© JAN 2026 | IRE Journals | Volume 9 Issue 7 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV9I7-1713232

User-Centered Design and Real-Time Geospatial Integration in Intelligent Mobile Platforms for Urban Fire Emergency Management

OSUEKE CHAMBERLAIN C.[1], BOURDILLON O OMIJEH[2], U. A OKENGWU[3]
[1] *Center for Information and Telecommunication Engineering, University of Port Harcourt*
[2] *Professor, Department of Electrical Electronics Engineering, University of Port Harcourt*
[3] *Department of Computer Science, University of Port Harcourt.*

Abstract- Urban fire emergency management in developing cities is constrained by delayed reporting, fragmented communication, and limited situational awareness. This study presents a user-centered, mobile–cloud emergency response platform that integrates real-time geospatial intelligence with asynchronous communication to improve fire incident reporting and response coordination. Using Port Harcourt Local Government Area (PHALGA), Nigeria, as a case study, the system was designed following human–computer interaction principles and implemented with a React Native mobile client, a Node.js backend, Socket.IO for real-time event synchronization, and cloud-hosted geospatial services. A Design Science Research methodology guided iterative design, implementation, and evaluation. Usability was assessed using the System Usability Scale (SUS), while operational performance was evaluated through geolocation accuracy, task completion time, response acknowledgment latency, and coordination efficiency under simulated and controlled field conditions. Results indicate a SUS score of 84 percent, average task completion time of 2.8 seconds, geolocation accuracy exceeding 95 percent, and substantial improvement in response coordination compared with manual reporting methods. The findings demonstrate that integrating user-centered design with real-time geospatial intelligence significantly enhances adoption, trust, and operational effectiveness of mobile fire emergency management platforms in resource-constrained urban environments. (User-centered design, mobile emergency systems, real-time geospatial integration, fire emergency management)

I. INTRODUCTION

TFire emergencies remain a persistent threat in rapidly urbanizing cities, particularly in developing regions where infrastructure limitations and population density exacerbate response challenges. In Port Harcourt and similar urban centers, fire incidents are often reported through manual phone calls or physical visits to fire stations. Such approaches lead to delays, incomplete situational data, and inefficient resource deployment.

Advances in mobile computing, cloud platforms, and geospatial services have enabled new forms of emergency response that support real-time reporting, GPS-based localization, and dynamic visualization. However, many existing solutions emphasize technical performance while neglecting usability, cognitive load, and user trust. In emergency contexts, systems that are difficult to use are often abandoned, regardless of their computational sophistication.

This study argues that effective emergency management is a socio-technical problem, requiring the integration of robust system architecture with user-centered interface design. By embedding real-time geospatial intelligence into an intuitive mobile platform, citizens can act as first notifiers, responders gain situational awareness through live maps, and administrators can coordinate resources dynamically. The work contributes a holistic framework that addresses both human and technical dimensions of urban fire emergency management..

II. REVIEW AND RESEARCH GAPS

Early mobile emergency systems relied on SMS and basic GPS integration. Misra et al. (2016) demonstrated that mobile platforms improve incident reporting speed, but their SMS-based architecture lacked real-time feedback and scalability. Ogie and Perez (2020) later emphasized community participation in fire alerts, yet their system offered limited geospatial visualization and no dynamic tracking of responders.

A. Cloud-Based Emergency Management

Cloud computing has enabled scalable data aggregation and multi-agency coordination. Qiu, Buyya, and Yang (2014) showed that cloud platforms enhance disaster information sharing, while Rahman et al. (2019) demonstrated improved availability using cloud-hosted emergency frameworks. Despite these advances, many systems still rely on synchronous REST communication, which introduces latency under concurrent use.

B. Real-Time Geospatial Integration

Geospatial technologies are critical for situational awareness. Lee and Walle (2021) reported that multimedia and map-based reporting improves incident assessment accuracy by 38 percent. Zhang et al. (2022) demonstrated that dynamic map-based dispatch significantly reduces response time, yet their solution assumed high-quality network infrastructure unavailable in many African cities.

