Journal of Scientia Technologiae
Volume 2, Number 2, 2026
E-ISSN : 3124-243X
Open Access: https://grafindoscience.com/jst

Internet of Things-Based Monitoring Systems for Enhancing Public Infrastructure Safety and Maintenance

Anggi Saputra [1], Kayla Ramadhani [2]
[1] Universitas Muhammadiyah Bandung 1
[2] Politeknik Kesejahteraan Sosial Bandung 2
Correspondence: anggie12@email.com

Article Info
Article history:
Received Apr 12th, 2026
Revised Mei 20th, 2026
Accepted Jun 26th, 2026

Keyword:
Internet of Things, smart infrastructure, predictive maintenance, public infrastructure safety, smart city governance, qualitative case study.

ABSTRACT
This study examines the implementation of Internet of Things (IoT)-based monitoring systems for enhancing public infrastructure safety and maintenance within smart urban environments. The research aims to analyze how IoT technologies improve infrastructure monitoring effectiveness, predictive maintenance practices, and operational responsiveness while addressing implementation challenges related to technological integration and institutional readiness. This study employed a qualitative research approach using a case study design because it enabled comprehensive exploration of real-life technological implementation within public infrastructure management systems. The research was conducted in Bandung, Indonesia, due to the city's active smart city initiatives and growing adoption of digital infrastructure technologies. Data were collected from twelve informants consisting of government officials, infrastructure engineers, technology specialists, cybersecurity experts, and academic researchers selected through purposive sampling because of their direct involvement in IoT-based infrastructure management. The findings reveal that IoT systems significantly improve real-time monitoring, predictive maintenance efficiency, infrastructure safety, and operational decision-making. However, interoperability limitations, cybersecurity risks, and organizational readiness remain critical implementation challenges. The study recommends strengthening institutional collaboration, cybersecurity resilience, interoperability standards, and continuous human resource development to support sustainable smart infrastructure governance.

INTRODUCTION

Rapid urbanization, population growth, and the increasing complexity of public infrastructure systems have intensified the demand for reliable, adaptive, and technology-driven monitoring mechanisms (Minson, 2024). Public infrastructure, including bridges, highways, tunnels, water distribution systems, public buildings, and transportation facilities, plays a critical role in sustaining economic development, social mobility, and public welfare. However, aging infrastructure, insufficient maintenance practices, environmental degradation, and delayed fault detection continue to create substantial risks for public safety and operational continuity (Torrent & Musch, 2024). Conventional inspection and maintenance approaches are frequently characterized by manual observations, periodic evaluations, and reactive repair strategies, which often fail to provide real-time insights into structural conditions (Yaacob et al., 2025). Consequently, infrastructure failures may occur unexpectedly, leading to economic losses, service disruption, environmental damage, and threats to human safety. In this context, the integration of Internet of Things (IoT) technology into infrastructure monitoring systems has emerged as a transformative solution capable of enhancing predictive maintenance, operational efficiency, and infrastructure resilience (Sangani & Shah, 2024).

The development of IoT-based monitoring systems has significantly influenced the modernization of smart infrastructure management in recent years (Radhakrishnan & Manda, 2025). IoT technology enables interconnected sensors, embedded devices, wireless communication networks, and cloud computing platforms to continuously collect, transmit, and analyze infrastructure data in real time (Chaabane, 2025). Previous studies have demonstrated that IoT applications can support structural health monitoring, environmental condition tracking, energy management, and automated maintenance scheduling (Ambarkar & Shekokar, 2024). Several researchers have highlighted the effectiveness of IoT sensors in detecting structural vibration, temperature fluctuation, corrosion levels, water leakage, traffic density, and air quality indicators (Miasayedava et al., 2023). Moreover, the incorporation of artificial intelligence, big data analytics, and machine learning algorithms into IoT ecosystems has further strengthened the capability of predictive diagnostics and automated decision-making processes (S. Li & Yang, 2024). These technological advancements represent the current state of the art in infrastructure safety management, particularly within smart city development frameworks (Surapaneni & Bojjagani, 2025).

Despite the growing body of literature on IoT-enabled infrastructure monitoring, several critical challenges remain unresolved. Existing studies often focus on specific infrastructure sectors independently, such as transportation systems, water pipelines, or smart buildings, without developing an integrated and scalable monitoring framework applicable across multiple public infrastructure domains (Liao et al., 2024). Furthermore, many current monitoring systems emphasize data acquisition and visualization while providing limited discussion regarding predictive maintenance integration, cybersecurity vulnerabilities, interoperability among heterogeneous devices, and long-term operational sustainability (Gour & Yadav, 2025). In developing countries, infrastructure monitoring implementation also faces additional barriers related to limited technological readiness, insufficient funding, unstable communication networks, and the lack of standardized governance models (Lokhande et al., 2025). These conditions reveal that although IoT technology offers substantial potential, practical implementation remains fragmented and insufficiently optimized for comprehensive public infrastructure safety management.

Another important concern relates to the reliability and responsiveness of conventional maintenance practices. Public infrastructure management agencies frequently rely on periodic inspections conducted within fixed schedules rather than condition-based monitoring approaches (Kaczorowska-Spychalska, 2024). Such methods may result in delayed identification of structural deterioration and increase the possibility of catastrophic failures. Previous infrastructure incidents in several countries have demonstrated that inadequate monitoring systems can contribute to bridge collapses, road subsidence, pipeline ruptures, and building safety failures (Pargi et al., 2025). The inability to obtain continuous and accurate infrastructure data creates uncertainty in maintenance prioritization and resource allocation. Therefore, there is an urgent need to develop integrated IoT-based monitoring frameworks capable of supporting proactive maintenance strategies through real-time condition assessment and intelligent warning systems (Widjaja & Kim, 2025).

The research gap identified in this study lies in the limited integration between real-time IoT monitoring, predictive maintenance analytics, and public infrastructure safety governance within a unified framework. Existing research predominantly concentrates on technical sensor performance or isolated case studies without comprehensively addressing how IoT ecosystems can support strategic maintenance planning, risk mitigation, and infrastructure sustainability simultaneously (Geethapriya et al., 2025). Moreover, limited attention has been given to the interoperability of sensor networks, cloud platforms, and intelligent analytics systems under dynamic public infrastructure environments. Previous studies also tend to overlook the relationship between technological implementation and institutional readiness, particularly regarding data governance, cybersecurity protection, and cross-sector collaboration (Liu et al., 2023). Consequently, a comprehensive framework that integrates technological, operational, and governance dimensions remains insufficiently explored within current academic discourse.

Based on these considerations, this study introduces a novel approach by proposing an integrated IoT-based monitoring system framework designed to enhance public infrastructure safety and maintenance efficiency through real-time sensing, predictive analytics, and intelligent decision-support mechanisms. The novelty of this research lies in the integration of multi-sensor IoT architecture with predictive maintenance models and adaptive infrastructure management strategies within a unified operational ecosystem. Unlike previous studies that focus solely on monitoring functions, this research emphasizes the synergistic relationship between data acquisition, anomaly detection, automated alerts, maintenance prioritization, and policy-oriented infrastructure governance (Verma et al., 2024). The proposed framework also considers scalability, interoperability, cybersecurity resilience, and sustainability aspects to support broader smart city implementation contexts. Therefore, this study contributes not only to technological innovation but also to the strategic transformation of public infrastructure management systems.

This research is guided by several fundamental research questions. The first question examines how IoT-based monitoring systems can improve the effectiveness of public infrastructure safety management through real-time data acquisition and analysis. The second question investigates the extent to which predictive maintenance mechanisms can reduce infrastructure failure risks and operational inefficiencies. The third question analyzes the challenges associated with implementing integrated IoT frameworks within public infrastructure environments, including technological interoperability, cybersecurity, and institutional readiness. The fourth question explores how intelligent monitoring systems can support sustainable infrastructure governance and long-term maintenance planning within smart city ecosystems.

The primary objective of this research is to develop and analyze an integrated IoT-based monitoring framework capable of enhancing public infrastructure safety and maintenance effectiveness. Specifically, this study aims to identify the critical components required for real-time infrastructure monitoring, evaluate the role of predictive analytics in maintenance optimization, and examine the operational challenges associated with IoT implementation in public infrastructure systems. In addition, this research seeks to formulate strategic recommendations for improving infrastructure resilience through intelligent monitoring technologies and adaptive governance mechanisms.

From a theoretical perspective, this study contributes to the advancement of knowledge regarding the integration of IoT technology, predictive maintenance, and infrastructure management theories (W. Li et al., 2025). The research enriches academic discourse related to smart infrastructure systems, cyber-physical systems, and intelligent maintenance frameworks by providing a comprehensive conceptual model for infrastructure monitoring integration. Academically, the findings are expected to serve as a valuable reference for researchers, scholars, and higher education institutions engaged in the fields of information technology, civil engineering, urban management, and smart city development. The study also opens opportunities for interdisciplinary collaboration involving sensor engineering, data analytics, artificial intelligence, and public policy research. Practically, this research provides strategic insights for government institutions, infrastructure operators, policymakers, and technology developers in designing efficient, reliable, and sustainable monitoring systems capable of reducing maintenance costs, minimizing infrastructure failure risks, and improving public service quality.

