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Integration of Location-Based Services Into an Android-Based Mobile GIS for Road Equipment Inventory and Monitoring in Kapuas Regency

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INTEGRATION OF LOCATION-BASED SERVICES INTO AN ANDROID-BASED MOBILE GIS FOR ROAD EQUIPMENT INVENTORY AND MONITORING IN KAPUAS REGENCY

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ABSTRACT:

Road equipment inventory is essential for supporting transportation safety and infrastructure management. However, conventional inventory practices commonly rely on handheld Global Navigation Satellite System (GNSS) devices and paper-based forms, resulting in fragmented spatial information, delayed data synchronization, and inefficient field operations. This study developed and evaluated an Android-based Mobile Geographic Information System (Mobile GIS) integrating Location-Based Services (LBS) and a serverless cloud architecture to support real-time road equipment inventory and monitoring in Kapuas Regency, Indonesia. The proposed system employs automated coordinate acquisition, spatial data binding, cloud-based synchronization, marker clustering, radius-based asset scanning, and route navigation to improve field data collection and management. System functionality was evaluated using Black Box Testing. At the same time, spatial performance was assessed through ground verification of 30 representative asset locations using the Spherical Law of Cosines (SLOC) to quantify horizontal positional deviations. The application successfully integrated 616 road equipment assets into a centralized geospatial database. Functional testing confirmed that all core modules operated successfully under predefined testing scenarios. Spatial validation produced an average horizontal deviation of 3.60 m, with deviations ranging from 0.68 m to 7.71 m, remaining within the expected positioning accuracy of navigation-grade smartphone GNSS devices. The serverless architecture also simplified database management by reducing dependence on dedicated physical servers while maintaining reliable synchronization between spatial attributes and multimedia data. These findings demonstrate that integrating LBS with Mobile GIS provides an efficient and practical framework for road equipment inventory, spatial data management, and transportation infrastructure monitoring in local government agencies.

Keywords: *Mobile GIS; Location-Based Service (LBS); GNSS; Road Infrastructure Inventory; Serverless Geospatial Database; Spatial Data Acquisition*

1. INTRODUCTION

Road transportation infrastructure plays a critical role in promoting traffic safety, enhancing regional mobility, and supporting economic development (Law of the Republic of Indonesia Number 22 of 2009 concerning Road Traffic and Transportation). Essential road equipment, including traffic signs (Minister of Transportation Regulation No. PM 13/2014), traffic signalling devices (APILL), and corner mirrors, require systematic management and maintenance. The Kapuas Regency Transportation Agency is responsible for overseeing these safety components and maintains a secondary repository comprising 616 road equipment assets (Minister of Transportation Regulation No. PM 49/2014; Minister of Transportation Regulation No. PM 48/2023).

Despite the considerable number of assets, field updates are still conducted using conventional and inefficient workflows (M. A. Rohman et al., 2018). Asset coordinates are collected with handheld GPS devices, while damage descriptions are recorded separately on paper, requiring manual post-processing and increasing the risk of data synchronization errors and human error. The absence of real-time spatial mapping limits policymakers' ability to identify clusters of asset damage, efficiently deploy repair teams, and optimize field logistics (Pakaya et al., 2020; Rafi et al., 2024). Although previous studies have demonstrated the utility of Mobile GIS for field mapping, most implementations have emphasized visualization rather than integrated field data acquisition, spatial validation, and cost-effective cloud synchronization.

Mobile Geographic Information Systems (Mobile GIS) integrated with Location-Based Services (LBS) provide an alternative for recording and validating spatial objects directly in the field using smartphones. LBS utilizes embedded Global Navigation Satellite System (GNSS) sensors, allowing smartphones to serve as immediate tools for horizontal coordinate acquisition (Kusuma et al., 2020; Irbad et al., 2022). However, the long-term adoption of geospatial systems is often constrained by database infrastructure requirements (Apriana et al., 2014; M. A. Rohman et al., 2018). Conventional GIS solutions typically depend on relational Database Management Systems (DBMS) such as PostgreSQL/PostGIS, which necessitate dedicated servers or virtual private servers, network and security configurations, and specialized technical personnel. These requirements can make conventional server-based systems unsustainable when budgets and technical resources are limited (Siahaan et al., 2025; Sutanto et al., 2018). Furthermore, the performance of Mobile GIS is contingent upon the stability of satellite positioning to ensure reliable spatial data acquisition (Wellenhof & Lichtenegger, 2007).

This research addresses operational and infrastructure limitations by developing a Flutter-based Mobile GIS ecosystem, referred to as the Geographical Road Infrastructure Location-Based System (Georoad-LBS). The system combines mobile GIS functionality with a serverless cloud architecture, employing Google Sheets as a textual database, Google Drive for multimedia storage, and Google Apps Script as a JSON-based asynchronous web service bridge for field-data synchronization (Pakaya

et al., 2020). This hybrid architecture reduces dependence on dedicated physical servers and associated maintenance, enabling future operational efforts to focus primarily on expanding cloud storage capacity (Rafi et al., 2024; Siahaan et al., 2025; Sutanto et al., 2018).

To evaluate the reliability of the proposed system, this study utilizes both functional testing and post-field geometric assessment using the Spherical Law of Cosines (SLOC). The SLOC method measures horizontal positional deviations between existing inventory coordinates and field observations at 30 ground-checking points (Chaidir & Akil, 2022). Furthermore, the Flutter-based client system is assessed through an integrated development environment simulation to determine its effectiveness in detecting location spoofing and maintaining spatial database integrity (Hagos, 2018; Alfarisyi Sholahuddin, 2024). The primary objective is to develop and assess an integrated Mobile GIS platform for road equipment inventory, spatial validation, real-time synchronization, and location-authenticity verification within a cost-effective serverless architecture.