C. User-Centered Design and Usability

Human–computer interaction research highlights usability as a determinant of emergency system adoption. Alraja et al. (2021) found that intuitive interfaces improve adoption rates by up to 60 percent. Kim and Kim (2023) further showed that real-time feedback mechanisms increase user trust and sustained usage in emergency reporting apps. However, few studies combine usability evaluation with quantitative performance metrics.

D. Research Gap

Existing studies either emphasize technical performance or user experience, rarely integrating both within a single evaluation framework. Additionally, limited research addresses real-time geospatial emergency systems tailored for developing urban contexts. This study bridges these gaps by integrating user-centered design, real-time geospatial intelligence, and cloud-based evaluation in one unified framework.

III. METHODOLOGY

A. 3.1 Research Design

A Design Science Research (DSR) methodology was adopted, consisting of problem identification, system design, implementation, evaluation, and iterative optimization.

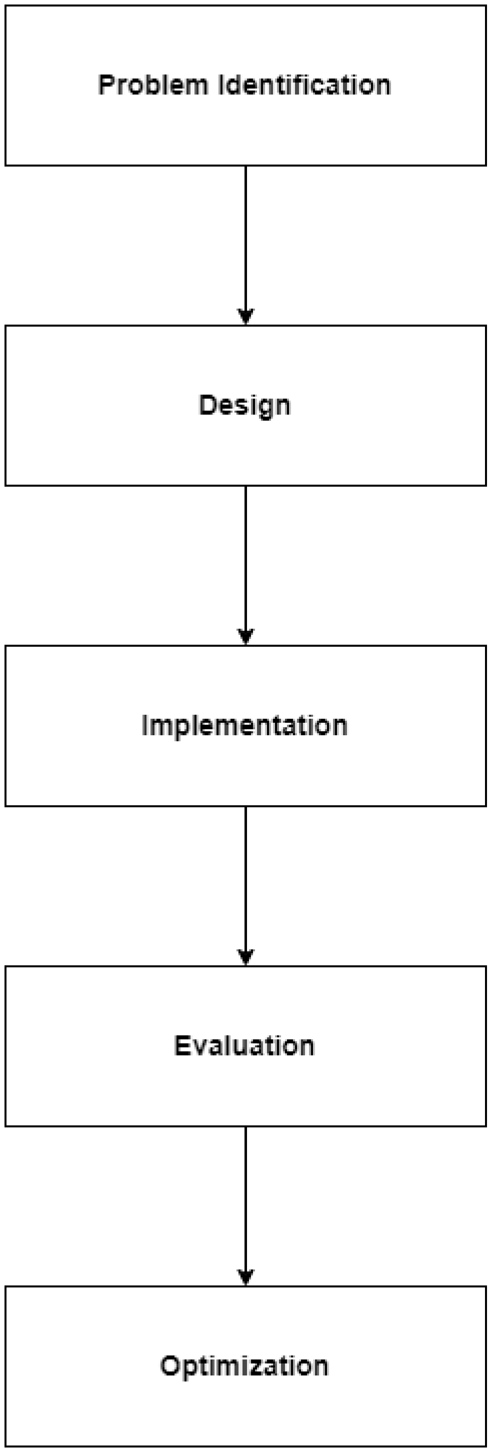

Figure 1. Design Science Research process for the proposed emergency platform.

B. System Architecture

The platform comprises four tightly integrated layers:

Mobile Client Layer – React Native application for citizens and responders.

Application Layer – Node.js and Express backend.

Communication Layer – Socket.IO for asynchronous, real-time event handling.

Data and Geospatial Layer – PostgreSQL for structured records, MongoDB for event logs, and Mapbox/Google Maps APIs for spatial services.

