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A data-driven GIS-integrated platform-agnostic system improved the latency of computational imaging of displaced persons during disasters

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ABSTRACT

Disaster-induced displacement remains a significant global challenge, requiring real-time tracking, efficient resource allocation, and coordinated emergency response. Traditional disaster management systems often suffer from fragmented information, high latency, and platform dependency, limiting their effectiveness in large-scale crises. This study introduces a GIS-integrated, platform-agnostic system designed for latency-optimized computational imaging of displaced persons, enhancing response efficiency and data accuracy. By leveraging geospatial analytics, artificial intelligence, and high-frequency data processing, the system enables real-time visualization and tracking of affected populations across multiple devices and infrastructures. Unlike existing disaster platforms, the proposed system emphasizes low-latency computational imaging and bidirectional interaction between displaced persons and LGUs. A mobile-based reporting tool allows evacuees and responders to transmit location-based data, while a web-based dashboard provides government agencies with dynamic mapping, predictive analytics, and real-time situational awareness. System evaluation based on ISO/IEC 25010 standards yielded the following scores: Functionality (81.6% for displaced persons, 97.3% for local government), Reliability (80.8%, 93.3%), Suitability (81.4%, 96.0%), and Performance Efficiency (79.9%, 95.0%), with an overall average of 80.9% for displaced persons and 95.4% for local government users. In conclusion, the proposed system establishes a scalable and adaptive framework for disaster response and humanitarian operations, addressing challenges in volcanic eruptions, earthquakes, hurricanes, and other large-scale crises. The results demonstrate high system usability and effectiveness, ensuring seamless cross-platform interoperability and improving emergency response efforts through real-time, data-driven decision-making.

Keywords: field responders, disaster risk reduction, cross-platform, spatial information, mobile application

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1. Introduction

Disaster-induced displacement poses significant challenges to emergency response efforts, necessitating efficient tracking, resource allocation, and coordination. Traditional disaster management systems often encounter issues such as fragmented information, high latency, and platform dependency, which hinder effective responses during large-scale crises. The integration of Geographic Information Systems (GIS) has emerged as a pivotal solution in addressing these challenges. GIS technology facilitates the collection, analysis, and visualization of geospatial data, thereby enhancing decision-making processes in disaster management.

GIS technology has been instrumental in various aspects of disaster management, including risk assessment, emergency response, and recovery planning. For instance, the Federal Emergency Management Agency (FEMA) utilizes GIS to support the emergency management community with geospatial information, services, and technologies, aiding in preparation, protection, and recovery efforts [1]. Similarly, the International Organization for Migration (IOM) employs GIS tools in its Displacement Tracking Matrix (DTM) to gather and analyze data on the mobility, vulnerabilities, and needs of displaced populations, enabling better-targeted assistance [2].

Recent advancements have demonstrated the efficacy of GIS in disaster scenarios. For instance, during the 2024 Valparaíso wildfires in Chile, a data visualization approach was employed to support rapid humanitarian response, aiding in the identification of spatial patterns of population displacement [3]. Another notable example is the development of an integrated geospatial information service system for disaster management in China, which addresses challenges such as fragmented data and inefficient resource utilization. This system employs a Focusing Service Mechanism to dynamically allocate resources, thereby enhancing the efficiency of disaster response operations [4]. While platforms such as FEMA GIS Hub and IOM DTM provide centralized geospatial monitoring, they primarily rely on periodic reporting and platform-specific workflows. The proposed system is novel in its integration of latency-optimized computational imaging, real-time mobile field reporting, and cloud-based GIS analytics within a platform-agnostic architecture, enabling continuous and bidirectional interaction between displaced persons and decision-makers.

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In this study, the integration of mobile-based reporting tools and web-based dashboards facilitates the transmission of location-based data by evacuees and responders, while providing government agencies with dynamic mapping, predictive analytics, and real-time situational awareness. This approach seeks to eliminate data silos and enable cross-platform interoperability, thereby establishing a scalable and adaptive framework for disaster response and humanitarian operations worldwide. The system aims to address the critical need for real-time tracking and efficient resource allocation in disaster-induced displacement scenarios by integrating advanced GIS technologies and data-driven methodologies.

2. Materials and methods

The system comprises three core components: field mobile applications, cloud GIS, and a web-based platform. These components function together to facilitate real-time data collection, processing, and visualization, thereby improving disaster response and management. Figure 1 shows the architecture of the system, with each component described.