2. STUDY AREA

The research was conducted in Kapuas Regency, Central Kalimantan Province, Indonesia. Kapuas Regency is situated between 0°08′48″ and 3°27′00″ South Latitude and between 112°02′36″ and 114°44′00″ East Longitude, spanning the Equator (**Fig. 1**). This location was purposively selected due to its alignment with the operational jurisdiction of the Kapuas Regency Transportation Office and its suitability as a case study for the development and implementation of the proposed Mobile GIS-based road equipment inventory and monitoring system. The secondary road equipment inventory is administratively distributed across the sub-districts of East Kapuas, Kapuas Hilir, Selat, Basarang, Pulau Petak, Kapuas Murung, and Dadahup. Preserving this administrative structure maintains the integrity of the agency's inventory and facilitates systematic database organization, location-based service (LBS) synchronization, and migration to a cloud-based spatial database.

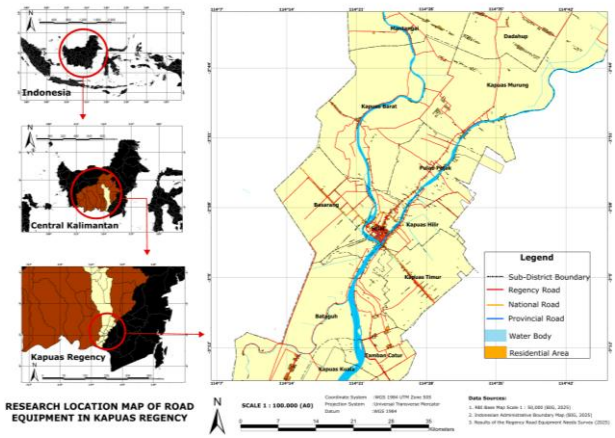


Fig. 1. Research Location

3. DATA AND METHODS

3.1. Position Information System (GPS) and Location-Based Services (LBS)

Modern positioning technology relies on the Global Navigation Satellite System (GNSS) as the primary source of spatial reference data for navigation and location-based applications. Abidin (2007) states that the Global Positioning System (GPS) delivers positioning, velocity, and timing information via satellite-based measurements. In smartphone applications, embedded GNSS receivers enable the automatic acquisition of geographic coordinates through satellite signal reception (Hati et al., 2013). GPS positioning depends on signal measurements from multiple satellites, with a minimum of four satellites required for three-dimensional positioning. The resulting geographic coordinates are typically referenced to the World Geodetic System 1984 (WGS 84) (Abidin, 2007).

Navigation-grade GNSS receivers integrated into smartphones typically provide horizontal positioning accuracy within the range of 3 to 10 meters. Although this accuracy is lower than the centimetre- to millimetre-level precision of geodetic-grade GNSS instruments, it remains adequate for infrastructure inventory, basic mapping, and navigation applications. Smartphone GNSS positioning accuracy may be influenced by satellite geometry, atmospheric conditions, signal attenuation, and multipath effects resulting from nearby buildings or vegetation (Stefano et al., 2024; Putri et al., 2020). Consequently, the latitude and longitude obtained from the smartphone GNSS sensor serve as the primary spatial dataset in this study (Ikawati & Santosa, 2023).

Location-Based Services (LBS) enhance positioning functionality by integrating geographic coordinates with mobile devices, communication networks, service providers, and spatial databases to deliver contextual location-based information (Pakaya et al., 2020; Chandra & Rahmaddeni, 2013; Susanty, 2019; Ratih Ningtias, 2020; Yuwamahendra & Ratnasari, 2020). While GPS primarily determines the user's geographic position, LBS utilizes this information to enable functions such as interactive mapping, proximity-based asset searching, route navigation, and location-aware services. Additionally, LBS applications may implement distance-computation methods to determine the proximity between users and target locations (Basri et al., 2021).

This study implemented GNSS positioning and LBS functions to support automatic coordinate acquisition, nearby asset identification, route navigation, interactive marker visualization, and field data synchronization within the proposed Mobile GIS platform. The application of digital map markers facilitates the identification and visualization of road equipment locations during field inventory activities (Hati et al., 2013).

3.2. Mathematical Formulation of Distance Computation (Spherical Law of Cosines)

The Spherical Law of Cosines (SLOC) is a fundamental equation in spherical trigonometry used to calculate the great-circle distance between two geographic coordinates by assuming a spherical Earth (A. Rohman et al., 2022). In this study, SLOC was used to quantify the horizontal positional

deviation between existing road equipment coordinates maintained by the Kapuas Regency Transportation Agency and coordinates acquired through the proposed Mobile GIS application during field validation. The horizontal distance between two geographic positions was calculated as:

$$d = \arccos(\cos(90^\circ - \phi_1) \cdot \cos(90^\circ - \phi_2) + \sin(90^\circ - \phi_1) \cdot \sin(90^\circ - \phi_2) \cdot \cos(\lambda_1 - \lambda_2)) \cdot R$$

where d is the great-circle distance between two points (m); $\phi 1$ and $\phi 2$ are the latitude coordinates of the existing reference and field-observed points, respectively; $\lambda 1$ and $\lambda 2$ are their corresponding longitude coordinates; and $\boldsymbol{R}$ is the mean Earth radius, set to 6,371,000 m (6,371 km).