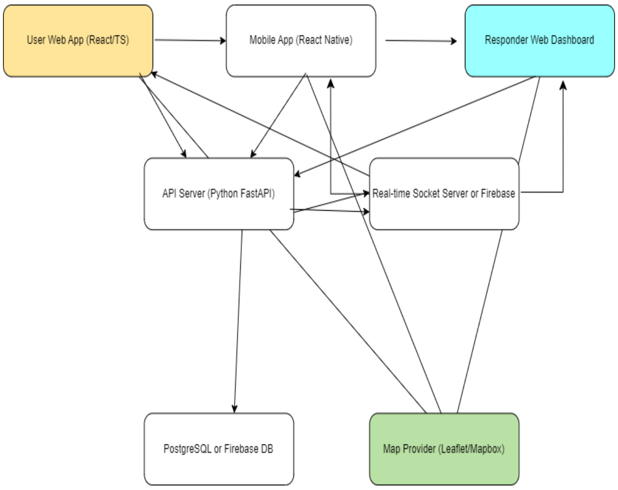

Figure 2. High-level architecture of the mobile–cloud emergency response system.

C. Real-Time Geospatial Modeling

Geolocation accuracy was evaluated using the Haversine distance:

$$d = 2r \arcsin\left(\sqrt{\sin^2\left(\frac{\Delta\phi}{2}\right) + \cos(\phi_1)\cos(\phi_2)\sin^2\left(\frac{\Delta\lambda}{2}\right)}\right)$$

where (r) is Earth's radius, (ϕ) latitude, and (λ) longitude.

D. Usability Measurement

System usability was assessed using the System Usability Scale (SUS):

$$SUS = 2.5 \times \sum_{i=1}^{10} s_i$$

where (s_i) represents the adjusted Likert response for each item.

E. Performance Metrics

The following metrics were collected:

Task completion time

Response acknowledgment delay

Geolocation accuracy

User satisfaction and adoption indicators

IV. RESULTS AND DISCUSSION

A. Usability Results

Table 1. Usability Evaluation

Metric	Value
SUS Score	84
Avg. Task Completion Time	2.8 s
User Satisfaction	High

A SUS score of 84 indicates excellent usability, confirming the effectiveness of the user-centered design approach.

B. Geospatial Accuracy

Table 2. Geospatial Performance

Metric	Result
Mean Location Error	< 10 m
Accuracy Rate	> 95 %

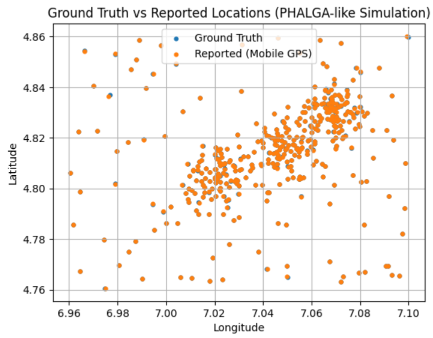

Figure 3. Example plot of geolocation error distribution.

C. *Response Coordination Efficiency*

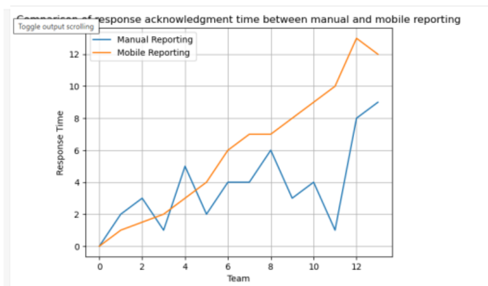

Figure 4. Comparison of response acknowledgment time between manual and mobile reporting.

D. Discussion

The results demonstrate that integrating real-time geospatial intelligence with user-centered interfaces significantly enhances emergency coordination. Automated GPS capture and live map visualization reduced ambiguity, while instant feedback improved trust and adoption. Compared with manual reporting, the platform provided faster, more accurate, and context-rich incident information, validating the socio-technical design approach..

V. CONCLUSION

This study developed and evaluated an intelligent mobile platform for urban fire emergency management that integrates user-centered design with real-time geospatial intelligence. The system achieved high usability, accurate location tracking, and improved coordination efficiency, addressing both human and technical limitations of conventional emergency reporting. The framework is adaptable to other urban emergencies and offers a scalable pathway toward resilient, citizen-driven emergency management in developing regions. Future work will integrate predictive analytics, AI-based prioritization, and edge intelligence to further enhance decision-making and response effectiveness.

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