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Next-Generation Emergency Communication Systems: Design and Evaluation of the e112 Mobile Application Platform

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ABSTRACT

This paper presents e112, a context-aware mobile emergency response application, designed to strengthen communication between citizens and authorities during disasters. Building on the ubiquity of smartphones, the system provides SOS requests, incident reporting, customized alerts, evacuation guidance, and moderated community interaction, supported by a cloud-based back end and an operator dashboard for situational awareness. A user-centered design approach guided our development, ensuring clarity and usability under stressful conditions. Evaluation through usability studies and technical audits demonstrated high user satisfaction, robust performance, and accessibility. The results show that a simple, well-designed mobile application can significantly enhance emergency preparedness and response, reducing risks to human life during climate change–driven emergencies.

1. Introduction

The frequency, severity, and impact of natural disasters have risen sharply in recent years, leading to loss of life, environmental degradation, urban infrastructure damage, and significant economic costs (Tin et al., 2024; Centre for Research on the Epidemiology of Disasters, 2025). Climate change is a central driver, producing higher temperatures, prolonged droughts, and more frequent extreme weather events (IPCC, 2022). These conditions accelerate wildfires that devastate ecosystems and human settlements (Jones et al., 2024), while leaving burned landscapes highly vulnerable to subsequent floods and landslides. Rapid urbanization further amplifies risks from both natural and human-induced hazards. Crucially, many disasters arise from compound events, where interacting climate drivers converge across spatial and temporal scales, generating cascading and magnified effects (Zscheischler et al., 2018).

Minimizing risk to human life during fast-moving disasters depends on the effectiveness of emergency services that can be alerted instantly, provide clear protective guidance, integrate situational awareness, and coordinate rapid deployment of assistance to the most affected areas. To support these functions, authorities (civil protection, fire brigade, police) operate emergency call centers as core components of *Emergency Services Communication Systems* (ESCS). Accessible through standardized numbers—112 in the EU, 911 in the US and Canada, and 999 in the UK—these centers ensure universal access to first responders. Emergency lines primarily enable citizens to report incidents and request aid, while also allowing authorities to disseminate urgent instructions such as evacuation orders via SMS and other alerting mechanisms.

Given the ubiquity of smartphones and mobile applications, these technology platforms present a significant opportunity to advance emergency communication and strengthen public safety services. On the one hand, smartphones can leverage their embedded sensors (GPS, cameras, and microphones) to capture critical contextual data, including precise geographic location and multimedia evidence, thereby enhancing, validating, and partially automating the information that individuals report to authorities during emergencies. On the other hand, authorities can disseminate targeted, timely, and context-aware alerts that range from evacuation routes and hazard warnings to locations of safe areas and available resources, thereby improving situational awareness, supporting safe and effective evacuation from danger zones, and enhancing coordinated emergency response.

As authorities worldwide modernize traditional ESCS frameworks, transitioning from circuit-switched infrastructures to Internet Protocol (IP)–based platforms (Wikipedia, 2025; Jordan and Stiber, 2024), smartphones and mobile applications are expected to emerge as the primary interface for two-way communication between citizens and emergency services. In this paper, we present the design, implementation, and evaluation of e122, a prototype interactive smartphone application platform developed to provide rapid and effective assistance during emergency situations. The application addresses key limitations of traditional communication methods by enabling structured text- and multimedia-based interaction with emergency operators. Core features

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include an SOS button for immediate help requests, real-time location tracking, and multimedia uploads. In addition, e122 delivers timely local updates and supports on-demand, location-aware private and group chat to facilitate information exchange and coordination between volunteers and emergency services.

The remaining of this paper is organized as follows: Section 2 discusses related work, section 3 presents the main concepts implemented in the application, section 4 presents the software design of the application and the server components and discusses implementation aspects. Evaluation of the prototype is presented in section 5 and we conclude in section 6 with a summary of conclusions and future work.