Before applying SLOC, latitude and longitude values in decimal degrees were converted to radians using the RADIANS() function in Microsoft Excel. The resulting distance represents the positional deviation between the existing inventory coordinates and field observations. Thus, SLOC was used as a measure of **geometric consistency rather than absolute positioning accuracy**. Centimetre-level accuracy would require survey-grade GNSS with differential correction, such as dual-frequency Real-Time Kinematic (RTK), which was beyond the scope of this study.

The proposed Geographical Road Infrastructure Location-Based System was designed to operate using navigation-grade GNSS receivers embedded in commercial Android smartphones, which typically provide approximately 3–10 m horizontal accuracy depending on satellite geometry (DOP), atmospheric conditions, signal attenuation, and multipath effects (Stefano et al., 2024). Accordingly, the SLOC-based evaluation determines whether the observed positional deviations remain within the expected operational tolerance of navigation-grade GNSS for road equipment inventory and monitoring.

3.3. Cloud Serverless Sync Architecture

The proposed Geographical Road Infrastructure Location-Based System utilizes a Serverless Database as a Service (DBaaS) architecture to enable cloud-based storage and synchronization, eliminating the need for dedicated on-premises servers. Google Apps Script (GAS) serves as lightweight middleware and operates as a Web API gateway between the Flutter-based Mobile GIS application and the cloud database (Buyya et al., 2009).

The mobile application compiles inventory attributes, geographic coordinates, and metadata into JSON format and transmits this data to the Google Apps Script Web App via an HTTP POST request. GAS processes the received data and distributes it to two synchronized cloud services for the storage of spatial attributes and multimedia documentation (Ramadhan et al., 2025):

- Google Sheets API: stores tabular inventory data, including asset identification, road segment details, and geographic coordinates derived from location-based services (LBS).

- Google Drive API: stores field photographs and links each image to its corresponding asset through a unique identification number.

Fig. 2 illustrates the complete workflow for data transmission and synchronization from the Mobile GIS application to the serverless cloud environment.

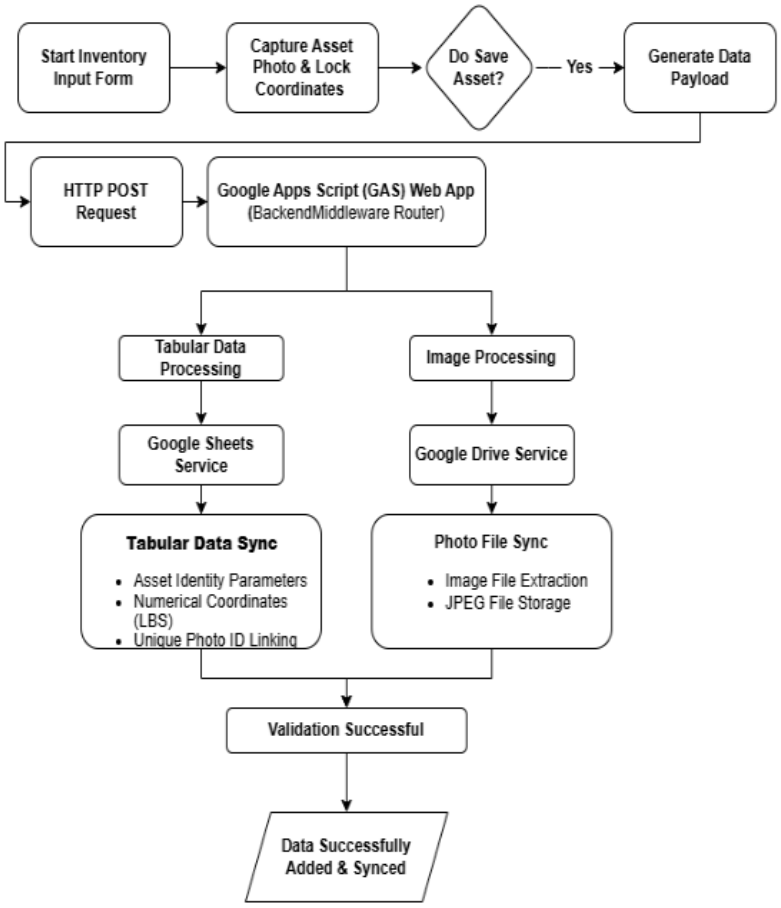


Fig. 2. Serverless Geospatial Data Synchronization Workflow

3.4. Research Flow Diagram

The research methodology consisted of four sequential phases, each comprising specific procedural steps: (1) problem identification and literature review, (2) system development and implementation, (3) field data acquisition and application testing, and (4) spatial validation and functional evaluation. The process commenced with problem identification and data acquisition, proceeded through system design, coding, implementation, and internal testing using the Android Studio emulator. Subsequently, the application was deployed for field validation and functional testing. The final phase involved feature and positional validation prior to the compilation and release of the application.