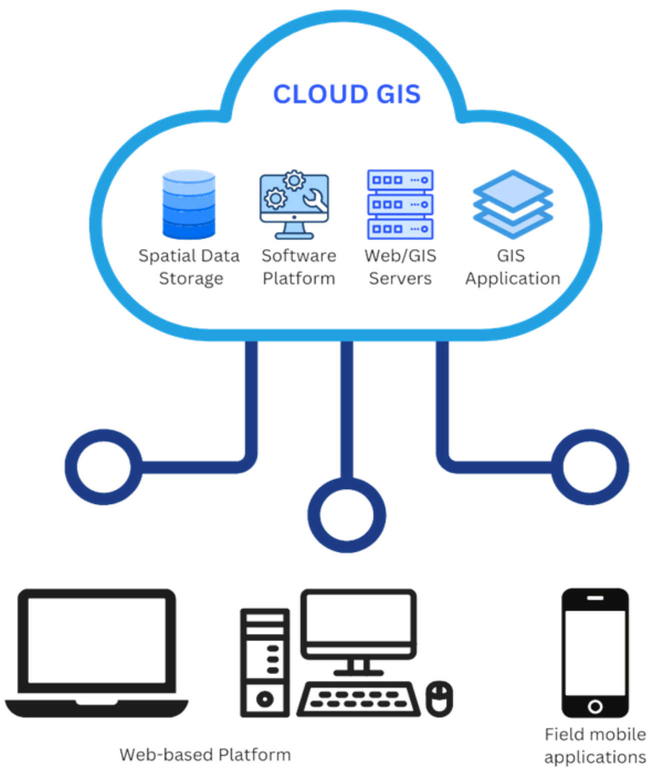

Figure 1. Architecture of the system.

The field mobile applications are designed for emergency responders operating in disaster-affected areas, allowing them to collect and transmit real-time data. Key functionalities include updating the number of displaced persons, geo-tagging individuals outside evacuation centers, and uploading photos of on-ground conditions. The mobile application supports offline data storage, ensuring that information is retained even in areas with limited connectivity, with automatic synchronization to the cloud when an internet connection becomes available.

The cloud GIS component acts as the central repository for spatial and non-spatial data, consolidating information from field mobile applications for further processing. This cloud infrastructure ensures efficient data management, scalability, and security, allowing disaster response agencies to access real-time updates. By leveraging cloud computing, GEDS enhances the speed and accuracy of decision-making, particularly in large-scale humanitarian operations.

The web-based platform serves as the main interface for government agencies, local government units (LGUs), and humanitarian organizations, integrating a database, GIS mapping system, and user dashboard with different levels of access. It allows authorities to monitor the real-time status of displaced populations, evaluate evacuation center capacities, and allocate resources efficiently. Additionally, the platform includes spatial analysis tools to assess hazard zones, road networks, hospitals, and administrative boundaries. A public-facing dashboard provides timely updates for affected communities and potential donors, fostering coordinated disaster response efforts.

The conceptual framework (Figure 2) illustrates how the GIS-integrated, platform-agnostic system transforms spatial data, mobile field inputs, and system design requirements into real-time, data-driven disaster response outputs. Core processes—including data acquisition through mobile applications, cloud-based GIS processing, computational imaging of displaced persons, and real-time information delivery—enable continuous flow and refinement of information across stakeholders. These processes generate key outputs such as dynamic mapping of displaced populations, evacuation center monitoring, hazard-aware routing, cross-platform dashboards, and timely distress response activation. The resulting outcomes include improved latency and accuracy of information, enhanced coordination among responders and government agencies, more efficient allocation of resources, and increased system usability and reliability. Ultimately, the framework supports a scalable and adaptive disaster response ecosystem that strengthens humanitarian operations through real-time, geospatially informed decision-making.

Figure 2. Conceptual framework of the data-driven GIS-integrated, platform-agnostic system showing the flow of spatial and field data through cloud-based geospatial analytics toward real-time decision support for displaced persons monitoring.

In this study, computational imaging refers to the algorithm-driven transformation of geo-tagged visual inputs, spatial datasets, and field-reported information into real-time situational maps of displaced populations. Latency is minimized through cloud processing, offline data caching, and asynchronous synchronization under constrained network conditions.