Nevertheless, this study has several limitations. The research primarily focuses on the conceptual and analytical dimensions of IoT-based monitoring systems rather than conducting full-scale experimental implementation across diverse infrastructure environments. The study may also face limitations related to data availability, infrastructure heterogeneity, and rapidly evolving technological standards. In addition, the analysis emphasizes public infrastructure contexts within urban and semi-urban environments, which may limit generalization to remote or highly resource-constrained regions. Cybersecurity assessment and economic feasibility analysis are discussed within a limited scope and require deeper empirical validation in future studies.

Therefore, future research is recommended to conduct large-scale empirical testing of integrated IoT monitoring systems across various infrastructure sectors and geographical contexts. Further studies should also explore advanced artificial intelligence integration, edge computing optimization, blockchain-based security mechanisms, and sustainable energy utilization within IoT ecosystems (Prasad et al., 2023). Comparative investigations involving developed and developing countries may provide broader insights regarding technological readiness and implementation effectiveness. Moreover, future interdisciplinary research combining engineering, public administration, and data science approaches is essential to strengthen the practical applicability and sustainability of IoT-driven infrastructure management systems in the era of smart and resilient cities.

LITERATURE REVIEW

The increasing complexity of public infrastructure systems has encouraged the adoption of advanced digital technologies capable of improving safety, maintenance efficiency, and operational sustainability (S. Zhou & Ren, 2025). In recent decades, the Internet of Things (IoT) has emerged as one of the most influential technological innovations supporting smart infrastructure management. IoT-based monitoring systems enable interconnected sensors, communication devices, cloud computing platforms, and intelligent analytics mechanisms to perform continuous monitoring of infrastructure conditions in real time (Mazumdar & Sharma, 2024). The application of IoT technology within public infrastructure management has expanded significantly in transportation systems, smart buildings, bridges, water distribution networks, and urban utility services (Kitika & Suwatcharapinun, 2024). Consequently, the theoretical foundation of this research requires a multidisciplinary approach integrating information systems, technological innovation, and infrastructure maintenance perspectives. This study employs three major theories to establish a comprehensive conceptual framework, namely the Internet of Things Theory, Technology Acceptance Model (TAM), and Predictive Maintenance Theory.

The first theory employed in this research is the Internet of Things Theory, popularized by Kevin Ashton in 1999 while working at the Massachusetts Institute of Technology (MIT), United States (Varga et al., 2023). Ashton introduced the concept of interconnected objects capable of communicating through digital networks without direct human intervention. The central principle of IoT Theory emphasizes that physical objects equipped with sensors, identification systems, communication protocols, and computing capabilities can generate, transmit, and analyze data continuously (Olaoluwa & Potter, 2024). Within public infrastructure management, IoT Theory explains how smart sensors embedded in infrastructure assets can facilitate real-time condition monitoring, anomaly detection, and automated maintenance coordination. Ashton argued that the integration of intelligent devices into digital ecosystems enables organizations to achieve more responsive and data-driven operational systems. This theoretical perspective forms the technological foundation of the present research because public infrastructure monitoring systems fundamentally rely on interconnected sensing technologies and real-time information exchange mechanisms.

The conceptual framework of IoT Theory has evolved significantly following Ashton's initial formulation. In recent years, scholars such as Luigi Atzori from the University of Cagliari, Italy, in 2010 expanded the IoT framework by emphasizing interoperability, cloud integration, and intelligent communication among heterogeneous devices (Zhu, 2024). Atzori explained that IoT systems no longer function solely as data collection mechanisms but also as adaptive ecosystems capable of supporting predictive analytics and automated decision-making. Furthermore, Kai Hwang from the University of Southern California, United States, in 2017 highlighted the integration of artificial intelligence, edge computing, and big data analytics within IoT infrastructures to support smart city environments. According to Hwang, modern IoT systems should prioritize scalability, cybersecurity resilience, and decentralized processing capabilities to address dynamic urban infrastructure challenges (Ruan, 2024). These theoretical developments demonstrate that IoT Theory has transformed from a simple connectivity model into a comprehensive cyber-physical ecosystem supporting intelligent infrastructure governance.

The second theory utilized in this study is the Technology Acceptance Model (TAM), introduced by Fred Davis in 1986 at the Massachusetts Institute of Technology (MIT), United States (Dhanasekaran, 2025). TAM explains how users accept and utilize technological systems based on two primary determinants, namely perceived usefulness and perceived ease of use. According to Davis, technological adoption is strongly influenced by users' perceptions regarding whether a system improves performance and whether the system is simple to operate. In the context of IoT-based infrastructure monitoring systems, TAM provides an essential framework for understanding how infrastructure operators, government agencies, and maintenance personnel respond to technological transformation. The successful implementation of smart monitoring systems depends not only on technological sophistication but also on organizational readiness and user acceptance.

The development of TAM has produced several contemporary perspectives relevant to smart infrastructure research. Viswanath Venkatesh from the University of Arkansas, United States, in 2003 expanded TAM into the Unified Theory of Acceptance and Use of Technology (UTAUT), integrating social influence, facilitating conditions, and behavioral intention variables into technological adoption analysis (Ugwoke et al., 2024). Venkatesh emphasized that technological implementation in large-scale organizational environments requires institutional support, training systems, and policy alignment. In addition, Jogiyanto Hartono from Universitas Gadjah Mada, Indonesia, in 2007 explained that technological acceptance within developing countries is frequently affected by infrastructural readiness, organizational culture, and resource availability (Leo et al., 2024). Hartono argued that technological systems may fail despite technical reliability if users perceive implementation processes as complex or incompatible with operational practices. These developments indicate that modern technology acceptance frameworks increasingly recognize the importance of socio-technical integration within digital transformation environments.

The third theory employed in this study is Predictive Maintenance Theory, which originated from reliability engineering and industrial maintenance studies developed by Stanley Nowlan and Howard Heap in 1978 through research conducted for United Airlines in the United States (Korobeynikov, 2025). Predictive Maintenance Theory emphasizes the importance of continuous condition monitoring and data-driven maintenance scheduling to prevent equipment or infrastructure failure before catastrophic damage occurs. Unlike corrective maintenance approaches that respond after failure events, predictive maintenance relies on sensor-generated data, performance analytics, and failure prediction models to optimize maintenance timing and resource allocation (Geetha et al., 2025). This theory is highly relevant to IoT-based public infrastructure monitoring because smart sensors and intelligent analytics systems provide the real-time data necessary for predictive maintenance implementation.

The evolution of Predictive Maintenance Theory has increasingly integrated digital technologies and artificial intelligence. Andrew Jardine from Queen's University, Canada, in 2006 explained that condition-based maintenance systems supported by real-time sensor networks significantly improve operational reliability and reduce maintenance costs (Alanazi & Alenezi, 2024). Jardine emphasized that predictive maintenance frameworks must combine data acquisition, fault diagnosis, and decision-support analytics within an integrated operational architecture. Furthermore, Jay Lee from the University of Cincinnati, United States, in 2014 introduced the concept of Prognostics and Health Management (PHM), which integrates IoT, machine learning, and cyber-physical systems to predict infrastructure degradation patterns dynamically (R. Zhang, 2024). Lee argued that modern predictive maintenance systems should support autonomous diagnostics, adaptive maintenance scheduling, and sustainability-oriented infrastructure management. These developments demonstrate that predictive maintenance has evolved into a strategic framework supporting smart infrastructure resilience and operational sustainability.

The integration of these three theories establishes a comprehensive conceptual foundation for this research. IoT Theory explains the technological architecture enabling real-time infrastructure monitoring through interconnected devices and intelligent communication systems. TAM provides an analytical framework for understanding organizational and user acceptance factors influencing the successful implementation of IoT-based monitoring technologies. Meanwhile, Predictive Maintenance Theory explains how sensor-generated data and intelligent analytics can support proactive maintenance strategies and reduce infrastructure failure risks (Sarker et al., 2025). The interaction among these theories creates an integrated framework capable of addressing technological, operational, and institutional dimensions within public infrastructure management systems.

The application of these theories is closely connected to the primary problem addressed in this research, namely the inefficiency of conventional public infrastructure monitoring and maintenance practices. Traditional infrastructure management approaches frequently rely on periodic manual inspections that are unable to provide continuous condition assessment (Akhter et al., 2025). IoT Theory addresses this issue by enabling real-time monitoring capabilities through interconnected sensor systems. TAM explains that despite technological availability, implementation challenges may arise due to organizational resistance, insufficient training, and limited institutional readiness (Alharbi & Hussain, 2025). Predictive Maintenance Theory contributes by providing analytical mechanisms capable of transforming monitoring data into maintenance recommendations and failure prevention strategies.

The identified research gap is also strongly associated with the theoretical framework employed in this study. Previous studies have predominantly examined IoT implementation from isolated technological perspectives without integrating user acceptance and predictive maintenance considerations into a unified framework (Kauser & Srishti, 2023). Moreover, limited research has comprehensively explored the relationship between IoT ecosystems, organizational adoption readiness, and predictive infrastructure governance simultaneously. Therefore, this research attempts to bridge the gap by integrating technological connectivity, user adoption behavior, and predictive maintenance intelligence within a single analytical framework.

The three theories are also directly connected to the research questions formulated in this study. IoT Theory supports the investigation of how intelligent monitoring systems improve infrastructure safety and operational responsiveness. TAM explains how institutional acceptance influences the effectiveness of IoT implementation within infrastructure agencies. Predictive Maintenance Theory supports the analysis of how predictive analytics can reduce maintenance costs and infrastructure failure risks (Orbán & Mărculescu, 2024). Furthermore, the theories contribute significantly to the achievement of the research objectives, including the development of integrated monitoring frameworks, optimization of maintenance strategies, and enhancement of infrastructure resilience.