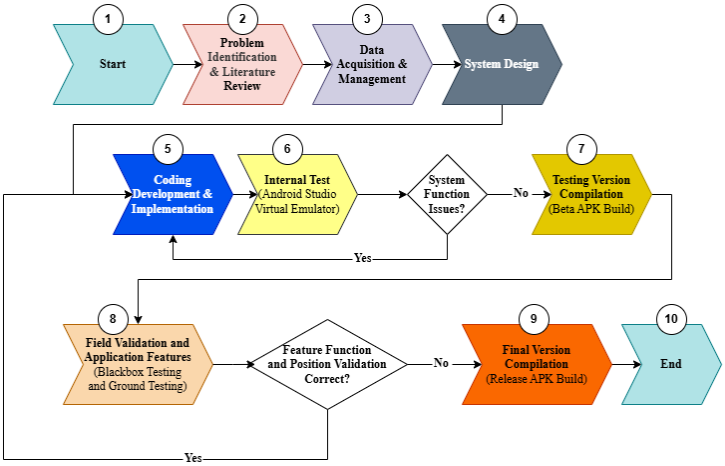


Fig. 3. Overall research methodology adopted in this study.

4. RESULTS AND DISCUSSIONS

4.1. LBS Spatial Logic Functional Testing Through Black Box Testing

The functional performance of the proposed Mobile GIS application was evaluated using Black Box Testing to verify the operational reliability of its Location-Based Service (LBS) components. The evaluation covered six functions: GPS-based position validation, marker clustering, radius-based asset scanning, route navigation, spatial data and multimedia acquisition, and location-spoofing detection. Each function was tested against predefined scenarios and expected system responses, as presented in **Table 1**.

Table 1. Matrix of Functional Test Results of LBS Components and Mobile GIS Control

No.	Function Tested	Testing Scenario	Expected System Response	Status
1	Location-Based Service (LBS) & GPS Validation	Activate position tracking and then turn off GPS.	Live tracking updates the marker and displays a warning notification.	Conform
2	Marker Clustering	Toggle marker grouping in asset-dense areas.	Nearby markers are grouped into numerical cluster symbols to reduce visual overlap.	Conform
3	Radius Scan	Press the “Scan Around” button at the field site.	The system identifies the user's position and lists nearby assets within a maximum radius of 1 km.	Conform
4	Route Navigation	Select a target asset and press the navigation icon.	An external intent launches Google Maps to generate the navigation route.	Conform
5	Add Data & Multimedia	Enter inventory data and capture field photographs.	Geographic coordinates are automatically associated with the	Conform

			inventory form and photographs are uploaded to the cloud.	
6	Location Security (Anti-Fake GPS)	Enable a third-party mock-location application before data input.	The system detects the mock location, blocks data transmission, and displays a warning.	Conform

All six tested functions satisfied the predefined operational requirements. GPS validation prevented records from being created without valid positioning, while marker clustering improved visualization in dense asset areas. The radius scan, route navigation, and automated data acquisition supported field operations, whereas the anti-fake GPS mechanism prevented simulated coordinates from being transmitted. These results demonstrate the functional reliability of the proposed Mobile GIS for road equipment inventory activities.

4.2. LBS-Based Route Navigation for Field Survey Operations

The proposed Mobile GIS application incorporates location-based service (LBS) route navigation to assist field surveyors in locating road equipment assets. As illustrated in **Fig. 4a**, navigation is initiated directly from a selected asset within the application. The system automatically retrieves the geographic coordinates of the selected asset and generates the navigation request, eliminating the need for manual coordinate entry.

Upon execution of the navigation command, the asset coordinates are transmitted to Google Maps via inter-application communication (**Fig. 4b**). Google Maps subsequently generates a navigation route from the surveyor's current location to the selected road equipment asset (**Fig. 4c**). This workflow streamlines access to geographically dispersed assets and minimizes the operational steps required to locate inventory items during field surveys.

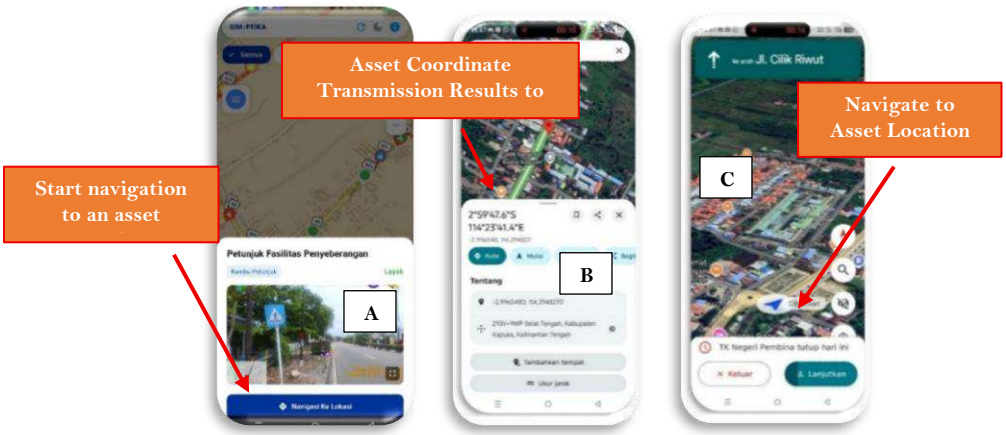


Fig. 4. (A) Initiation of navigation from a selected asset; (b) automatic transfer of asset coordinates to Google Maps; and (c) generated navigation route to the asset location.

4.3. LBS-Based Radius Search for Nearby Road Equipment

The proposed Mobile GIS application utilizes a radius-based spatial query to identify road equipment in proximity to the surveyor's current GNSS position. Activation of the nearby asset scanning command prompts the application to acquire the user's geographic coordinates and filter the inventory based on a predefined search radius.

In this study, the maximum search radius was established at 1 km (1,000 m). Assets within this radius were automatically identified and displayed as an interactive list containing relevant inventory information. This feature enabled field personnel to efficiently locate and inspect nearby road equipment. The successful execution of this function was verified through Black Box Testing, as shown in **Table 1**.