2.1. Spatial information

This study employed a structured methodology to develop the data-driven GIS-integrated platform-agnostic system, integrating geospatial analytics and mobile-based reporting tools to enhance disaster response operations. The methodology began with the creation of spatial information of available evacuation centers in the Batangas region, followed by geospatial analysis. Data collection was conducted in coordination with LGUs and Disaster Risk Reduction and Management Offices (DRRMOs). Meetings were held with representatives from these agencies to obtain the necessary information, including attribute tables for geoprocessing. Field validation and geo-tagging of evacuation centers were carried out, and GIS maps were created using QGIS to visualize critical infrastructure such as roads, terrains, evacuation centers, schools, and hospitals. These maps were then stored in Google Drive under the Geospatial Analytics and Disaster Coordination (GADC) system. Initial geospatial analysis was performed using QGIS, including route mapping for emergency access, area coverage assessment, and the identification of the nearest evacuation centers for displaced individuals.

2.2. Platform-agnostic

In the development of the system, a platform-agnostic approach was adopted to ensure seamless interoperability across multiple devices and operating systems. This approach allows both the web-based platform and mobile application to function efficiently on various hardware configurations, including desktops, tablets, and smartphones, regardless of their operating system.

2.2.1. Web-based platform

To facilitate real-time data transmission and enhance coordination, a web-based platform was developed, incorporating a relational database and multi-level user access. System requirements for both the web-based and field application platforms were analyzed, leading to the design of a dashboard and graphical user interface (GUI). Extraction modules were developed to process collected information and its associated space-time coordinates. Structured Query Language (SQL) was used for database management, while Hypertext Markup Language (HTML) and PHP: Hypertext Preprocessor (PHP) were utilized for the web system. GIS features and cloud services, including user account creation and push notifications, were integrated using Software Development Kits (SDKs) and Application Programming Interfaces (APIs). The system's design ensured cross-platform interoperability and real-time situational awareness for decision-makers.

2.2.2. Mobile application

The mobile application, developed specifically for field responders, was designed to function on Android devices running version 8.1 (API Level 27) and higher. Kotlin was used as the primary programming language for the application. The development process included alpha testing and user interface assessment to optimize accessibility and usability. The mobile application was integrated with the web -based system to allow seamless data sharing and reporting from the field to central command centers.

2.2.3. Evaluation

To ensure the system's functionality, usability, and consistency, multiple testing phases were conducted. Functional testing was performed to verify that all components met specific requirements. This included assessments of the web dashboard's performance, hazard and distress call map accuracy, push notification efficiency, and displaced persons monitoring capabilities. Mobile application functionalities, such as weather forecasting, earthquake monitoring, evacuation center routing, hazard alerts, emergency notifications, distress calls, and emergency speed dialing, were tested for accuracy and responsiveness. Integration testing was carried out to evaluate the interoperability of various system components, while system testing was performed in an environment simulating real-world conditions to ensure comprehensive functionality.

The researchers conducted a survey to gather feedback from the end users of the platform-agnostic platform. To ensure responsible data handling, the study complied with the Data Privacy Act of 2012 (RA 10173). Ethical safeguards include:

- Informed consent for all respondents
- Anonymization of personal data
- Encryption of sensitive information
- Role-based user authentication
- Limiting data storage to essential fields only

Evaluation was conducted using the ISO/IEC 25010 quality model. The sample size for possible displaced persons was determined using Slovin's formula, given Region IV-A's population of approximately 16.1 million:

$$n = \frac{N}{1+Ne^2}$$

With a margin of error of 5%, a survey sample of 400 displaced persons and 20 local government personnel (SWDO and DRRMO) was collected. Consequently, the researchers used the 5-point Likert Scale ISO/IEC 25010 standard in assessing the responses provided by the respondents based on the predefined criteria such as functionality, reliability, suitability, and performance efficiency.

3. Results and discussion

This section presents the evaluation of the system in terms of its functionality, accuracy, and efficiency in disaster response operations. The analysis focuses on the spatial distribution of evacuation centers, the effectiveness of real-time data transmission, and the system's performance in geospatial analytics.