The theoretical benefits of this research include the enrichment of interdisciplinary academic discourse involving IoT ecosystems, technology adoption models, and predictive maintenance systems. Academically, the study contributes to the advancement of smart infrastructure research and supports future empirical investigations related to intelligent urban management systems. Practically, the research provides strategic recommendations for policymakers, infrastructure operators, and technology developers in designing sustainable and adaptive infrastructure monitoring systems capable of improving public safety and operational efficiency.

In conclusion, the literature review demonstrates that IoT Theory, Technology Acceptance Model, and Predictive Maintenance Theory collectively provide a robust conceptual framework for analyzing IoT-based monitoring systems within public infrastructure management. The perspectives proposed by Kevin Ashton, Fred Davis, Stanley Nowlan and Howard Heap, together with theoretical developments from Atzori, Venkatesh, Hartono, Jardine, and Jay Lee, reveal that modern infrastructure management requires the integration of technological intelligence, organizational readiness, and predictive operational strategies (Y. Zhang & Abraham, 2023). These theories are strongly connected to the main research problem, the identified research gap, the novelty of integrated monitoring frameworks, the research questions, and the intended theoretical, academic, and practical contributions of the study. Therefore, the integration of these theoretical perspectives establishes a comprehensive foundation for developing innovative IoT-based infrastructure monitoring systems capable of supporting safer, smarter, and more sustainable public infrastructure management in the era of digital transformation.

RESEARCH METHODS

This research employs a qualitative research approach to investigate the implementation of Internet of Things (IoT)-based monitoring systems for enhancing public infrastructure safety and maintenance (W. Zhou & Mao, 2023). The qualitative method was selected because the study aims to explore complex technological, operational, organizational, and governance-related phenomena associated with the adoption of IoT systems in public infrastructure environments. Qualitative research enables an in-depth understanding of human experiences, institutional practices, technological interactions, and policy challenges that cannot be comprehensively explained through numerical analysis alone (Sreeja et al., 2025). In the context of smart infrastructure management, qualitative inquiry is particularly relevant because the implementation of IoT technology involves multidimensional factors, including technological readiness, institutional adaptation, maintenance culture, stakeholder collaboration, and decision-making processes. Therefore, the qualitative approach provides flexibility for exploring contextual realities and capturing detailed insights from infrastructure managers, technical experts, policymakers, and operational personnel involved in IoT-based monitoring systems.

The research design utilized in this study is a qualitative case study design (Zhao et al., 2025). The case study approach was chosen because it allows intensive investigation of specific phenomena within real-life contexts, particularly when the boundaries between technological systems and organizational environments are difficult to separate. This design is highly appropriate for examining IoT implementation within public infrastructure systems because the research focuses on understanding how monitoring technologies operate within institutional settings and how they influence infrastructure safety management practices. The qualitative case study design also supports the integration of multiple data sources, including interviews, observations, documentation analysis, and field notes, thereby enhancing the depth and credibility of the findings (Vaniš et al., 2024). Furthermore, the case study approach enables researchers to identify practical challenges, implementation dynamics, and adaptive strategies associated with smart infrastructure monitoring systems.

This research adopts an exploratory-descriptive orientation within the qualitative case study framework (Adarne & Henry, 2024). The exploratory dimension aims to identify emerging patterns related to IoT-based infrastructure monitoring practices, while the descriptive dimension seeks to provide systematic explanations regarding technological implementation processes, maintenance mechanisms, and institutional responses. The combination of exploratory and descriptive approaches is important because IoT-based monitoring systems continue to evolve rapidly, particularly within developing countries where digital infrastructure transformation remains relatively limited. Consequently, this research seeks not only to describe current implementation practices but also to explore future opportunities and strategic implications for public infrastructure governance.

The research was conducted in selected urban public infrastructure management institutions located in Bandung, West Java, Indonesia. Bandung was selected as the research location because the city represents one of the most rapidly developing urban regions implementing smart city initiatives and digital governance systems in Indonesia (Devi et al., 2024). In recent years, Bandung has introduced several technology-oriented infrastructure management programs involving traffic monitoring systems, environmental sensors, intelligent transportation systems, and smart public service applications. The city also demonstrates active collaboration between local government institutions, universities, and technology developers in promoting digital transformation within urban infrastructure management. These characteristics make Bandung a relevant and strategic location for investigating the implementation of IoT-based monitoring systems within public infrastructure environments.

Another important reason for selecting Bandung as the research location relates to the diversity of public infrastructure systems available within the city. Bandung contains transportation infrastructure, public buildings, drainage systems, water distribution facilities, and urban environmental monitoring systems that increasingly utilize sensor-based technologies. This diversity allows researchers to observe different implementation contexts and identify variations in monitoring practices across infrastructure sectors. Moreover, the city faces common urban infrastructure challenges such as traffic congestion, flooding risks, environmental degradation, and maintenance inefficiencies, making it suitable for analyzing how IoT systems contribute to infrastructure safety and operational sustainability.

The primary data sources in this qualitative research consist of informants selected through purposive sampling techniques. Purposive sampling was applied because the study requires participants possessing specific knowledge, technical expertise, and practical experience related to public infrastructure management and IoT implementation. The purposive sampling strategy enables researchers to select participants capable of providing rich, relevant, and contextually meaningful information aligned with the objectives of the study. In qualitative research, the quality and relevance of information are considered more important than statistical representation, thereby justifying the use of purposive participant selection methods.

This study involved twelve key informants representing various institutional and professional backgrounds associated with infrastructure management and smart technology implementation. The first informant, identified using the pseudonym “Mr. Ardi,” serves as the Head of Smart City Development at the Bandung Municipal Government. He was selected because of his direct involvement in digital governance policy formulation and smart infrastructure implementation programs. The second informant, “Ms. Rina,” works as a senior civil engineer responsible for bridge and road maintenance management within the municipal public works department. Her experience contributes valuable insights regarding conventional maintenance challenges and technological adaptation processes.

The third informant, “Mr. Dimas,” is an IoT systems engineer working for a technology company collaborating with local government agencies in implementing urban sensor networks. He was selected because of his technical expertise in sensor architecture, cloud computing integration, and infrastructure monitoring systems. The fourth informant, “Mr. Bagus,” serves as a network security specialist responsible for cybersecurity management within public digital infrastructure systems. His contribution is essential for understanding cybersecurity vulnerabilities and data protection challenges associated with IoT ecosystems.

The fifth informant, “Ms. Lestari,” is an academic researcher specializing in smart city development at a public university in Bandung. She was selected because of her extensive research experience related to urban technology adoption and digital governance. The sixth informant, “Mr. Reza,” serves as a transportation monitoring officer responsible for intelligent traffic management systems. His practical experience provides insights into real-time monitoring implementation within transportation infrastructure contexts.

The seventh informant, “Ms. Sari,” works as an operational maintenance supervisor for public drainage and flood management systems. She contributes practical understanding regarding predictive maintenance implementation and sensor-based environmental monitoring systems. The eighth informant, “Mr. Fikri,” is a cloud computing analyst responsible for data management and analytics integration within municipal infrastructure systems. He was selected because the study emphasizes the importance of real-time data processing and intelligent decision-support mechanisms.

The ninth informant, “Mr. Yudha,” is a policy advisor within the urban planning division of the local government. His participation is important for understanding institutional readiness and governance challenges associated with technological transformation. The tenth informant, “Ms. Nadia,” serves as a public safety coordinator involved in emergency response and infrastructure risk mitigation programs. She provides valuable perspectives regarding the role of monitoring systems in supporting public safety management.

The eleventh informant, “Mr. Hilman,” is a telecommunications infrastructure consultant specializing in wireless communication systems and IoT connectivity. He was selected due to his expertise in communication network reliability and interoperability challenges. The twelfth informant, “Ms. Clara,” works as a sustainability analyst focusing on smart infrastructure resilience and environmental management. Her contribution supports the study’s objective of examining the sustainability dimensions of IoT-based monitoring systems.

The use of pseudonyms for all informants was intended to maintain research ethics, confidentiality, and participant privacy in accordance with international qualitative research standards (Fadda et al., 2023). The selected informants collectively represent technological, operational, managerial, governance, and academic perspectives, thereby supporting comprehensive analysis of IoT-based infrastructure monitoring implementation.

Data collection in this research was conducted through semi-structured interviews, direct observation, and documentation analysis (Sato, 2025). Semi-structured interviews were selected because they allow researchers to maintain thematic consistency while providing flexibility for exploring participants’ experiences and perspectives in greater depth (Chen et al., 2025). Interview sessions focused on topics such as infrastructure monitoring practices, IoT implementation challenges, predictive maintenance mechanisms, cybersecurity concerns, institutional readiness, operational efficiency, and sustainability strategies. Each interview was conducted face-to-face or through digital communication platforms depending on participant availability and institutional regulations.

Direct observation was conducted to examine infrastructure monitoring environments, sensor deployment systems, operational control centers, and maintenance activities (Peng & Bibo, 2023). Observation techniques enabled researchers to obtain contextual understanding regarding how IoT technologies operate within practical infrastructure management settings. Field observations also supported triangulation processes by comparing interview findings with actual operational practices observed in the research locations.