4.4. LBS-Based Automated Spatial Data Acquisition and Cloud Synchronization

The proposed Mobile GIS application automates spatial data acquisition by integrating the smartphone GNSS receiver with the Location-Based Services (LBS) module during field inventory activities. Upon opening the data entry form, the application initializes the GNSS sensor and automatically retrieves the current geographic coordinates, which are then populated into the inventory form without requiring manual coordinate entry (**Fig. 5a**).

Field photographs are captured directly through the application (**Fig. 5b**), ensuring that the geographic coordinates remain associated with the corresponding inventory record. Upon submission (**Fig. 5c**), inventory attributes, coordinates, and image files are packaged into a JSON payload and transmitted via an HTTP POST request to the serverless cloud architecture described in **Fig. 2**. This workflow preserves the association between spatial attributes and photographic documentation during cloud synchronization.

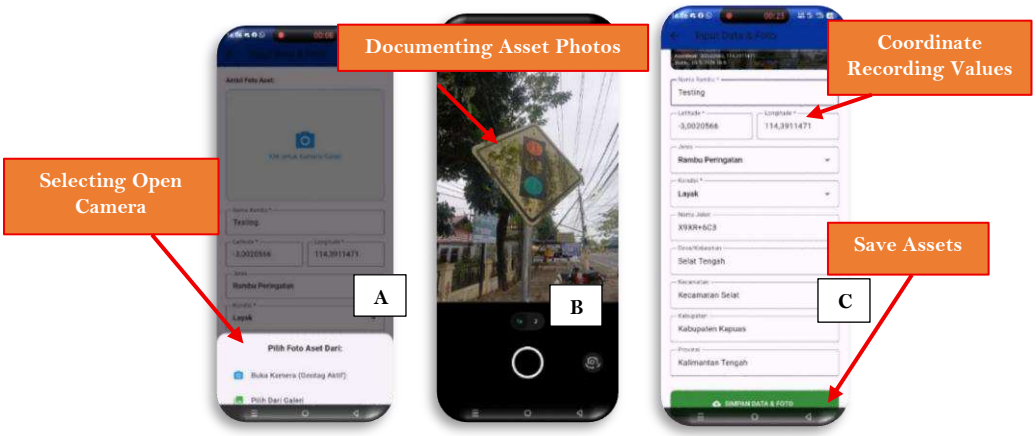


Fig. 5. Automated spatial data acquisition: (a) automatic coordinate acquisition during form initialization; (b) field photograph acquisition; and (c) synchronized storage of inventory attributes and spatial data.

4.5. *Location Security and Spatial Data Integrity*

To ensure the reliability of collected spatial information, the proposed system integrates a location-authenticity verification mechanism utilizing the Android Location.isFromMockProvider API. The evaluation process consisted of three sequential stages: enabling mock-location permission (**Fig. 6a**), activating simulated positioning (**Fig. 6b**), and monitoring the system response when manipulated positioning information was detected (**Fig. 6c**).

The evaluation demonstrated that the application successfully detected the mock-location condition and prevented submission of the affected coordinates. Upon identification of simulated positioning, the system displayed a warning and blocked the asset submission process. This mechanism offers an additional safeguard against location spoofing and supports the integrity of spatial information synchronized with the cloud database.

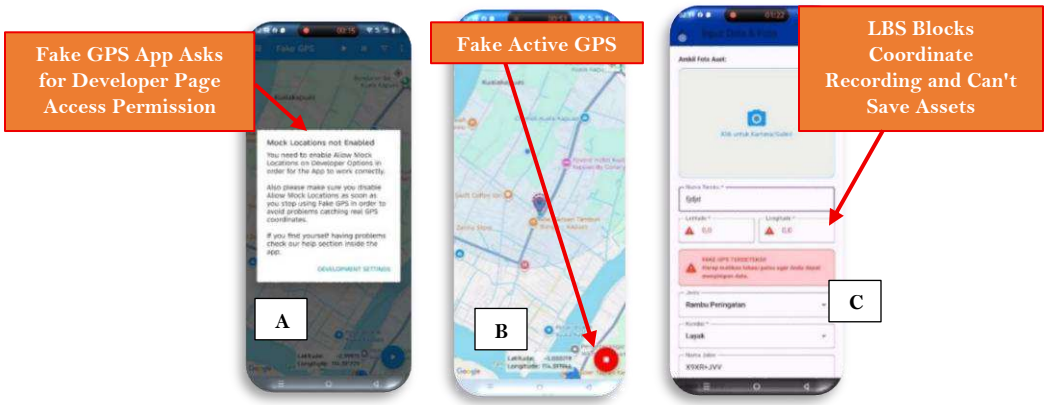


Fig. 6. Verification of spatial data integrity using mock-location detection: (a) enabling mock-location permission; (b) simulated coordinate manipulation; and (c) automatic blocking of invalid coordinate submission by the LBS module.

4.6. *Quantitative Analysis and Spatial Distribution of Road Equipment Assets*

The migration of the existing road equipment inventory to the proposed Mobile GIS platform resulted in the consolidation of 616 **assets** into a centralized spatial database. This inventory now provides the baseline for field validation and future updates, encompassing five administrative regions in Kapuas Regency, as indicated in **Table 2**.