In the Philippines, the eruption of the Taal volcano in 2020 has become one of the most challenging disasters encountered by Batangas and its neighboring provinces. By March 12, 2020, over 846,000 people (220,673 families) were affected by the Taal Volcano eruption in 228 barangays from the CALABARZON region. 4,114 people took temporary shelter in 10 evacuation centers, and 11,216 people stayed with their relatives and/or friends [5]. Calabarzon has over 1000 evacuation centers, but due to the vast number of people and area affected, some displaced persons stayed outside the evacuation centers due to overcrowding and lack of facilities. Unlike typhoons and other disasters, the scope of the damage in volcanic eruptions is generally geographically dispersed and may affect vast numbers of people and cause extensive damage to infrastructure; thus, it was a challenge for the government in monitoring displaced constituents and allocating resources (ex. food, health care).

Figure 3 illustrates the number of evacuation centers in five provinces: Batangas, Cavite, Quezon, Laguna, and Rizal. Batangas has the highest number of evacuation centers, totaling 512, followed by Laguna with 459 and Quezon with 423. Cavite has significantly fewer centers at 238, while Rizal has the lowest number with only 126. This data highlights the varying capacities of different provinces to accommodate displaced individuals during emergencies. The higher number of evacuation centers in Batangas, Laguna, and Quezon suggests a greater preparedness for disaster response, whereas the lower numbers in Cavite and Rizal may indicate a need for additional infrastructure and resources to support disaster-stricken populations.

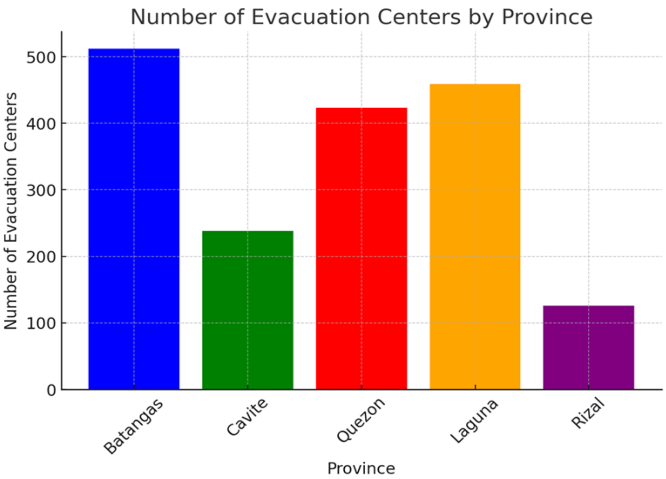

Figure 3. Number of evacuation centers in Region IV-A CALABARZON.

The Displaced Person Monitoring System (DPMS) is designed to facilitate real-time data collection, monitoring, and response coordination for displaced individuals during disasters. The system integrates multiple stakeholders, including displaced persons (DPs), field responders, the Local Government Social Welfare and Development Office (SWDO), and the Local Government Disaster Risk Reduction and Management Office (DRRMO). Each stakeholder plays a critical role in ensuring efficient communication and response during emergencies.

Figure 4 presents a use case diagram of the system, wherein field responders provide essential field information, including evacuation status, available supplies, and optimal routes, which is transmitted to the system for further processing. Additionally, they collect and update the personal details of displaced individuals, such as name, age, sex, and location, ensuring proper documentation and assistance. The SWDO is responsible for receiving and managing this information, assessing the needs of displaced persons, and making necessary updates to facilitate effective disaster response.

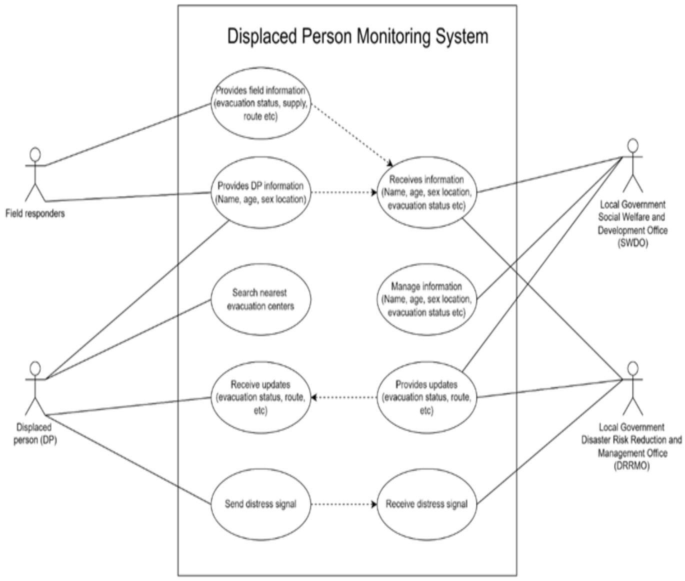

Figure 4. Use case diagram of the displaced person monitoring system.

