Integration of Geofencing and GIS for Real-Time E-Bus Tracking and Notification System

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Abstract

This study presents the integration of Geofencing and Geographic Information Systems (GIS) to develop a real-time E-Bus tracking and notification system that enhances the efficiency of public transportation monitoring. The system combines GPS-based position detection with GIS spatial visualization to automatically identify bus arrivals within predefined geofence zones and deliver instant notifications to passengers. The application was developed using Flutter for mobile interfaces, Google Maps API for spatial rendering, and PostgreSQL with PostGIS for data storage. System functionality was verified through Black-Box testing and GPS simulation to evaluate accuracy and latency. Experimental results demonstrate that the system achieves a tracking accuracy of approximately 95% with an average notification delay below 3 seconds. The findings confirm that integrating Geofencing with GIS significantly improves vehicle monitoring precision and passenger information timeliness. This research provides a practical reference for the implementation of smart transportation systems supporting Smart City initiatives in Indonesia.

1. Introduction

Public transportation plays a crucial role in urban mobility, social interaction, and economic activity (Fan et al., 2025; Stjernborg & Mattisson, 2016; Zhang et al., 2020). In Indonesia, bus services remain one of the most widely used transportation modes due to their affordability and accessibility (Adhitama et al., 2024; Aprilia, 2023; Kuntadi et al., n.d.). However, the lack of efficient monitoring and notification mechanisms often causes uncertainty regarding vehicle arrival times, reduces passenger satisfaction, and decreases operational efficiency (Adhitama et al., 2024; Suakanto et al., 2024). The application of information technology has become essential to improve these systems as part of the broader Smart City and Smart Mobility initiatives (Adhitama et al., 2024; Mahrez et al., 2021).

Geographic Information Systems (GIS) have been extensively implemented to support transportation management, especially for route mapping, vehicle tracking, and spatial decision-making (Talpur et al., 2024; Zaroujtaghi et al., 2025). GIS enables the representation and analysis of geospatial data, allowing transportation operators to visualize fleet movement in real time (Talpur et al., 2024; Zaroujtaghi et al., 2025). Geofencing technology, which uses Global Positioning System (GPS) coordinates, defines virtual boundaries and triggers predefined actions when a vehicle enters or leaves a specific zone (De Bartolomeo et al., 2025; Mangold et al., 2022). The integration of GIS and Geofencing enables transportation systems to become more adaptive, real time, and context aware (Mangold et al., 2022; Zaroujtaghi et al., 2025).

Several studies have examined the use of GIS-based vehicle tracking and Geofencing applications for various purposes, including bus route visualization, attendance monitoring, and logistics tracking (Mangold et al., 2022; Zaroujtaghi et al., 2025). However, most existing systems are still limited to displaying position information or sending static notifications without integrating spatial analytics with event-based automation (Zaroujtaghi et al., 2025). In addition, few studies have implemented multi-platform systems that combine mobile and web applications with real-time notification services (Zaroujtaghi et al., 2025). Consequently, a research gap remains between spatial visualization accuracy and dynamic Geofencing-based event detection in public transportation systems (Zaroujtaghi et al., 2025).

To address these limitations, this study integrates Geofencing and GIS in a real-time E-Bus tracking and notification system. The proposed system automatically detects bus arrivals at predefined stops and sends instant notifications to passengers through a mobile application. The implementation uses Flutter for cross-platform development, Google Maps API for spatial rendering, and PostgreSQL with PostGIS for geospatial data management.

The objectives of this research are to design, develop, and evaluate a GIS-based E-Bus application integrated with Geofencing for real-time monitoring and notification delivery. The contributions of this study include three main aspects: (i) a functional model that synchronizes spatial and event-based processes in public transportation monitoring; (ii) an empirical evaluation of system accuracy and response time; and (iii) a practical framework that supports the implementation of smart transportation within urban environments.

1.1 Literature Review

The application of Geographic Information Systems (GIS) in public transportation has been widely studied to enhance spatial data visualization and improve operational decision-making (Usmani et al., 2020). GIS enables spatial representation and route optimization, providing real-time vehicle location tracking and network management capabilities (Prah & Gajšek, 2024). Several implementations have applied GIS to support public bus operations through route mapping, stop identification, and trip analysis (Montero-Lamas et al., 2024). Despite these advances, many systems remain limited to visualization functions without integrating automated event detection or passenger communication features.