Table 2. Quantitative Volume Distribution of Road Equipment Assets by Administrative Region

Code	Sub-District Territorial Coverage	Total Assets
W-1	Kapuas Timur Sub-District and Kapuas Hilir Sub-District	102
W-2	Selat Sub-District	307
W-3	Basarang Sub-District	95

W-4	Pulau Petak Sub-District	56
W-5	Kapuas Murung Sub-District and Dadahup Sub-District	56
Overall Total		616

The quantitative distribution reveals that Selat (W-2) contains the largest number of recorded assets, with 307 units (49.8%), representing nearly half of the total inventory. In contrast, Pulau Petak (W-4) and Kapuas Murung–Dadahup (W-5) have the smallest inventories, each with 56 assets (9.1%). This distribution demonstrates substantial variation in road equipment inventory among the administrative regions.

Table 3. Classification of Road Equipment Asset Objects Based on Territorial Territory

No	Asset Object Type Classification	W-1	W-2	W-3	W-4	W-5
1	Traffic Sign Command Type	1	21	1	0	0
2	Traffic Signs Guide Type	26	70	23	23	15
3	Traffic Sign Prohibition Type	28	71	36	33	41
4	Traffic Sign Warning Type	35	132	27	0	0
5	Traffic Light Signal Devices (APILL)	12	6	8	0	0
6	Road Safety Devices (Traffic Mirrors)	0	4	0	0	0
7	Unknown Types of Signs	0	3	0	0	0
Total Asset		102	307	95	56	56

Table 3 indicates that warning signs and prohibition signs constitute the predominant asset categories, whereas traffic mirrors, APILL, and unidentified signs are present in significantly smaller quantities. The distribution of these assets also differs among administrative regions. For instance, warning signs are primarily located in W-1, W-2, and W-3, while prohibition signs are distributed across all five regions.

Fig. 7 presents the spatial distribution of the 616 road equipment assets. The assets are categorized by equipment type, which facilitates the examination of their geographic distribution and concentration across the five administrative regions. This map offers a spatial perspective on the inventory that supplements the quantitative data in Tables 2 and 3.

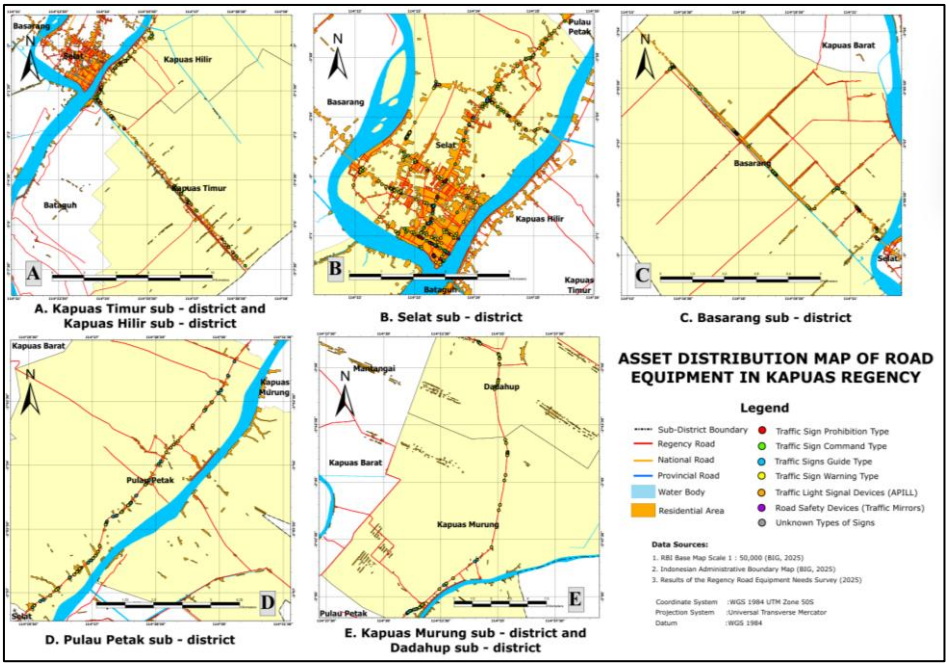


Fig. 7. Spatial distribution of road equipment assets classified by asset type across the five administrative regions of Kapuas Regency.

4.7. Ground Validation of Positional Consistency Using the Spherical Law of Cosines

The positional consistency of the proposed Mobile GIS application was assessed through ground validation involving **30 representative road equipment samples** distributed throughout the study area. Table 4 displays six representative samples, comparing the existing inventory coordinates (Point A) with those obtained via the Location-Based Services (LBS) module during field observations (Point B).

The horizontal positional deviation between the two coordinate datasets was calculated independently using the **Spherical Law of Cosines (SLOC)** described in Section 3.2. Coordinates recorded by the Mobile GIS application were extracted from the cloud database and subsequently processed in Microsoft Excel to calculate the linear distance between the existing inventory coordinates and field observations. This independent post-processing procedure ensured that the positional evaluation was separated from the application itself.

Table 4. Representative Samples of Horizontal Positional Deviations Obtained from Ground Validation

No	Sample ID	Code Sub-District	Geodetic Coordinates (Latitude / Longitude)	Data Category	Linear Deviation (m)
1	605	W-1	-3.030513/114.39753	Baseline Data	0,68
	627		-3.0305167/114.39753	Captured (LBS)	
2	502	W-1	-3.010261/114.408850	Baseline Data	7,71

	623		-3.0103076/114.40879	Captured (LBS)	
3	539	W-5	-2.680948/114.581123	Baseline Data	5,56
	631		-2.6808991/114.58113	Captured (LBS)	
4	406	W-4	-2.953276/114.429651	Baseline Data	2,42
	636		-2.9532639/114.42966	Captured (LBS)	
5	237	W-3	-2.979319/114.353449	Baseline Data	4,71
	641		-2.979334/114.353471	Captured (LBS)	
6	482	W-2	-2.986684/114.417999	Baseline Data	3,66
	621		-2.9867083/114.417976	Captured (LBS)	

The calculated horizontal positional deviations ranged from 0.68 m to 7.71 m among the 30 validation samples. The observed deviations indicate meter-level geometric consistency between the existing inventory coordinates and the coordinates acquired through the Mobile GIS application. The results therefore demonstrate that the proposed system provides positional information suitable for road equipment inventory and monitoring activities.