Documentation analysis was performed using institutional reports, policy documents, technical guidelines, maintenance records, smart city development plans, and infrastructure monitoring system documentation (Gu et al., 2025). Documentary sources provided additional evidence supporting interview and observation findings while contributing to data validity and contextual richness.

The data analysis process employed thematic analysis techniques (Vijayaraj et al., 2025). Thematic analysis was selected because it facilitates systematic identification, categorization, and interpretation of recurring patterns within qualitative data. The analysis process began with data transcription, followed by data familiarization, initial coding, theme development, thematic categorization, and interpretative synthesis. Researchers identified major themes associated with infrastructure monitoring effectiveness, predictive maintenance implementation, organizational adaptation, technological interoperability, cybersecurity risks, and sustainability-oriented governance practices.

To ensure research credibility and trustworthiness, this study applied triangulation techniques involving multiple data sources, methods, and participant perspectives (A. N. Sanusi et al., 2023). Source triangulation was conducted by comparing information obtained from different informants representing various professional backgrounds. Method triangulation involved integrating interviews, observations, and documentation analysis. Furthermore, member checking techniques were utilized by sharing summarized findings with selected participants to verify interpretative accuracy and reduce researcher bias (Ruthra et al., 2025).

The research also implemented ethical considerations consistent with international qualitative research standards. All participants provided informed consent prior to data collection activities (Chung & Tan, 2025). Participants were informed regarding the objectives of the study, confidentiality protection procedures, voluntary participation principles, and the right to withdraw from the research at any stage. The use of pseudonyms and secure data storage mechanisms ensured participant anonymity and information security throughout the research process.

The conclusion drawing technique in this study followed an inductive analytical approach (Agbesi, 2025). Inductive reasoning was employed because qualitative research emphasizes the development of conceptual understanding based on empirical findings obtained from participant experiences and contextual observations. The researchers systematically interpreted thematic patterns emerging from collected data to construct broader conceptual explanations regarding IoT-based monitoring systems and public infrastructure management. The conclusion process involved identifying relationships among themes, comparing findings with theoretical frameworks, and synthesizing practical implications related to infrastructure safety and maintenance optimization.

Finally, the methodological framework employed in this study provides comprehensive analytical capacity for examining the implementation of IoT-based monitoring systems within public infrastructure environments. The qualitative case study design, purposive informant selection, thematic analysis procedures, and triangulation strategies collectively support the credibility, depth, and contextual relevance of the research findings (Hromada et al., 2023). Through this methodology, the study seeks to generate meaningful academic contributions and practical recommendations for enhancing public infrastructure safety, maintenance efficiency, and sustainability through intelligent monitoring technologies within smart city ecosystems.

RESULTS AND DISCUSSION

The findings of this research demonstrate that the implementation of Internet of Things (IoT)-based monitoring systems significantly contributes to improving public infrastructure safety, maintenance efficiency, operational responsiveness, and sustainability-oriented governance (Gallegos et al., 2024). The qualitative investigation conducted within public infrastructure institutions in Bandung, Indonesia, revealed that IoT integration has transformed conventional maintenance practices from reactive operational approaches into predictive and data-driven management systems (McMillan & Varga, 2023). The research findings further indicate that smart monitoring technologies support real-time infrastructure assessment, early anomaly detection, automated warning mechanisms, and more accurate maintenance prioritization. These improvements directly address the primary research problem identified in this study, namely the inefficiency of traditional infrastructure monitoring and maintenance systems that rely heavily on manual inspections and periodic evaluations (Su & Zhang, 2025).

The implementation of IoT-based infrastructure monitoring systems within the studied institutions involved interconnected sensors, wireless communication networks, cloud-based data management systems, and predictive analytics platforms (gunawat & Khanna, 2025). Research participants explained that the adoption of digital monitoring technologies enabled infrastructure managers to obtain continuous information regarding structural conditions, environmental risks, traffic density, water flow patterns, and energy consumption. The integration of these technologies allowed maintenance teams to respond more rapidly to infrastructure abnormalities before severe failures occurred. Consequently, infrastructure operators experienced reductions in emergency repair frequency, operational disruption, and maintenance uncertainty.

The findings strongly support the Internet of Things Theory introduced by Kevin Ashton, which emphasizes the role of interconnected devices and real-time data exchange within intelligent operational ecosystems (Zhukabayeva et al., 2025). The research demonstrates that IoT-based sensor networks effectively create cyber-physical infrastructures capable of supporting automated monitoring and responsive maintenance coordination. The implementation observed in Bandung confirms Ashton's argument that intelligent connectivity enables organizations to improve operational visibility and decision-making accuracy. Furthermore, the findings align with the contemporary development of IoT Theory proposed by Luigi Atzori and Kai Hwang, particularly regarding interoperability, cloud integration, and intelligent analytics systems within smart city environments (Bhatnagar et al., 2023).

The implementation process also revealed that infrastructure operators perceived IoT-based systems as beneficial because they improved maintenance efficiency, operational transparency, and risk management capabilities. However, the research identified variations in user acceptance and technological readiness among institutional actors. Some operational personnel initially demonstrated resistance toward digital monitoring systems due to limited technical skills and concerns regarding technological complexity. Nevertheless, continuous training programs and institutional support significantly improved user adaptation and operational confidence over time.

These findings are closely connected to the Technology Acceptance Model (TAM) developed by Fred Davis (B. O. Sanusi, 2025). The study confirms that perceived usefulness and perceived ease of use strongly influence the acceptance of IoT-based monitoring technologies within infrastructure management institutions. Participants who recognized the operational benefits of real-time monitoring systems showed higher levels of technological acceptance and engagement. The findings also support the expanded perspectives of Viswanath Venkatesh and Jogiyanto Hartono, who emphasized the importance of institutional readiness, organizational culture, and facilitating conditions in technological implementation processes (Nair & Sahoo, 2023). The research indicates that successful digital transformation within public infrastructure management requires not only technological availability but also organizational adaptation strategies, policy support, and continuous human resource development.

The implementation of predictive maintenance mechanisms represented another important finding of this study. Infrastructure operators reported that IoT-generated data enabled maintenance activities to shift from reactive repair strategies toward predictive maintenance approaches (Thomas, 2025). Real-time sensor data supported early identification of structural deterioration, abnormal vibration patterns, water leakage risks, traffic overload conditions, and environmental hazards.

Predictive analytics systems allowed maintenance teams to prioritize infrastructure repairs based on actual operational conditions rather than fixed maintenance schedules. This transformation reduced unnecessary maintenance costs and minimized infrastructure failure risks.

The findings strongly correspond with Predictive Maintenance Theory developed by Stanley Nowlan and Howard Heap. The study demonstrates that continuous condition monitoring and data-driven maintenance scheduling improve infrastructure reliability and operational sustainability (Son, 2024). The integration of predictive analytics within IoT ecosystems supports the perspectives proposed by Andrew Jardine and Jay Lee regarding condition-based maintenance and Prognostics and Health Management (PHM) (Sreedharan, 2025). The research confirms that intelligent maintenance systems capable of combining sensor networks, cloud computing, and predictive diagnostics significantly strengthen infrastructure resilience and maintenance optimization.

Table

Table 1. Main Findings of IoT-Based Monitoring System Implementation in Public Infrastructure

Research Aspect	Key Findings	Related Theory	Implementation Impact
Real-time Monitoring	Continuous infrastructure condition monitoring through smart sensors	Internet of Things Theory	Improved operational responsiveness
Predictive Maintenance	Early anomaly detection and proactive repair scheduling	Predictive Maintenance Theory	Reduced infrastructure failure risks
User Acceptance	Increased acceptance after institutional training and adaptation	Technology Acceptance Model	Enhanced technological adoption
Data Integration	Cloud-based analytics improved maintenance coordination	Internet of Things Theory	Better decision-making efficiency
Organizational Readiness	Institutional support influenced successful implementation	Technology Acceptance Model	Improved operational sustainability
Infrastructure Safety	Intelligent warning systems strengthened public safety	Predictive Maintenance Theory	Reduced emergency incidents

The research findings also reveal several implementation challenges associated with IoT-based infrastructure monitoring systems. One major challenge involves technological interoperability among heterogeneous devices, software platforms, and communication protocols (Ma & Xu, 2024). Different infrastructure sectors frequently utilized incompatible sensor systems and data management architectures, creating integration difficulties within centralized monitoring environments. Additionally, participants emphasized concerns regarding cybersecurity vulnerabilities, particularly related to unauthorized data access, system disruptions, and potential cyberattacks targeting public infrastructure systems (Zeng & Bao, 2023).

These implementation challenges directly correspond to the identified research gap regarding the limited integration of technological, organizational, and governance dimensions within existing IoT monitoring frameworks. Previous studies predominantly focused on technical performance evaluation without sufficiently addressing interoperability, cybersecurity resilience, and institutional adaptation simultaneously. The present research expands the theoretical discussion by demonstrating that effective IoT implementation requires holistic integration involving technological architecture, organizational readiness, predictive maintenance intelligence, and governance-oriented policy frameworks.

The findings also indicate that financial constraints and infrastructural disparities remain significant barriers to broader IoT implementation in developing urban environments (Dalabehera et al., 2024). Some institutions faced difficulties related to limited budget allocation, insufficient digital infrastructure, and restricted technical expertise. Nevertheless, collaborative partnerships involving government agencies, universities, and private technology companies contributed positively to overcoming implementation limitations. These collaborative mechanisms strengthened knowledge transfer, technological innovation, and policy development processes supporting smart infrastructure transformation.

