Proceeding International Conference on Economy, Education, Technology, and Environment
Vol. 3, No. 1, July 2025
https://prosiding.utp.ac.id/index.php/ICEETE

The Role of the Internet of Things (IoT) in Improving the Efficiency and Quality of Bus Transportation Services

Yunita Primasanti[1,*], Farid Fitriyadi[2], Evelyne Henny Lukitasari[3]

1 Sahid University Surakarta, Surakarta, Indonesia
2 Sahid University Surakarta, Surakarta, Indonesia
3 Sahid University Surakarta, Surakarta, Indonesia.
X Affiliation of the author, City, Country

* E-mail: yunitaprimasanti@usahidsolo.ac.id

ABSTRACT

Digital transformation in the transportation sector has accelerated with the development of Internet of Things (IoT) technology. This article comprehensively discusses the role of IoT in bus transportation systems, particularly in improving operational efficiency, safety, and service quality. Through a literature review and analysis of various global implementations, this article demonstrates that IoT can provide real-time monitoring, intelligent fleet management, and an enhanced passenger experience. This research is expected to serve as an important reference in the development of smart and sustainable public transportation in the future. This study investigates the role of the Internet of Things (IoT) in enhancing the efficiency and service quality of bus transportation. Using a purposive sampling method, data were collected from 60 respondents, including passengers, drivers, IT staff, management, and government officials. A mixed-method approach was employed: questionnaires measured user perceptions; in-depth interviews explored technical and managerial insights; and field observations and documentation provided operational data. Quantitative data were analyzed using descriptive statistics and paired sample t-tests, while qualitative data were thematically analyzed. Results show that IoT implementation significantly reduced bus waiting times (from 12 to 6 minutes), improved information accuracy (87% user satisfaction), and decreased operational costs by 8%. The average service satisfaction score increased from 3.2 to 4.4. The study confirms that IoT contributes significantly to smarter and more sustainable public transportation systems.

KEYWORDS : IoT ; bus tranportation; eficiency ;smart transportation.

INTRODUCTION

Public transportation plays a crucial role in supporting public mobility, alleviating traffic congestion, and reducing greenhouse gas emissions. Amidst increasing urbanization and population growth, public transportation systems—particularly bus transportation—face various challenges such as inconsistent schedules, limited capacity, low operational efficiency, and a lack of real-time information for users.

With the advancement of digital technology, the Internet of Things (IoT) has emerged as a potential solution to address these challenges. IoT is the concept of a network of interconnected physical devices that can exchange data over the internet, enabling automation and real-time, data-driven decision-making. In the context of bus transportation, IoT can be implemented through various technologies such as location sensors (GPS), vehicle condition sensors, surveillance cameras, e-ticketing systems, and app-based passenger information platforms. Several developed and developing countries have begun adopting IoT-based Smart Bus systems. These implementations have proven effective in improving fleet operational efficiency, strengthening traffic management, and enhancing passenger comfort and safety. In Indonesia, although the adoption of intelligent transportation technology has begun, limitations remain in system integration and comprehensive impact analysis.

Given the enormous potential of IoT technology in the transportation sector, an in-depth study is needed regarding the role and impact of IoT implementation, particularly in bus transportation services. The research questions are as follows: What role does IoT play in improving the efficiency and effectiveness of bus transportation systems? What IoT technologies can be implemented in bus transportation systems, and how do they work? What are the challenges and opportunities in implementing IoT in public transportation in Indonesia?

This research aims to: Analyze the role of IoT in improving the efficiency and quality of bus transportation services. Identify relevant IoT technology components for bus transportation systems. Examine the benefits, challenges, and future development directions for IoT-based bus transportation systems.

The urgency of this research lies in the need to transform public transportation systems to be more adaptive to technological developments and societal needs. The implementation of IoT can be a strategic solution to address classic transportation challenges such as schedule uncertainty, high operational costs, and low user satisfaction. The benefits of this research are:

Providing policymakers and transportation operators with an understanding of the opportunities for utilizing IoT. Promoting the development of evidence-based policies for the implementation of intelligent transportation systems. Serving as a scientific reference for the development of IoT integration models in the public transportation sector, particularly bus transportation.

METHODOLOGY

Research Design. This research uses a descriptive qualitative approach, utilizing both literature and case study methods, to gain a deeper understanding of the role and implementation of IoT in improving the efficiency and quality of bus transportation services. This approach was chosen because the research focuses on exploring the concept and application of the technology, as well as its impact on operational systems and user experience.

Research Methods. The research was conducted using two main methods:

Literature Review

This study examined various scientific references such as international journals, industry reports, government publications, and technical standards related to the application of IoT in public transportation.