It should be emphasized that this evaluation represents a geometric consistency assessment rather than an absolute positioning accuracy test. Achieving centimetre-level positional accuracy requires survey-grade dual-frequency GNSS observations supported by Real-Time Kinematic (RTK) corrections, which were beyond the scope of the present study.

The observed positional deviations should be interpreted as the combined uncertainty of two independent datasets. The existing inventory coordinates were originally collected using handheld navigation GPS devices and therefore also contain inherent positional uncertainty. Likewise, the positional quality of smartphone GNSS observations is affected by satellite geometry, multipath effects, and local environmental conditions during field acquisition. Consequently, the measured deviations cannot be attributed solely to the proposed Mobile GIS application but rather represent the cumulative uncertainty of both coordinate sources.

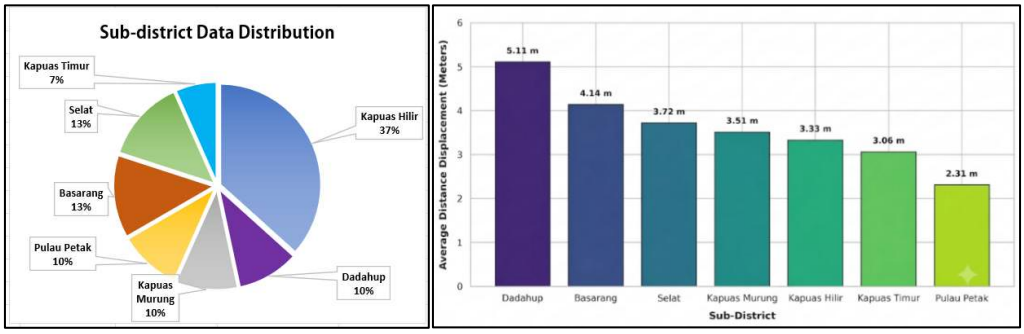


Fig. 8. Distribution of the 30 ground-checking points and mean positional deviation by sub-district.

A representative field validation workflow is illustrated in **Fig. 9**. The example shows the relationship between the existing inventory location and the surveyor's position during field acquisition (**Fig. 9a**), the coordinate values recorded through the Mobile GIS application (**Fig. 9b**), and the resulting synchronized asset marker after cloud submission (**Fig. 9c**). This workflow demonstrates how field observations were spatially linked to the existing inventory and subsequently incorporated into the centralized database.

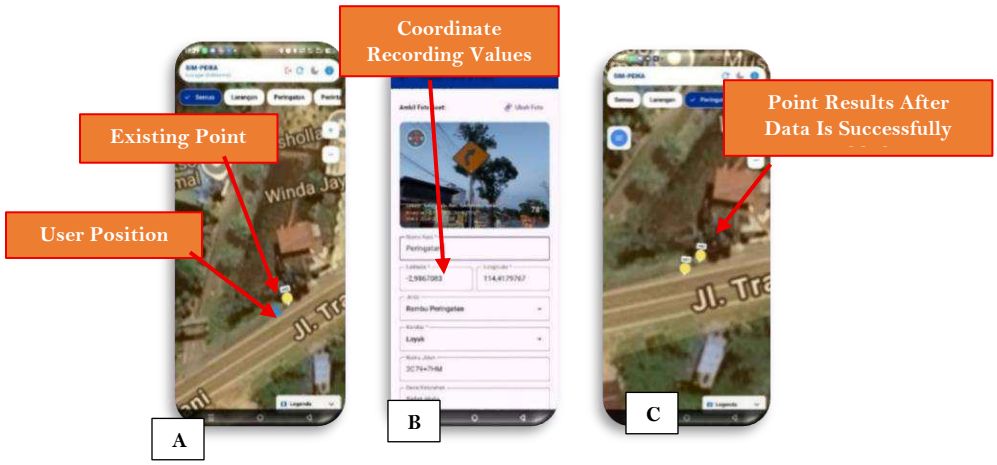


Fig. 9. Example of ground validation showing (a) the existing inventory location and surveyor position; (b) field coordinate acquisition through the Mobile GIS application; and (c) synchronized asset visualization after cloud submission..

4.8. Operational Comparison Between Conventional and Mobile GIS-Based Inventory Methods

To evaluate the operational advantages of the proposed system, the developed Mobile GIS platform was qualitatively compared with the conventional inventory workflow based on handheld GPS and separate camera use. The comparison considered five operational aspects: data input, position validation, file management, data updating, and integration of field information. The results are summarized in **Table 5**.

The comparison demonstrates that the proposed platform reduces the number of discrete processing steps required in conventional field inventory. Coordinate acquisition, attribute recording, photographic documentation, and cloud synchronization are integrated into a unified workflow, thereby minimizing the need for manual association between spatial and non-spatial information.