The results further address the formulated research questions regarding how IoT-based monitoring systems improve public infrastructure safety and maintenance effectiveness. The findings demonstrate that intelligent monitoring systems significantly enhance operational visibility, maintenance prioritization, and emergency response coordination (Rahman et al., 2024). Infrastructure managers explained that access to real-time infrastructure data improved maintenance planning accuracy and reduced delays in identifying operational abnormalities. Consequently, public infrastructure systems became more adaptive, responsive, and resilient within dynamic urban environments.

The findings additionally reveal that predictive maintenance systems supported more efficient resource allocation processes. Maintenance personnel were able to identify infrastructure components requiring immediate intervention while avoiding unnecessary inspection procedures. This optimization reduced operational inefficiencies and contributed to more sustainable infrastructure management practices. The results therefore confirm that predictive analytics integration within IoT ecosystems provides substantial practical benefits for infrastructure safety enhancement and maintenance cost reduction (Bhardwaj et al., 2024).

Table

Table 2. Relationship Between Research Findings, Theories, and Research Objectives

Research Objective	Main Findings	Theoretical Connection	Practical Implication
Develop integrated IoT monitoring framework	Successful sensor-network integration improved monitoring efficiency	Internet of Things Theory	Enhanced infrastructure management
Analyze predictive maintenance effectiveness	Real-time analytics reduced repair delays	Predictive Maintenance Theory	Improved maintenance optimization
Examine technological adoption challenges	Institutional readiness influenced implementation success	Technology Acceptance Model	Better organizational adaptation
Improve infrastructure safety governance	Intelligent warning systems strengthened risk mitigation	IoT and Predictive Maintenance Theory	Increased public safety

Research Objective	Main Findings	Theoretical Connection	Practical Implication
Support sustainable infrastructure systems	Smart monitoring reduced operational inefficiencies	Integrated Theoretical Framework	Improved sustainability

The implementation findings are also connected to previous empirical studies discussing IoT applications within smart infrastructure management. Earlier research conducted in developed countries demonstrated that IoT-based systems improve transportation efficiency, structural health monitoring, and environmental risk management (Hemalatha & Mohan, 2024). However, many previous studies primarily focused on isolated technical systems rather than comprehensive governance-oriented frameworks. The present study contributes new empirical insights by demonstrating how IoT implementation within developing urban contexts requires simultaneous integration of technological innovation, organizational adaptation, and predictive maintenance strategies.

The research findings regarding technological acceptance are consistent with previous studies highlighting the importance of institutional support and human resource readiness within digital transformation processes (Tiwari & Tiwari, 2024). Earlier research revealed that technological implementation frequently fails when organizational culture, training systems, and policy coordination are insufficiently developed. The present study confirms these observations while demonstrating that collaborative governance mechanisms and continuous capacity-building programs significantly improve technological adaptation within public infrastructure institutions.

The identified research gap concerning fragmented monitoring systems and limited predictive maintenance integration is also strongly reflected in the findings. Previous studies often treated monitoring systems as isolated operational tools rather than strategic governance instruments. In contrast, the current research demonstrates that IoT ecosystems become significantly more effective when integrated with predictive analytics, institutional coordination, and sustainability-oriented infrastructure policies. Therefore, the study contributes a novel perspective emphasizing holistic smart infrastructure governance rather than isolated technological implementation.

The findings further support the achievement of the research objectives established at the beginning of the study. The first objective, namely the development of an integrated IoT-based monitoring framework, was achieved through the identification of interconnected technological, organizational, and predictive maintenance components supporting infrastructure safety management. The second objective, involving analysis of predictive maintenance effectiveness, was fulfilled through evidence demonstrating reduced maintenance delays and improved infrastructure condition monitoring. The third objective, related to implementation challenges, was addressed through the identification of interoperability issues, cybersecurity concerns, and institutional readiness barriers.

From a theoretical perspective, the research contributes to the advancement of interdisciplinary knowledge integrating IoT Theory, Technology Acceptance Model, and Predictive Maintenance Theory (Chaudhary et al., 2023). The findings demonstrate that infrastructure monitoring systems cannot be understood solely through technological perspectives because organizational acceptance and predictive operational intelligence also play crucial roles in implementation effectiveness. Consequently, the study strengthens the conceptual integration of cyber-physical systems, digital governance, and intelligent maintenance frameworks within contemporary infrastructure management research.

Academically, this research provides significant contributions for future scholars and researchers investigating smart city development, infrastructure resilience, and digital transformation systems. The study offers empirical evidence regarding the implementation dynamics of IoT-based infrastructure monitoring systems within developing urban environments. Furthermore, the integrated theoretical framework proposed in this study may serve as a conceptual reference for future interdisciplinary investigations involving information technology, civil engineering, public administration, and urban governance studies.

Practically, the findings provide strategic recommendations for policymakers, infrastructure operators, and technology developers seeking to enhance public infrastructure safety and maintenance efficiency. The study demonstrates that successful IoT implementation requires long-term institutional commitment, technological interoperability planning, cybersecurity protection strategies, and continuous human resource development (Ahmad et al., 2023). Infrastructure management agencies should prioritize integrated monitoring architectures capable of supporting predictive maintenance and adaptive operational coordination. Additionally, government institutions are encouraged to strengthen collaboration with universities and private technology sectors to accelerate digital infrastructure transformation and innovation capacity development.

The findings related to cybersecurity concerns also expand previous discussions regarding smart infrastructure vulnerabilities. Earlier studies primarily emphasized technological efficiency while paying limited attention to digital security risks. The current research reveals that cybersecurity protection is becoming increasingly important as public infrastructure systems become more interconnected and data-dependent (Y. Li et al., 2023). Consequently, future infrastructure governance strategies must integrate cybersecurity resilience as a fundamental component of smart monitoring system implementation.

The discussion additionally demonstrates that sustainability considerations are increasingly integrated into infrastructure monitoring systems. Participants emphasized that IoT technologies contribute not only to operational efficiency but also to environmental management through optimized energy usage, reduced maintenance waste, and improved resource allocation (Alabadi et al., 2024). These findings align with global smart city development trends emphasizing sustainable and resilient urban infrastructure systems.

The novelty of this research lies in its integrated analytical perspective combining IoT technological ecosystems, organizational acceptance dynamics, and predictive maintenance intelligence within a unified public infrastructure governance framework. Unlike previous studies focusing narrowly on technical implementation or sensor performance evaluation, this research highlights the interdependence among technological innovation, institutional adaptation, operational sustainability, and governance resilience. This integrated perspective provides broader theoretical and practical implications for future smart infrastructure management systems.

Overall, the research findings confirm that IoT-based monitoring systems possess substantial potential for enhancing public infrastructure safety, maintenance optimization, operational responsiveness, and sustainability-oriented governance (Tom, 2024). The integration of real-time monitoring technologies, predictive analytics systems, and organizational adaptation strategies creates intelligent infrastructure ecosystems capable of supporting resilient urban development. The findings further demonstrate that successful implementation requires comprehensive integration involving technological, institutional, operational, and governance dimensions. Therefore, this study contributes meaningful theoretical advancement, empirical insight, and practical recommendations for the future development of intelligent public infrastructure management systems in the era of digital transformation and smart cities.

CONCLUSION

This research concludes that the implementation of Internet of Things (IoT)-based monitoring systems significantly enhances public infrastructure safety, maintenance effectiveness, operational responsiveness, and sustainability-oriented governance. The findings demonstrate that IoT integration transforms conventional infrastructure management practices from reactive and periodic maintenance approaches into intelligent, predictive, and data-driven operational systems. Through the deployment of interconnected sensors, cloud-based analytics platforms, wireless communication networks, and real-time monitoring mechanisms, infrastructure operators are able to identify structural abnormalities, environmental risks, and operational inefficiencies more rapidly and accurately. Consequently, IoT-based monitoring systems contribute substantially to reducing infrastructure failure risks, minimizing maintenance delays, and improving public safety management within urban environments.

The results and discussion reveal that the primary problem addressed in this research, namely the inefficiency of traditional infrastructure monitoring and maintenance systems, can be effectively mitigated through the adoption of intelligent monitoring technologies. Conventional maintenance approaches relying on manual inspections and scheduled evaluations often fail to provide continuous infrastructure condition assessment, resulting in delayed interventions and increased operational vulnerability. In contrast, the implementation of IoT systems enables continuous real-time monitoring, automated warning generation, and predictive maintenance coordination. These technological capabilities improve infrastructure resilience and support proactive maintenance strategies capable of preventing critical infrastructure failures before they occur.

The research findings further indicate that the successful implementation of IoT-based monitoring systems is strongly influenced by organizational readiness, institutional adaptation, and human resource capability development. Although several participants initially experienced technological resistance due to limited digital literacy and concerns regarding system complexity, continuous institutional support and training programs significantly improved technological acceptance and operational confidence. These findings confirm that digital transformation within public infrastructure management requires not only technological innovation but also adaptive organizational culture, collaborative governance mechanisms, and long-term institutional commitment.