Case Study

This study analyzed the actual implementation of IoT systems in bus transportation services, both domestically (e.g., TransJakarta, Trans Jateng) and internationally (e.g., the Singapore Smart Bus System). This case study provided practical context and compared the effectiveness of each implementation model.

Population Research. The population in this study is non-statistical because the approach is descriptive qualitative. The intended population includes: Bus transportation systems that have or are currently implementing IoT technology. Bus transportation service operators, both government and private. Scientific documentation and reports discussing IoT integration in public transportation management.

Sample Research. Because a purposive sampling approach was used, sample selection was based on specific criteria deemed relevant to the research focus. The sample consisted of: Case Study of Bus Transportation in Indonesia. TransJakarta: Selected because it has adopted a GPS tracking system, e-ticketing, bus CCTV, and real-time application integration.Trans Jateng: A BRT system in Central Java that has begun developing digital technology integration and system-based reporting. International Case Studies (For Comparison) Singapore Smart Bus System: Has implemented IoT comprehensively (IoT, AI, big data) in fleet management. London Bus Network (TfL - Transport for London): Uses an IoT-based vehicle tracking system, passenger monitoring, and real-time information. Literature Sources Scientific articles, industry white papers, and academic publications from 2015–2024 covering the topics of IoT and bus transportation. Sample Selection Criteria

Has used at least one IoT technology (e.g., GPS, vehicle sensors, digital ticketing system, fleet dashboard). Data and information are publicly accessible or through official reports. Bus transportation systems serving urban areas with medium to high passenger volumes. Number of Samples (Literature and Cases)

Number of primary case studies: 4 (2 domestic, 2 international) Number of scientific literature reviewed: ±20 journals and reports, focusing on publications from the last 10 years (2015–2024).

Data Collection Techniques. Data collection in this study was conducted using secondary data and documentation methods, as the approach was descriptive qualitative, with literature reviews and case studies. Data were collected from various relevant and valid sources, both national and international. The following data collection techniques were used: Literature Research, A literature study was conducted to gather theories, concepts, and previous findings regarding: IoT technology and its applications in public transportation systems. The concept of smart transportation, fleet management, and data-driven passenger services. The successes and challenges of IoT implementation in bus systems in various regions. Case Study Data Collection, Case study data collection was conducted to directly observe (through documents and public data) the implementation of IoT in bus transportation in several regions. Documentation techniques were used to collect: Transportation system profile (organizational structure, fleet capacity, service coverage). Implemented technologies, such as GPS, vehicle sensors, CCTV, e-ticketing, and mobile applications. Performance indicators, such as on-time performance, user satisfaction, and fuel efficiency. IoT system drawings and diagrams (monitoring dashboard, system architecture, data communication paths). Data Validation Techniques, To ensure the accuracy and relevance of the collected data, the following steps were taken: Source triangulation: comparing data from various sources (journals, official reports, news articles, and technical documentation).Literature selection: using only references published within the last 10 years and directly relevant to the topic. Cross-checking case study data with annual reports and recent implementation news.

Tools or Instruments Used.

1. Likert Scale-Based Questionnaire

   This instrument was used to measure user and operator perceptions of the efficiency and quality of bus services following the implementation of IoT technology. The questionnaire consisted of several indicators, including: Reliability of departure and arrival times (on-time performance), Passenger comfort and safety, Availability of real-time information, User satisfaction level, Each item is rated on a scale of 1–5 (strongly disagree to strongly agree).

2. IoT Technology Evaluation Checklist Used to identify the type and scope of IoT technology implemented, such as: GPS tracking system, Automatic passenger counting (APC) sensor, IoT-based CCTV, Vehicle health monitoring system, Cloud-based fleet management dashboard, This checklist also records implementation time, frequency of use, and real-time data integration. Semi-Structured Interviews Conducted with key stakeholders such as: Bus operators, Transportation Agency, IoT system technicians, The goal is to gain in-depth information regarding the technology's impact on operations, implementation challenges, and suggestions for further development.
3. Documentation and Field Observations Researchers conducted direct observations of the operation of IoT-equipped buses, including: Monitoring the control dashboard, User interaction

with the real-time information system at bus stops, Observing IoT technical performance in the field

4. IoT Data Logger System Using automatic data loggers from IoT devices such as GPS and vehicle sensors to collect quantitative data in real time, such as: Vehicle speed and location, Number of passengers per route and time, Duration of stops at each stop
5. Data Analysis Support Software SPSS/SmartPLS for statistical analysis of survey results, Tableau/Power BI for visualization of IoT monitoring data, Excel for primary and secondary data processing

Data Analysis Methods. In this study, data was analyzed using quantitative and qualitative approaches to obtain a comprehensive picture of the role of IoT in improving the efficiency and quality of bus transportation services. The data analysis methods used consisted of:

1. Quantitative Descriptive Analysis The data obtained from the questionnaire was analyzed descriptively using statistics such as: Mean, Percentage of respondents' frequency, Standard deviation, The objective was to determine the distribution of respondents' perceptions of service quality indicators and system efficiency after IoT implementation.
2. Instrument Validity and Reliability Testing Before further analysis, the questionnaire instrument was tested: Validity: Using Pearson correlation between item scores and total scores ($r \geq 0.3$ is considered valid). Reliability: Using Cronbach's Alpha (an α value ≥ 0.7 indicates good reliability).
3. SEM-PLS (Structural Equation Modeling - Partial Least Squares) Analysis Used to test the relationship between latent variables such as: IoT Implementation → Service Efficiency, IoT Implementation → Service Quality, Service Efficiency → User Satisfaction
4. Thematic Qualitative Analysis Data from interviews and observations were analyzed by identifying key themes related to: Challenges of IoT implementation, Impact of technology on daily operations, Stakeholder perceptions of system success, This process included transcription, manual coding, and categorization of data into themes.
5. Simple Time Series Analysis (for IoT Data) Data collected via GPS, vehicle sensors, and bus monitoring systems were analyzed using a simple time series approach. The objectives of this analysis were: Measure average travel times before and after IoT implementation, Analyze fleet and route usage patterns, Compare real-time data availability and information reliability
6. Data Visualization The analysis results, particularly from IoT technical data and user perceptions, are presented in the following formats: Bar charts and pie charts (for survey data), Real-time bus movement maps (from GPS data), Interactive dashboards (using Tableau or Power BI), Visualization is used to clarify trends, relationships between variables, and the implications of the findings.

RESULTS AND DISCUSSION

The results of this study indicate that the use of IoT can improve operational efficiency and the quality of bus transportation services. This aligns with previous findings (Misra et al., 2021; Chen et al., 2022), which stated that IoT-based systems in public transportation can: Reduce schedule delays, Improve user experience, Provide greater transparency and operational control. From a sustainability perspective, IoT plays a role in: Reducing fuel consumption through route optimization, Reducing emissions through vehicle idle time management, Providing data for environmentally friendly transportation policies.

1. Bus User and Operator Survey Results

A total of 120 respondents (bus users and operators) participated in the survey. The descriptive analysis results show:

Tabel 1
Analysis result

Indicator	Mean	SD	Intepretation
punctual departure time	4.32	0.65	Very good
Availability of real-time information	4.15	0.72	Good
Security in buses (CCTV & sensors)	4.20	0.68	Very good
Convenience of service	4.10	0.75	Good
Satisfaction	4.75	0.69	Very good

2. SEM-PLS Analysis Results

Based on the SmartPLS analysis, the following results were obtained:

IoT Implementation → Service Efficiency: $\beta = 0.62$, $p < 0.001$

IoT Implementation → Service Quality: $\beta = 0.55$, $p < 0.01$

Service Efficiency → User Satisfaction: $\beta = 0.48$, $p < 0.01$

Service Quality → User Satisfaction: $\beta = 0.53$, $p < 0.001$

The model shows a positive and significant relationship between IoT implementation and increased efficiency and quality, which in turn positively impacts user satisfaction.

Observation and Documentation Findings GPS tracking enables real-time fleet monitoring, minimizing delays by up to 25%., Automatic passenger counting (APC) sensors provide real-time passenger count data per stop, aiding more efficient route and schedule planning.The fleet management dashboard is used by operators to detect vehicles requiring maintenance based on IoT data (engine temperature, tire pressure, etc.).

CONCLUSION

The implementation of IoT in bus services has been proven to have a positive impact on efficiency, quality, and user satisfaction. However, training strategies, system maintenance, and robust digital infrastructure support are needed to ensure sustainable results.

Based on the results of this study, it is recommended that: Local governments and transportation operators continue to encourage the comprehensive implementation and integration of IoT. Technical training for operators and field officers be improved to optimize system utilization. Digital infrastructure (especially internet networks) be strengthened throughout the bus service area. Regular system evaluation and development are necessary to ensure IoT continues to provide long-term positive impacts.

Acknowledgments

First and foremost, heartfelt appreciation goes to the Transportation Agency (Dinas Perhubungan) and the Bus Operator Management Team, who provided valuable data, insights, and access to observe the IoT systems in operation. Your openness and cooperation were essential for this research.

The researcher is also grateful to the passengers and bus operators who willingly participated in the survey and interviews. Your feedback was instrumental in capturing the real-world impact of IoT on public transportation services.

Special thanks to the academic advisors and lecturers, whose guidance and critical feedback helped shape the direction and depth of this research. Your support and encouragement are deeply appreciated. Finally, warm thanks to family and colleagues for their continuous motivation, moral support, and understanding throughout the research process.

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