The serverless architecture enables the system to function without the need for dedicated on-premises spatial database infrastructure. Nevertheless, scalability is constrained by the capacity and service limitations of the chosen cloud platform. Consequently, the primary operational advantage identified in this study is the simplification of field-to-database workflows, rather than a measurable reduction in total operational cost.

Table 5. Comparison of Operational Characteristics Between Conventional and Mobile GIS-Based Inventory Methods

Yes	Parameter	Conventional Method (GPS & Separate Camera)	Integrated LBS Platform
1	Input Method	Coordinates, photos, and field notes are combined manually in the office.	Attributes, geotagged photos, and coordinates are completed in a single application.
2	Position Validation	The raw file (.gpx/.kml) is plotted manually on desktop GIS.	Positions are validated and mapped on the screen in *real-time*.
3	File Management	Manual photo file transfer (high risk of being swapped/lost).	Photos are automatically bound with the unique ID of the asset on cloud *storage*.
4	Data Updates	Delays due to re-entry (not *real-time*) processes.	Data updates run instantly (*real-time synchronization*).

5. DISCUSSION

The results demonstrate that integrating Location-Based Services (LBS), Mobile Geographic Information Systems (GIS), and serverless cloud services transforms conventional road equipment inventory into a unified field-to-database workflow. Functional evaluation confirmed that all six tested modules GPS validation, marker clustering, radius-based search, route navigation, spatial data and multimedia acquisition, and mock-location detection met the predefined operational requirements, thereby supporting routine road equipment inventory and monitoring.

The operational comparison indicates that **workflow integration** is the primary advantage of the proposed platform. Unlike conventional methods that separate coordinate recording, photographic documentation, attribute entry, and database updating, the proposed system consolidates these activities within a single mobile workflow and directly links field observations to cloud-based records. This integration reduces repetitive data handling and improves the consistency of both spatial and attribute information.

Positional validation further supports the system's suitability for inventory applications. Thirty ground-validation samples produced a mean horizontal deviation of approximately **3.60 meters, indica**ting geometric consistency between two independent coordinate datasets rather than absolute positioning accuracy. Because both handheld GPS and smartphone-derived coordinates have inherent uncertainties, the observed deviation cannot be attributed solely to the proposed application. Additional factors, including satellite geometry, environmental conditions, and multipath effects, may also contribute to this variation.

The serverless architecture offers an alternative to traditional server-based deployment by utilizing cloud services for data and multimedia storage, with Google Apps Script functioning as the communication layer. This approach simplifies infrastructure requirements for the implemented prototype and enables centralized synchronization of field observations. However, larger-scale deployment should account for cloud storage capacity, service quotas, network dependency, and long-term data management.

The mock-location detection mechanism adds an additional spatial integrity control by preventing data submission when simulated positioning is detected. This feature is particularly relevant for field inventory applications where coordinate validity is essential. However, the mechanism should be considered a safeguard against detected mock-location conditions rather than a guarantee of absolute authenticity for every Global Navigation Satellite System (GNSS) observation.

In summary, the findings indicate that the proposed Mobile GIS provides a practical, integrated workflow for road equipment inventory by combining spatial acquisition, field documentation, navigation, cloud synchronization, and location-integrity control within a single platform.

6. CONCLUSIONS

An Android-based Mobile GIS platform was developed through the integration of Location-Based Services, GNSS-based positioning, automated spatial data acquisition, serverless cloud synchronization, and location-integrity control to support road equipment inventory and monitoring in Kapuas Regency.

Black Box Testing demonstrated that all six tested LBS-related modules met their predefined operational requirements, which included GPS validation, marker clustering, radius-based asset search, route navigation, spatial data and multimedia acquisition, and mock-location detection. Additionally, the system integrated **616 existing road equipment assets** into a centralized spatial database.

Ground validation of **30 representative samples** yielded a mean horizontal positional deviation of approximately **3.60 m**, demonstrating meter-level geometric consistency between the existing inventory coordinates and those acquired using the Mobile GIS application. However, this result does not represent absolute GNSS accuracy, as both coordinate datasets possess independent positional uncertainties.

The proposed serverless workflow consolidates coordinate recording, photographic documentation, attribute management, and cloud synchronization within a single field application, thereby reducing manual processing between field acquisition and database updating. This system offers a practical solution for routine road equipment inventory and monitoring. Future development

should prioritize survey-grade GNSS integration, large-scale cloud deployment, and enhanced spatial analytics for infrastructure condition assessment.

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8. GenAI Statement

The authors used ChatGPT to assist with language editing, including improvements in clarity, coherence, and formatting. The authors take full responsibility for the scientific content, analysis, interpretation, and conclusions presented in this manuscript.

9. Declarations

Conflict of Interest

The authors declare no conflict of interest.

Consent to Publish

Not applicable. No identifiable personal information or individual participant data are presented in this study.

Consent to Participate

Not applicable. This study did not involve human participants or the collection of personal or sensitive individual data.

Ethics Approval

Not applicable. The study involved road equipment inventory, geospatial data acquisition, system development, and field validation and did not involve human clinical research or animal experimentation.

Author Contributions

Faris Ade Irawan: conceptualization, methodology, system design, data analysis, validation, and manuscript preparation. Muhammad Syahid: system development, field data acquisition, and validation. Ucu Syauqi: system development, field data acquisition, and manuscript review. All authors approved the final version of the manuscript.

Data Availability

The datasets generated and analysed during the current study are available from the corresponding author on reasonable request. Access to institutional road equipment inventory data may be subject to permission from the relevant authority.

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