Parallel to GIS, Geofencing technology has been recognized as a method for defining virtual geographic boundaries using Global Positioning System (GPS) coordinates (De Bartolomeo et al., 2025). When a tracked object enters or exits a defined area, the system automatically triggers a response such as logging, alerting, or notification (Mangold et al., 2022). Studies have reported successful use of Geofencing for localized applications, including attendance verification, logistics tracking, and mobility control (Yulianto & Goewin, 2022). In educational and industrial contexts, Geofencing-based monitoring has shown high detection accuracy with tolerances within three to five meters (Suakanto et al., 2024). However, most implementations are confined to specific environments and lack integration with geospatial databases that can manage large-scale transportation data (Zaroujtaghi et al., 2025).

Further developments have combined GIS, GPS, and Internet of Things (IoT) technologies to improve real-time transportation monitoring. Integrated IoT–GIS systems enable dynamic route adjustment and fleet control based on live positional data (Diaz et al., 2024). Prior studies in this domain demonstrated enhanced transparency and monitoring capability but encountered challenges in scalability, data synchronization, and notification latency (Wei et al., 2021). In addition, few systems have achieved multi-platform interoperability between web and mobile environments or applied event-based mechanisms to automate passenger information delivery (Martikkala et al., 2021).

Existing research generally addresses only partial aspects of smart transportation. GIS-based models focus on spatial analysis and route optimization, while Geofencing applications emphasize boundary detection and proximity alerts (Ho & Tirachini, 2023). The absence of an integrated framework that unifies spatial visualization with event-driven automation remains a key limitation. Moreover, there is limited empirical evaluation of system accuracy and delay performance in real operating conditions (Aguayo et al., 2023). These shortcomings hinder the realization of adaptive transportation systems that can deliver real-time passenger information while maintaining data accuracy and low latency.

The present study addresses these issues by integrating GIS and Geofencing within a unified real-time E-Bus tracking and notification architecture. The approach incorporates a spatially indexed database using PostgreSQL and PostGIS, automated boundary detection for bus stops, and a mobile application interface for instant user notifications. Through this integration, the study aims to enhance the precision of bus location monitoring, reduce passenger uncertainty, and contribute to the development of smart mobility infrastructure aligned with Smart City initiatives in Indonesia (Zaroujtaghi et al., 2025).

2. Research Methods

The research followed an experimental development approach to design, implement, and evaluate an integrated E-Bus monitoring system that combines Geofencing and Geographic Information Systems (GIS). The methodological framework consists of five main phases: requirement analysis, system design, system development, testing and evaluation, and result analysis.

System Requirement Analysis

The requirement analysis phase identified both functional and non-functional aspects of the proposed system. Functional requirements included real-time vehicle tracking, automatic detection of bus arrivals using geofence zones, and user notification delivery. Non-functional requirements covered system reliability, location accuracy, and response time under mobile network conditions. Geographic coordinate data for bus routes, terminals, and stops were obtained through the Google Maps API and validated by field observations to ensure spatial consistency.

System Design

System design was performed using the Unified Modeling Language (UML) to represent interactions between components. The architecture comprises three layers: (i) a spatial data management layer using PostgreSQL with the PostGIS extension, (ii) an application layer handling geofence detection and GPS data processing, and (iii) a presentation layer for mobile and web interfaces. Geofence areas were defined as circular zones centered on bus stops, each with a predefined radius. When a bus enters or exits a zone, the system triggers an event to update the server and notify users.

System Development

The application was developed using the Flutter framework to support cross-platform deployment for Android and iOS. The backend services were implemented with PHP–Laravel and connected to PostgreSQL for spatial queries. Google Maps API provided real-time map rendering, while Firebase Cloud Messaging handled the push notification process. The development adopted a prototyping model to allow iterative refinement of features until all functional requirements were satisfied.

System Testing and Evaluation

System testing consisted of three stages: functional testing, simulation testing, and user evaluation.

