integration in order to optimize its benefits in developing countries such as Indonesia [43]. On the other hand, the research provides a critical view of the implementation of such high-tech traffic control systems. In their review, the researchers emphasize that although AI-based signal control methods and algorithm optimization have developed rapidly, their effectiveness in the field is often hampered by infrastructure limitations, high implementation costs, and a lack of reliable real-time data in many developing cities. They also highlight the security and data privacy risks arising from the widespread use of IoT networks in public spaces. This shows that the success of STMS is not only determined by its technological sophistication, but also by the readiness of the digital ecosystem, transportation governance, and adequate data protection [44].

In addition to addressing traffic congestion, the implementation of STMS also plays an important role in reducing the environmental impact of the transportation sector. Research conducted through a multi-objective optimization approach found that AI-based traffic light control can reduce fuel consumption and carbon emissions by up to 23% compared to conventional systems. This study demonstrates the real potential of STMS to support green transportation policies and achieve net zero emission targets in densely populated urban areas [45]. However, other studies highlight that although AI and IoT-based systems can reduce emissions, the process of training algorithms and processing big data itself requires high computational energy consumption. This can create a new "digital carbon footprint" if it is not balanced with the use of renewable energy in server systems and data centers. Thus, STMS optimization should also consider energy sustainability from the perspective of supporting technology [46].

5. CONCLUSION AND RECOMMENDATIONS

The results of the study indicate that the implementation of Smart Traffic Management Systems (STMS) has made a significant contribution to addressing traffic congestion and reducing urban carbon emissions. The integration of IoT, AI, and big data technologies enables adaptive traffic signal management, preventing vehicles from remaining idle for extended periods — ultimately reducing fuel consumption and greenhouse gas emissions. Both international and national studies consistently demonstrate that STMS can improve travel efficiency, enhance traffic flow by up to 50%, and reduce carbon emissions by 30–40% per year.

In Indonesia, although the implementation of STMS is still limited to pilot projects, trials in Jakarta have shown positive impacts on reducing travel time and improving traffic flow. Challenges such as limited digital infrastructure, inter-agency integration, and high investment costs remain, but the long-term benefits outweigh these barriers. With strong government policy support, effective implementation strategies, and a commitment to sustainable investment, STMS has the potential to become a key foundation in transforming the national transportation system toward smart, environmentally friendly, and sustainable mobility.

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