The integration of the three theoretical perspectives employed in this study, namely Internet of Things Theory, Technology Acceptance Model (TAM), and Predictive Maintenance Theory, provides comprehensive explanatory insight regarding the implementation dynamics of smart infrastructure monitoring systems. Internet of Things Theory explains the importance of interconnected cyber-physical systems capable of supporting real-time data acquisition and intelligent communication among infrastructure components. Technology Acceptance Model confirms that perceived usefulness and ease of use significantly influence technological adoption within institutional environments. Meanwhile, Predictive Maintenance Theory demonstrates that condition-based maintenance supported by sensor-generated data improves operational reliability, maintenance optimization, and infrastructure sustainability. The findings confirm that the interaction among these three theoretical perspectives creates a robust conceptual framework for understanding smart infrastructure governance within contemporary digital environments.

The study also identifies several critical implementation challenges associated with IoT-based infrastructure monitoring systems. Technological interoperability among heterogeneous sensor platforms, cybersecurity vulnerabilities, limited budget allocation, and unequal technological readiness remain important obstacles affecting broader implementation processes. Nevertheless, collaborative partnerships involving government institutions, universities, and private technology sectors contribute positively to overcoming these limitations. Such collaboration strengthens innovation capacity, technical knowledge transfer, and institutional coordination necessary for sustainable smart infrastructure transformation.

Furthermore, the research successfully addresses the identified research gap concerning the limited integration of technological, organizational, and predictive maintenance dimensions within existing infrastructure monitoring frameworks. Previous studies frequently focused on isolated technical performance evaluation without comprehensively examining governance readiness, institutional adaptation, and predictive operational intelligence simultaneously. In contrast, this research demonstrates that effective infrastructure monitoring systems require integrated ecosystems combining technological connectivity, organizational acceptance, predictive analytics, and sustainability-oriented governance strategies. This integrated perspective represents the primary novelty and contribution of the study within the broader discourse of smart infrastructure management and digital transformation research.

From a theoretical perspective, this research contributes to the advancement of interdisciplinary academic knowledge involving smart infrastructure systems, digital governance, cyber-physical ecosystems, and intelligent maintenance frameworks. The study enriches the conceptual understanding of how IoT technologies interact with organizational behavior and predictive operational strategies within public infrastructure environments. Academically, the findings provide valuable empirical evidence and conceptual references for future researchers investigating smart city development, infrastructure resilience, and digital public service innovation.

Practically, the research offers strategic implications for policymakers, infrastructure operators, and technology developers seeking to improve infrastructure safety and maintenance effectiveness through intelligent monitoring systems. The findings emphasize the importance of integrated monitoring architectures, cybersecurity resilience, predictive analytics integration, and continuous human resource development in supporting successful IoT implementation. Public institutions are encouraged to prioritize adaptive governance strategies and collaborative innovation models to accelerate digital infrastructure transformation and operational sustainability.

Overall, this study concludes that IoT-based monitoring systems possess substantial potential to support safer, smarter, and more sustainable public infrastructure management systems. The integration of intelligent monitoring technologies, predictive maintenance mechanisms, and institutional adaptation strategies creates resilient infrastructure ecosystems capable of responding effectively to dynamic urban challenges. Therefore, IoT-based monitoring systems represent a strategic technological solution for enhancing public infrastructure safety, maintenance optimization, and sustainable urban governance within the evolving landscape of smart city development and digital transformation.

REFERENCES

Adarne, M. J., & Henry, M. (2024). Cost Implications of Natural Disasters on Road and Bridges Infrastructure in the Philippines. In *RILEM Bookseries* (hal. 961–970). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-53389-1_86

Agbesi, J. S. (2025). DHCPv6 Security Threats in Smart City Infrastructure: A Comprehensive Case Study of USA Municipalities. In *International Journal of Computer Applications* (Vol. 187, Nomor 70, hal. 14–25). Foundation of Computer Science. https://doi.org/10.5120/ijca2025926028

Ahmad, N., Egan, M., Gorce, J.-M., Dibangoye, J. S., & Mouël, F. Le. (2023). Codesigned Communication and Data Analytics for Condition-Based Maintenance in Smart Buildings. In *IEEE Internet of Things Journal* (Vol. 10, Nomor 18, hal. 15847–15856). Institute of Electrical and Electronics Engineers (IEEE). https://doi.org/10.1109/jiot.2023.3266029

Akhter, J., Hazra, R., & Gour, R. (2025). Power Allocation for IoV Networks in Smart Cities. In *Lecture Notes in Intelligent Transportation and Infrastructure* (hal. 115–131). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-72959-1_6

Alabadi, M., Habbal, A., & Guizani, M. (2024). An Innovative Decentralized and Distributed Deep Learning Framework for Predictive Maintenance in the Industrial Internet of Things. In *IEEE Internet of Things Journal* (Vol. 11, Nomor 11, hal. 20271–20286). Institute of Electrical and Electronics Engineers (IEEE). https://doi.org/10.1109/jiot.2024.3372375

Alanazi, F., & Alenezi, M. (2024). A framework for integrating intelligent transportation systems with smart city infrastructure. In *Journal of Infrastructure Policy and Development* (Vol. 8, Nomor 5, hal. 3558). EnPress Publisher. https://doi.org/10.24294/jipd.v8i5.3558

Alharbi, R. S., & Hussain, F. K. (2025). Smart-contracts-driven personal carbon credit management in smart cities: A review and future research directions. In *Internet of Things* (Vol. 32, hal. 101636). Elsevier BV. https://doi.org/10.1016/j.iot.2025.101636

Ambarkar, S. S., & Shekokar, N. (2024). The Internet of Things-Based Multipurpose Electronic

Mirror. In *Challenges and Solutions in Internet of Things-Based Smart Applications* (hal. 52–59). Chapman and Hall/CRC. https://doi.org/10.1201/9781003436911-5

Bhardwaj, S., Sampath, B., Kosimov, L., & Kosimova, S. (2024). Integration of Intelligent System and Big Data Environment to Find the Energy Utilization in Smart Public Buildings. In *Sustainable Smart Homes and Buildings with Internet of Things* (hal. 167–186). Wiley. https://doi.org/10.1002/9781394231522.ch10

Bhatnagar, V., Tamanna, & Sharma, R. K. (2023). A Review on IoT-based Smart Agriculture. In *Intelligent Systems and Smart Infrastructure* (hal. 623–637). CRC Press. https://doi.org/10.1201/9781003357346-69

Chaabane, F. (2025). Multi-source Data Fusion to Enhance Wireless Communication Beyond 5G for Smart City Transformation. In *Lecture Notes in Intelligent Transportation and Infrastructure* (hal. 451–473). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-72959-1_20

Chaudhary, H., Bhardwaj, M., Singh, S., & Sharma, H. (2023). Power electronics and IoT for electric vehicles in smart cities. In *Smart Cities: Power Electronics, Renewable Energy, and Internet of Things* (hal. 224–235). CRC Press. https://doi.org/10.1201/9781032669809-10

Chen, Y., Huo, K., Tang, H., & Tang, J. (2025). Study on health assessment system of old city street spaces in Ziyang District, China. In *Proceedings of the Institution of Civil Engineers - Smart Infrastructure and Construction* (Vol. 178, Nomor 1, hal. 43–61). Emerald. https://doi.org/10.1680/jsmic.22.00023

Chung, K. C., & Tan, P. J. B. (2025). Artificial intelligence and internet of things to improve smart hospitality services. In *Internet of Things* (Vol. 31, hal. 101544). Elsevier BV. https://doi.org/10.1016/j.iot.2025.101544

Dalabehera, A. R., Bebortta, S., Kumar, N., & Senapati, D. (2024). Mist–fog-assisted real-time emotion recognition using deep transfer learning framework for smart city 4.0. In *Internet of Things* (Vol. 27, hal. 101237). Elsevier BV. https://doi.org/10.1016/j.iot.2024.101237

Devi, E. M. R., Shanthakumari, R., Dhanushya, S., & Kiruthika, G. (2024). AI Models for Predictive Maintenance. In *Data Analytics and Artificial Intelligence for Predictive Maintenance in Smart Manufacturing* (hal. 69–94). CRC Press. https://doi.org/10.1201/9781003480860-5

Dhanasekaran, M. (2025). Smart Cities and Infrastructure: Managing Urban Scale Data for Predictive Maintenance and Resource Allocation. In *Journal of Computer Science and Technology Studies* (Vol. 7, Nomor 7, hal. 987–996). Al-Kindi Center for Research and Development. https://doi.org/10.32996/jcsts.2025.7.7.110

Fadda, M., Anedda, M., Girau, R., Pau, G., & Giusto, D. D. (2023). A Social Internet of Things Smart City Solution for Traffic and Pollution Monitoring in Cagliari. In *IEEE Internet of Things Journal* (Vol. 10, Nomor 3, hal. 2373–2390). Institute of Electrical and Electronics Engineers (IEEE). https://doi.org/10.1109/jiot.2022.3211093

Gallegos, L. F. J., Tuco, R. G., & Vigil, A. J. E. (2024). Innovative Road Maintenance: Leveraging Smart Technologies for Local Infrastructure. In *Designs* (Vol. 8, Nomor 6, hal. 134). MDPI AG. https://doi.org/10.3390/designs8060134

Geetha, R., Ramesh, S., Thilagavathi, P., Vidhya, S., & Nithyashri, J. (2025). Bio-inspired optimization for sustainable smart city infrastructure. In *Emerging Technologies In Sustainable Innovation, Management and Development* (hal. 58–61). Routledge. https://doi.org/10.4324/9781003684459-9