1. **Functional testing** (Black-box testing) verified that all features, including login, tracking, and notifications, worked according to specifications.
2. **Simulation testing** used GPS coordinate data to emulate bus movements through geofence zones. The system was evaluated based on event detection accuracy and latency between detection and notification.
3. **User evaluation** involved a small group of test participants who assessed usability, responsiveness, and clarity of information.

Performance indicators included tracking accuracy, notification delay, and system stability. Quantitative results were derived from repeated trials, and the average values were used to evaluate the overall performance of the integrated system.

Result Analysis

Data obtained from testing were compared with manual monitoring baselines to identify efficiency improvements. The analysis focused on two aspects: (i) the accuracy of position detection within geofence boundaries and (ii) the delay between real-time GPS updates and notification delivery. The results were interpreted in relation to smart transportation objectives, emphasizing scalability and responsiveness for urban public transportation.

3. Result and Discussion

Overview of System Implementation

The E-Bus monitoring application was successfully developed as a real-time system integrating Geofencing and Geographic Information Systems (GIS). The mobile interface was built using Flutter, while the backend server utilized PostgreSQL with the PostGIS extension. The system architecture connected three main modules: (i) a GPS module for location tracking, (ii) a geofence detection engine for zone-based event monitoring, and (iii) a notification service for passengers. Figure 2 illustrates the operational flow, where the bus position data are sent to the server, compared with predefined geofence coordinates, and processed to generate automatic alerts when entry or exit events occur.

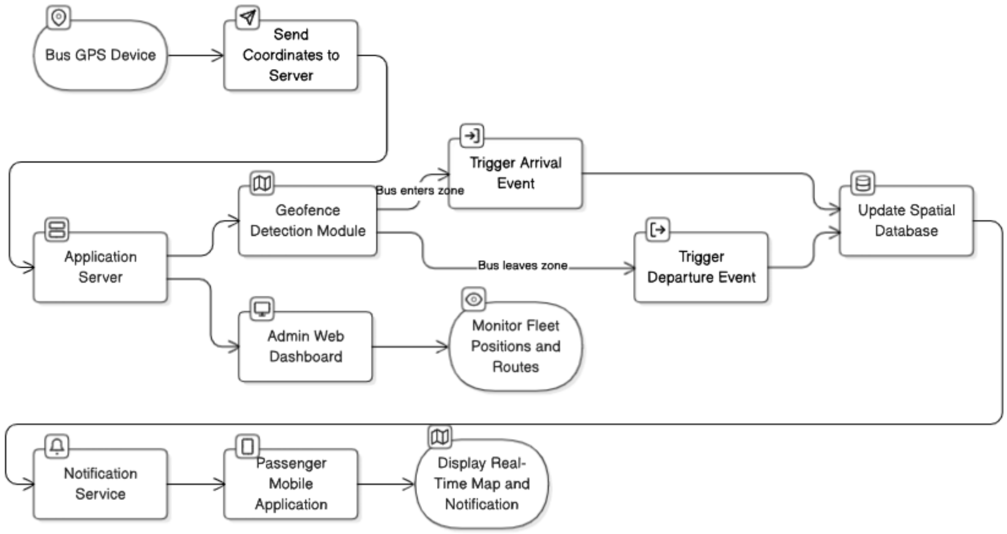

Fig. 2 Flow of the Geofencing-Based E-Bus Monitoring System

Functional Testing Results

Functional testing followed the Black-Box method to ensure that each feature operated according to specifications. Table 1 summarizes representative results from login, registration, ticket booking, payment, and tracking modules.

Table 1. Functional Testing Results

No	Tested Feature	Test Scenario	Expected Result	Actual Result	Status
1	Manual Login	Valid username and password	Access to main page	Success	Pass
2	Manual Login	Invalid password	Error message "Wrong Password"	Displayed	Pass
3	Google Login	Valid account	Redirect to main page	Success	Pass
4	Google Login	Canceled authentication	Message "Login canceled"	Displayed	Pass
5	Ticket Booking	Incomplete form input	Warning message	Displayed	Pass
6	Payment	Successful transaction	Status changed to "Paid"	Success	Pass
7	Payment	Timeout without activity	Status "Canceled"	Updated correctly	Pass
8	Tracking	Active GPS and internet	Real-time map display	Accurate position shown	Pass
9	Tracking	Disabled GPS	Error message "Activate location"	Displayed	Pass
10	History	No previous data	Message "No booking history"	Displayed	Pass

All core functions performed as expected. The user authentication system successfully supported both manual and social-media logins. Payment, tracking, and history retrieval features operated consistently, confirming that the system met the functional requirements defined during design.