The system also allows displaced persons to search for the nearest evacuation centers based on their location, ensuring timely relocation to safer areas. Furthermore, the SWDO manages and organizes collected data to optimize resource allocation. The DRRMO plays a crucial role in consolidating and providing real-time updates regarding evacuation status, available routes, and relief operations. Displaced individuals can receive these updates through the system, keeping them informed of critical developments.

One of the key features of the DPMS is its distress signal function, which enables displaced persons to send emergency alerts requesting immediate assistance. The DRRMO receives and responds to these distress signals, ensuring rapid intervention in critical situations. The system is designed to be platform-agnostic, meaning it can operate seamlessly across multiple devices, including mobile applications for field responders and displaced persons, as well as web-based dashboards for government agencies. This interoperability ensures efficient real-time data sharing, enhancing coordination efforts. Additionally, the system leverages cloud -based GIS technology to process spatial data and provide dynamic mapping functionalities.

A total of 400 respondents participated in the survey to gather feedback. For the local government, 20 respondents were surveyed, including the SWDO and DRRMO. The survey used the 5-point Likert Scale ISO/IEC 25010 standard, which involves assessing the responses provided by the respondents based on the predefined criteria, which involves the following: (a) functionality, (b) reliability, (c) suitability, and (d) performance efficiency.

Figure 5 illustrates the evaluation of the platform based on functionality, reliability, suitability, and performance efficiency, comparing the perceptions of possible displaced persons (blue bars) and local government representatives (red bars).

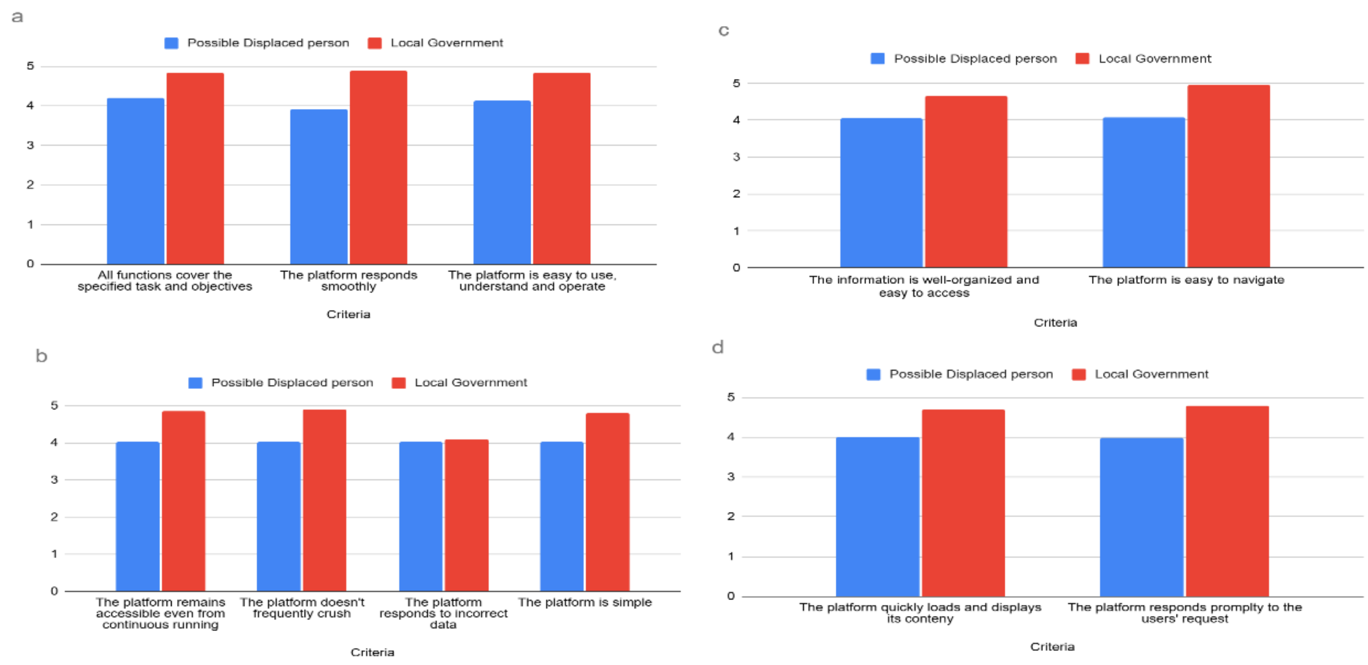

Figure 5. Result of the ISO/IEC 25010 standard survey per criteria for possible displaced persons and local government personnel: (a) functionality, (b) reliability, (c) suitability, and (d) performance efficiency.