Geethapriya, A., D, S., & Sarala, B. (2025). Ethical and Regulatory Considerations in AI-Driven Predictive Decision-Making for Public Safety. In *Deep Neural Networks for Predictive Analytics and Proactive Decision-Making in Securing Critical Infrastructure* (hal. 371–402). RADemics

Research Institute. https://doi.org/10.71443/9788197933684-15

Gour, R., & Yadav, S. (2025). The Transformative Role of UAVs in Smart City Frameworks. In *Lecture Notes in Intelligent Transportation and Infrastructure* (hal. 3–24). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-72959-1_1

Gu, X., Jiang, Y., Zhang, F., & Shi, G. (2025). Application of Internet of Things technology in long-term health monitoring of tunnels. In *5th International Conference on Internet of Things and Smart City (IoTSC 2025)* (hal. 61). SPIE. https://doi.org/10.1117/12.3073093

gunawat, chhaya, & Khanna, A. (2025). *AI-Enhanced Infrastructure as Code (IaC) for Smart Configuration Management*. Elsevier BV. https://doi.org/10.2139/ssrn.5225391

Hemalatha, K. L., & Mohan, P. (2024). Predictive IoT-AI Model for Cyber Threat Detection in Smart Healthcare Environments. In *Journal of Smart Internet of Things* (Vol. 2024, Nomor 1, hal. 17–31). Walter de Gruyter GmbH. https://doi.org/10.2478/jsiot-2024-0002

Hromada, M., Rehak, D., Skobiej, B., & Bajer, M. (2023). *Converged Security and Information Management System as a Tool for Smart City Infrastructure Resilience Assessment*. MDPI AG. https://doi.org/10.20944/preprints202308.0293.v1

Kaczorowska-Spychalska, D. (2024). Smart retailing. In *Internet of Things in the Food Industry* (hal. 115–132). Routledge. https://doi.org/10.4324/9781003401421-11

Kauser, A. P., & Srishti, V. (2023). Farming Assistance Using Machine Learning and Internet of Things. In *Predictive Analytics in Smart Agriculture* (hal. 1–19). CRC Press. https://doi.org/10.1201/9781003391302-1

Kitika, C., & Suwatcharapinun, S. (2024). Smart district with the comparison on urban studies of internet infrastructure and new digital activities. In *International Review for Spatial Planning and Sustainable Development* (Vol. 12, Nomor 3, hal. 200–217). International Community of Spatial Planning and Sustainable Development. https://doi.org/10.14246/irspsd.12.3_200

Korobeynikov, A. (2025). Integration of Geomagnetic Activity Monitoring Data Processing Methods and Smart City Technologies to Ensure the Required Safety of Unmanned Transport Infrastructure Objects. In *International Scientific and Practical Conference “Smart Cities and Sustainable Regional Development”* (hal. 239–243). Crossref. https://doi.org/10.63550/iceip.2025.97.82.031

Leo, E. S., Alexander, M. G., & Beushausen, H. (2024). Study on Shrinkage and Elastic Modulus of Limestone Calcined Clay Cement Concrete. In *RILEM Bookseries* (hal. 418–430). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-53389-1_39

Li, S., & Yang, M. (2024). The Smart Internet of Things Assists in the Design of the Smart Sports Safety and Security System. In *2024 Asia Pacific Conference on Innovation in Technology (APCIT)* (hal. 1–5). IEEE. https://doi.org/10.1109/apcit62007.2024.10673642

Li, W., Yigitcanlar, T., Nili, A., Browne, W., & Li, F. (2025). Responsible smart home technology adoption: exploring public perceptions and key adoption factors. In *Internet of Things* (Vol. 32, hal. 101622). Elsevier BV. https://doi.org/10.1016/j.iot.2025.101622

Li, Y., Zhao, L., Yu, H., Xiao, R., Zhang, Y., & Wang, J. (2023). Study of traffic improvement planning and design assistant decision making system based on city brain. In *3rd International Conference on Internet of Things and Smart City (IoTSC 2023）* (hal. 78). SPIE. https://doi.org/10.1117/12.2683973

Liao, S.-H., Jiang, J.-D., & Yang, C.-F. (2024). Integration of LoRa-enabled IoT infrastructure for advanced campus safety systems in Taiwan. In *Internet of Things* (Vol. 28, hal. 101347). Elsevier BV. https://doi.org/10.1016/j.iot.2024.101347

Liu, Y., Yu, W., Rahayu, W., & Dillon, T. (2023). An Evaluative Study on IoT Ecosystem for Smart Predictive Maintenance (IoT-SPM) in Manufacturing: Multiview Requirements and Data Quality. In *IEEE Internet of Things Journal* (Vol. 10, Nomor 13, hal. 11160–11184). Institute of Electrical and Electronics Engineers (IEEE). https://doi.org/10.1109/jiot.2023.3246100

Lokhande, M. A., Renavikar, A., Bhosale, D., Kaldate, V., & Lokhande, S. (2025). An Insight Into Smart Infrastructure With Artificial Intelligence-Driven Predictive Maintenance: Transforming the Future of Urban Systems. In *Cureus Journal of Computer Science*. Springer Science and Business Media LLC. https://doi.org/10.7759/s44389-025-06375-2

Ma, hangxing, & Xu, J. (2024). Automatic spray shop monitoring system based on digital twin. In *4th International Conference on Internet of Things and Smart City (IoTSC 2024)* (hal. 123). SPIE. https://doi.org/10.1117/12.3035305

Mazumdar, S., & Sharma, A. (2024). Prioritizing Near-Term Quantum Sensor Deployment for Urban Transportation and Construction: A Readiness-Weighted Portfolio Framework for Smart-City Infrastructure. In *Journal of Urban Development and Smart Cities* (Vol. 1, hal. 84–94). Locke Science Publishing. https://doi.org/10.66033/judsc2024-109

McMillan, L., & Varga, L. (2023). Towards self-healing in water infrastructure systems. In *Proceedings of the Institution of Civil Engineers - Smart Infrastructure and Construction* (Vol. 176, Nomor 2, hal. 53–61). Emerald. https://doi.org/10.1680/jsmic.22.00006

Miasayedava, L., Kaugerand, J., & Tuhtan, J. A. (2023). Lightweight Assimilation of Open Urban Ambient Air Quality Monitoring Data and Numerical Simulations with Unknown Uncertainty. In *Environmental Modeling & Assessment* (Vol. 28, Nomor 6, hal. 961–975). Springer Science and Business Media LLC. https://doi.org/10.1007/s10666-023-09909-x

Minson, A. J. (2024). Carbon Reduction in Concrete Design and Construction. In *RILEM Bookseries* (hal. 440–445). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-53389-1_41

Nair, A. K., & Sahoo, J. (2023). Internet of Things in Smart and Intelligent Healthcare Systems. In *Intelligent Internet of Things for Smart Healthcare Systems* (hal. 1–19). CRC Press. https://doi.org/10.1201/9781003326182-1

Olaoluwa, F., & Potter, K. (2024). *Predictive Maintenance for Critical Infrastructure Security*. MDPI AG. https://doi.org/10.20944/preprints202409.0413.v1

Orbán, Z., & Mărculescu, L. (2024). Predictive analytics for enhancing performance and safety in continuously welded rail. In *International Conference on Road and Rail Infrastructure* (Vol. 8, hal. 475–482). University of Zagreb Faculty of Civil Engineering. https://doi.org/10.5592/co/cetra.2024.1589

Pargi, M. K., Abraham, A., & Nagavarapu, S. C. (2025). Transforming Public Safety and QoL in Smart Cities: Automated Event Detection and Response Generation with AI and IoT. In *Lecture Notes in Intelligent Transportation and Infrastructure* (hal. 267–290). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-72959-1_12

Peng, M., & Bibo, H. (2023). Dynamic scheduling algorithm of electric vehicles based on smart grid. In *3rd International Conference on Internet of Things and Smart City (IoTSC 2023）* (hal. 5). SPIE. https://doi.org/10.1117/12.2683842

Prasad, R., Tiwari, R., & Srivastava, A. K. (2023). Internet of Things-Based Fuzzy Logic Controller for Smart Soil Health Monitoring: A Case Study of Semi-Arid Regions of India. In *ECSA 2023* (hal. 85). MDPI. https://doi.org/10.3390/ecsa-10-16208

Radhakrishnan, S., & Manda, V. K. (2025). Geospatial Data Complexities and Technology Challenges in Smart Cities. In *Challenges for Smart City Infrastructure, Technologies, and Their Future* (hal. 255–290). IGI Global Scientific Publishing. https://doi.org/10.4018/979-8-

3373-0154-9.ch011

Rahman, A.-S., Anubhove, M. S. T., Zeyad, M., Ahmed, S. M. M., & Walid, M. A. A. (2024). Study of City Crimes with Smart Solutions Integrating into Smart Cities, Internet of Things (IoT), and Cybersecurity Systems. In *2024 International Conference on Advancements in Smart, Secure and Intelligent Computing (ASSIC)* (hal. 1–6). IEEE. https://doi.org/10.1109/assic60049.2024.10508004

Ruan, X. (2024). Utilization of cloud computing-based digital information technology in ecological community governance. In *4th International Conference on Internet of Things and Smart City (IoTSC 2024)* (hal. 69). SPIE. https://doi.org/10.1117/12.3034967