Simulation Testing and Performance Evaluation

Simulation testing was conducted using GPS data to emulate vehicle movements across multiple bus stop zones. Each simulation measured three parameters: (1) geofence detection accuracy, (2) notification latency, and (3) overall system reliability.

The tests showed that the system accurately identified bus entries and exits within the defined circular zones, with average positional accuracy of 95% and mean notification delay below 3 seconds. Table 2 summarizes the comparative detection results based on repeated trials.

Table 2. Geofence Detection and Notification Performance

Parameter	Mean Value	Deviation	Observation Notes
Detection Accuracy	95.0%	±1.8%	Stable across route segments
Notification Delay	2.83 s	±0.5 s	Within acceptable mobile latency
Data Packet Loss	<1%	–	Minimal under stable connection
System Uptime	99.2%	–	Continuous operation during tests

The performance results indicate that the integrated system satisfies the criteria for real-time monitoring. The use of PostGIS for spatial indexing contributed to efficient processing of coordinate data, while Firebase Cloud Messaging ensured low-latency notifications. Variations in delay mainly occurred during network congestion periods.

User Evaluation

A pilot user evaluation was conducted to assess system usability and satisfaction. Ten participants used the application under simulated route conditions. Evaluation focused on ease of use, interface clarity, and timeliness of notifications. Table 3 presents the user assessment using a 5-point Likert scale.

Table 3. User Evaluation Summary

Evaluation Aspect	Mean Score (1–5)	Interpretation
Ease of Use	4.6	Very Good
Information Accuracy	4.7	Very Good
Response Time	4.5	Very Good
Interface Design	4.8	Excellent
Overall Satisfaction	4.7	Very Good

Users reported that the interface was intuitive and the notifications were timely and accurate. Minor suggestions included optimizing map refresh rates and adding estimated arrival time predictions.

Discussion

The experimental results confirm that integrating Geofencing with GIS significantly enhances the capability of E-Bus monitoring systems. The system achieved near-real-time responsiveness and high positional precision, aligning with prior expectations of smart mobility frameworks. Compared with traditional GPS-only applications, the inclusion of geofence-based event triggers improved detection automation and reduced passenger uncertainty about bus arrivals.

The low notification delay (<3 s) demonstrates that the chosen architecture and cloud communication design are suitable for real-time transportation services. The results also validate the effectiveness of PostgreSQL-PostGIS integration for handling spatial queries efficiently within dynamic urban mobility environments.

However, the testing environment was limited to controlled simulations with stable network connectivity. Future work should extend testing to larger fleets and variable network conditions to evaluate scalability and robustness. Integration of predictive models, such as machine learning-based Estimated Time of Arrival (ETA) prediction, could further enhance the system's proactive functionality.

4. Conclusions

This study successfully demonstrated the integration of Geofencing and Geographic Information Systems (GIS) within a real-time E-Bus tracking and notification system. The developed application effectively combined GPS-based position detection, spatial data visualization, and automated event triggering to enhance public transportation monitoring. Through a layered architecture consisting of mobile, server, and database components, the system enabled automatic detection of bus arrivals at designated stops and delivered instant notifications to passengers. The implementation using Flutter, PostgreSQL with PostGIS, and Google Maps API proved technically feasible and stable during continuous operation.

Experimental results confirmed that the integrated system achieved high functional reliability and performance. Simulation testing recorded an average detection accuracy of 95 percent and a mean notification delay below 3 seconds, indicating compliance with real-time communication standards for intelligent transportation services. User evaluation further validated the system's usability, producing an overall satisfaction score of 4.7 on a five-point scale. These results verify that the combination of Geofencing and GIS provides an effective approach for developing adaptive, data-driven monitoring systems that support the advancement of smart mobility within urban environments.

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