In terms of functionality, both groups rated the platform positively, with the local government giving slightly higher scores across all criteria. This indicates that government users find the platform more responsive and easier to operate than displaced persons do. Similarly, in reliability, the local government consistently rated the platform higher, particularly regarding its accessibility and resistance to crashes, suggesting that officials perceive the system as more stable compared to displaced individuals.

For suitability, the platform was rated highly by both groups, with the local government again providing slightly higher ratings, particularly on ease of navigation. This suggests that while both groups find the platform useful, officials may have a better understanding of its structure and organization. Lastly, in performance efficiency, the platform's loading speed and responsiveness were well-rated by both groups, though government users again expressed slightly greater satisfaction.

Overall, the results suggest that while the platform is well -received by both displaced persons and local government users, the latter group consistently rates it higher in all aspects, indicating greater familiarity and ease of use with the system. These insights highlight potential areas for improvement, particularly in user experience and accessibility for displaced persons.

Figure 6 presents the overall evaluation results of the system based on the ISO/IEC 25010 standard, comparing feedback from two groups: possible displaced persons and local government representatives. The evaluation criteria include functionality, reliability, suitability, and performance efficiency. The results indicate that local government representatives consistently rated the system higher across all criteria, with scores reaching approximately 5.0. Meanwhile, possible displaced persons provided slightly lower ratings, averaging around 4.0. This suggests that while both groups found the system effective, local government representatives perceived it as more reliable and efficient. The difference in ratings may be attributed to varying levels of familiarity with the system or differences in expectations regarding its functionality and usability.

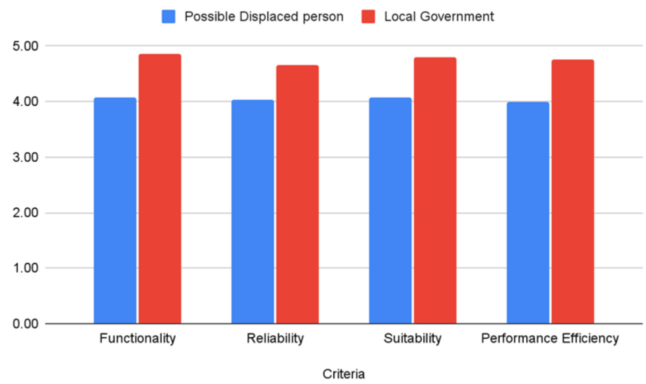

Figure 6. Overall evaluation result of the ISO/IEC 25010 standard survey per criteria for possible displaced persons and local government personnel.

Results show higher ISO/IEC 25010 scores from LGU users than displaced persons. This disparity reflects architectural alignment with institutional workflows and greater digital familiarity among LGUs. The cloud-based GIS architecture directly contributed to higher reliability and performance efficiency scores, while lower ratings from displaced persons highlight usability challenges during high-stress emergency conditions.

The study is geographically limited to Region IV-A (CALABARZON), which may constrain generalizability. Variable internet connectivity during disasters and sample representativeness under emergency conditions are also recognized limitations.

4. Conclusions

In conclusion, the evaluation of the platform based on functionality, reliability, suitability, and performance efficiency demonstrates that it effectively meets the needs of both possible displaced persons and local government representatives. The consistently higher ratings from the local government suggest that officials find the platform more intuitive, stable, and efficient, likely due to their familiarity with digital systems. While displaced persons also provided positive feedback, slightly lower scores indicate areas for improvement, particularly in enhancing ease of use and accessibility. To maximize the platform's impact, further refinements should focus on making it more user-friendly for displaced individuals, ensuring a seamless experience for all users. Overall, the platform shows strong potential as a disaster response tool, providing critical support in emergencies. Future work will address broader geographic deployment and further user experience optimization for displaced populations.

Acknowledgment

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Finally, the researchers acknowledge the guidance and encouragement of mentors, colleagues, and all individuals who contributed to the study. Their insights and expertise have been crucial in refining and enhancing the research outcomes.

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