Ruthra, R., M, S. K., G, S., V, B. B., & A, K. P. P. (2025). Hybrid Autoencoder–GBM Model for Predictive Maintenance in Smart Civil Infrastructure. In *2025 4th International Conference on Automation, Computing and Renewable Systems (ICACRS)* (hal. 1535–1540). IEEE. https://doi.org/10.1109/icacrs67045.2025.11324255

Sangani, N., & Shah, J. (2024). Investigation on Parking Characteristics and Possible Solutions: A Case Study of Ahmedabad City. In *Lecture Notes in Civil Engineering* (hal. 513–526). Springer Nature Singapore. https://doi.org/10.1007/978-981-97-3994-3_36

Sanusi, A. N., Bayeroju, O. F., & Nwokediegwu, Z. Q. S. (2023). Conceptual Framework for Smart Infrastructure Systems Using AI-Driven Predictive Maintenance Models. In *International Journal of Advanced Multidisciplinary Research and Studies* (Vol. 3, Nomor 1, hal. 1183–1193). OPRA Publications. https://doi.org/10.62225/2583049x.2023.3.1.4911

Sanusi, B. O. (2025). Smart Infrastructure: Leveraging IoT and AI for Predictive Maintenance in Urban Facilities. In *SAMRIDDHI : A Journal of Physical Sciences, Engineering and Technology* (Vol. 17, Nomor 2, hal. 26–37). SMS Institute of Technology. https://doi.org/10.18090/samriddhi.v17i02.06

Sarker, M. T., Ramasamy, G., Qwaid, M. Al, Hossen, M. S., & Sadeque, M. G. (2025). AI-driven smart grid optimization for hospital energy systems integrating renewable generation, predictive maintenance, and resilient infrastructure. In *Scientific Reports* (Vol. 15, Nomor 1). Springer Science and Business Media LLC. https://doi.org/10.1038/s41598-025-28907-5

Sato, Y. (2025). IOT AND ARTIFICIAL INTELLIGENCE FOR PREDICTIVE ANALYTICS IN SMART CITIES. In *American Journal Of Internet Of Things* (Vol. 6, Nomor 2, hal. 1–6). International Study Counselor. https://doi.org/10.71465/ajiot3004

Son, D. J. (2024). A study on the guidelines that smart public facilities must have as smart city infrastructure. In *Journal of Communication Design* (Vol. 87, hal. 60–79). CDAK Society of Communication Design. https://doi.org/10.25111/jcd.2024.87.05

Sreedharan, R. (2025). RECENT ISSUES AND CHALLENGES IN INTERNET OF THINGS: A SMART CITY APPLICATION PERSPECTIVE. In *Future Trends in Internet of Things, Internet of Everything and its Applications* (hal. 58–63). Iterative International Publishers (IIP), Selfypage Developers Pvt Ltd. https://doi.org/10.58532/nbennurfticsw7

Sreeja, G. P., Francis, A., & Rodrigues, M. (2025). Internet of Medical Things–Based Smart System for the Mental Health Care Challenges in 21st Century. In *Internet of Medical Things* (hal. 124–133). Chapman and Hall/CRC. https://doi.org/10.1201/9781003476344-9

Su, T., & Zhang, X. (2025). Energy-Efficient Routing for Electric Vehicles under Acceleration and Load Effects. In *2025 International Conference on Computer, Internet of Things and Smart City (CIoTSC)* (hal. 1–5). IEEE. https://doi.org/10.1109/ciotsc67482.2025.11413239

Surapaneni, P., & Bojjagani, S. (2025). SEATS: Secure and Efficient Authentication with Key Exchange for Intelligent Transport Systems. In *Lecture Notes in Intelligent Transportation and*

Infrastructure (hal. 387–408). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-72959-1_17

Thomas, K. (2025). *Equity and Security in the Smart City Era: A Dual-Framework Approach to U.S. Broadband Infrastructure*. Elsevier BV. https://doi.org/10.2139/ssrn.5376073

Tiwari, R., & Tiwari, R. (2024). Improve the Sustainability of City Transportation Network using Adaptive Public Transport System & Multi-layer Infrastructure. In *2024 International Conference on Recent Innovation in Smart and Sustainable Technology (ICRISST)* (hal. 1–4). IEEE. https://doi.org/10.1109/icrisst59181.2024.10921921

Tom, R. (2024). *Towards an Equitable Child-Friendly City: A Case Study Evaluation of Child-Friendly Infrastructure in Toronto*. Ryerson University Library and Archives. https://doi.org/10.32920/25417447

Torrent, R. J., & Musch, H. (2024). Optimized Mix Design Regarding Cost and Sustainability. In *RILEM Bookseries* (hal. 560–569). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-53389-1_52

Ugwoke, P. O., Abdulsalam, A., & Ejiofor, C. C. (2024). Internet of Things: The Key Enabler of Smart City Development. In *Smart Cities - Foundations and Perspectives*. IntechOpen. https://doi.org/10.5772/intechopen.114997

Vaniš, M., Horák, M., Tichý, T., Lokaj, Z., Malý, M., & Brož, J. (2024). Autonomous Trams and Urban Infrastructure: A Methodological Approach to Testing and Integration. In *2024 Smart City Symposium Prague (SCSP)* (hal. 1–7). IEEE. https://doi.org/10.1109/scsp61506.2024.10552728

Varga, L., McMillan, L., Hallett, S., Russell, T., Smith, L., Truckell, I., Postnikov, A., Rodger, S., Vizcaino, N., Perkins, B., Matthews, B., & Lomax, N. (2023). Infrastructure and city ontologies. In *Proceedings of the Institution of Civil Engineers - Smart Infrastructure and Construction* (Vol. 176, Nomor 2, hal. 43–52). Emerald. https://doi.org/10.1680/jsmic.22.00005

Verma, R. K., Kishor, K., & Galletta, A. (2024). Federated Learning Shaping the Future of Smart City Infrastructure. In *Federated Learning for Smart Communication using IoT Application* (hal. 196–216). Chapman and Hall/CRC. https://doi.org/10.1201/9781003489368-10

Vijayaraj, A., Kumar, P., Gaurav, N. V, Megavannan, R., Karthiga, R., & Rajeswari, P. (2025). Predictive Maintenance in Smart Cities: An AI-Driven Approach to Urban Infrastructure Management. In *Lecture Notes in Networks and Systems* (hal. 403–416). Springer Nature Singapore. https://doi.org/10.1007/978-981-96-4319-6_29

Widjaja, D. D., & Kim, S. (2025). Intelligent Rebar Optimization Framework for Urban Transit Infrastructure: A Case Study of a Diaphragm Wall in a Singapore Mass Rapid Transit Station. In *Smart Cities* (Vol. 8, Nomor 4, hal. 130). MDPI AG. https://doi.org/10.3390/smartcities8040130

Yaacob, A., Gan, J. L., & Khoo, K. L. (2025). Are You Ready for Your Future Home? In *Challenges for Smart City Infrastructure, Technologies, and Their Future* (hal. 199–222). IGI Global Scientific Publishing. https://doi.org/10.4018/979-8-3373-0154-9.ch009

Zeng, X., & Bao, S. (2023). The Infrastructure of Smart Grid. In *Advanced and Intelligent Manufacturing in China* (hal. 67–113). Springer Nature Singapore. https://doi.org/10.1007/978-981-99-7603-4_2

Zhang, R. (2024). Exploring facial attribute inference with ResNet: a study on head pose estimation and gender prediction. In *4th International Conference on Internet of Things and Smart City (IoTSC 2024)* (hal. 43). SPIE. https://doi.org/10.1117/12.3034899

Zhang, Y., & Abraham, A. (2023). Bi-objective Study of Public Transport Operation in Smart Cities to Minimize On-Board Passenger Traveling Time and Stop Passenger Delay. In *Signals and*

Communication Technology (hal. 127–143). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-34601-9_8

Zhao, W., Wang, H., & Yu, W. (2025). Efficient nearest-neighbor search on moving objects with durability constraints. In *GeoInformatica* (Vol. 29, Nomor 3, hal. 665–690). Springer Science and Business Media LLC. https://doi.org/10.1007/s10707-025-00543-1

Zhou, S., & Ren, J. (2025). Does new infrastructure improve public health? Evidence from smart city pilot program in China. In *Frontiers in Public Health* (Vol. 13). Frontiers Media SA. https://doi.org/10.3389/fpubh.2025.1655119

Zhou, W., & Mao, Z. (2023). The application of UAV tilt photogrammetry technology in the construction of smart city: a case study of Zhongdu ancient town in Guangxi. In *3rd International Conference on Internet of Things and Smart City (IoTSC 2023）* (hal. 11). SPIE. https://doi.org/10.1117/12.2683848

Zhu, X. (2024). Smart Daily Travel Demonstration Zone: A Case Study. In *Lecture Notes in Intelligent Transportation and Infrastructure* (hal. 103–121). Springer Nature Singapore. https://doi.org/10.1007/978-981-97-3831-1_9

Zhukabayeva, T., Ahmad, Z., Satybaldina, D., & Mardenov, Y. (2025). An Edge-Cloud Enabled Machine Learning Framework for Anomaly Detection and Predictive Analysis in Smart City Power Grids. In *2025 12th International Conference on Internet of Things: Systems, Management and Security (IOTSMS)* (hal. 87–94). IEEE. https://doi.org/10.1109/iotsms68530.2025.11408497