2. Background and Related Work

Since the earliest developments of public warning systems, authorities have sought to design alerts and delivery mechanisms that balance accuracy, clarity, and urgency (National Academies of Sciences and Medicine, 2018). As these systems evolve from traditional broadcast methods to mobile communications and social platforms, scientific studies increasingly explore how message features and communication dynamics could influence public response during crises (Chen et al., 2024). In an early study of this question, authors of (Mileti and Sorensen, 1990) reviewed a large number of prior studies, identified the stages of a typical warning sequence (hear → confirm → understand → believe → personalize → act) and demonstrated its applicability to both pre- and post-impact contexts (Mileti and O'Brien, 1992). Their Warning Response Model (WRM) stressed that effective warnings must be hazard-specific, provide clear protective guidance, indicate who is at risk and where, state when action is required, and identify trusted sources. They also showed that individuals rarely act on the first warning alone but instead seek confirmation from multiple channels and social contacts, making clarity, consistency, and repetition across sources essential for eliciting timely and appropriate protective action. They posited that the response of the public to post-impact warnings is shaped not only by message content but also by the recipients' prior experiences of loss, damage, and disruption. Authorities have sought to operationalize these principles in the design of systems like the Emergency Alert System (EAS) (Federal Communications Commission, 2025), and adapt them to the mobile era. Typically, current EAS employ *Wireless Emergency Alerts* (WEAs) (Federal Emergency Management Agency, 2025), which are delivered directly to personal communication devices in the form of short 90-character messages issued by government authorities and delivered free of charge by wireless carriers to individuals who face imminent threats such as fires, tornadoes or floods. A recent study explored what the addition of maps to WEAs could bring from the perspective of decision clarity, compliance to instructions, and information sharing in various disaster scenarios (Liu et al., 2017). This study presented two experiments involving U.S. adults and found that while maps marginally improved message comprehension, their overall impact on compliance and sharing behavior was limited. This result highlights the need for further research on optimizing visual aids in emergency messaging, for instance by dynamic and interactive map visualizations (Bartling et al., 2022) and support for real-time decision-making.

Another key factor in the effectiveness of emergency communication systems are offline social networks, such as family, community groups, kinship ties, and voluntary associations. These networks strongly influence how warnings are shared, interpreted, and acted upon (Mileti and Sorensen, 1990; Mileti and O'Brien, 1992). Close social connections not only facilitate the dissemination and discussion of warnings but also strengthen understanding, credibility, and timely response. The mutual trust embedded in such networks enhances the persuasiveness of warnings and motivates protective action, while also providing essential support and resources during crises. Consequently, as online social networks have become a ubiquitous platform for communication and rich information exchange (Pallis et al., 2011), new opportunities have emerged for disseminating emergency alerts (Facebook, 2025; Vera-Burgos and Griffin Padgett, 2020; Atkinson et al., 2021) and embedding social communication features into alert systems. However, effective use of these platforms requires sensitivity to cultural and community contexts that shape how warnings are perceived and acted upon. Moreover, while social networks can accelerate the spread of accurate information, they are also vulnerable to inadvertent misinformation or deliberate disinformation attacks (Paschalides et al., 2021). Ensuring the accuracy and consistency of emergency messages is therefore essential to prevent confusion and preserve the effectiveness of warning systems.

3. Main Design Concepts

Based on the above observations we implemented the e112 system as a cross-platform smartphone application integrated with a cloud-based back-end. The mobile application provides citizens with access to location-aware emergency reporting and disaster-related information. The back-end supports emergency operators through a web-based dashboard, manages context-aware communication with users, and integrates external services such as Google Maps for geospatial data, Firebase (Firebase, 2025) for real-time synchronization, and Twilio (Twilio, 2025) for secure user verification.

We formulated the functionality of the mobile application by designing first the *User Experience* (UX) it should offer. UX addresses the overall experience of a person interacting with a service, including usability, utility, and emotional impact, with the goal of solving real user problems effectively and intuitively (Klein, 2013). For the UX analysis, we adopted a user-centered design methodology inspired by design thinking principles, and modeled user needs through *personas* (end users and system operators), *customer journeys*, and *empathy maps*. Customer journey

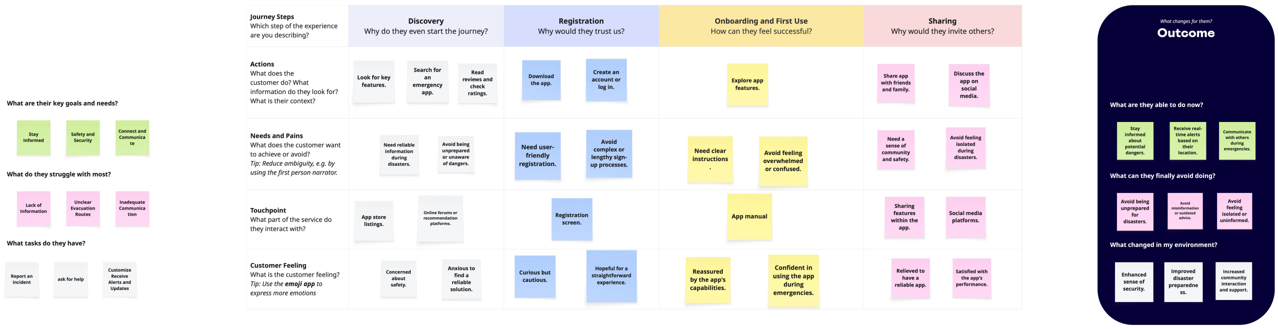

Figure 1: Customer-journey map for user registration and application on-boarding.

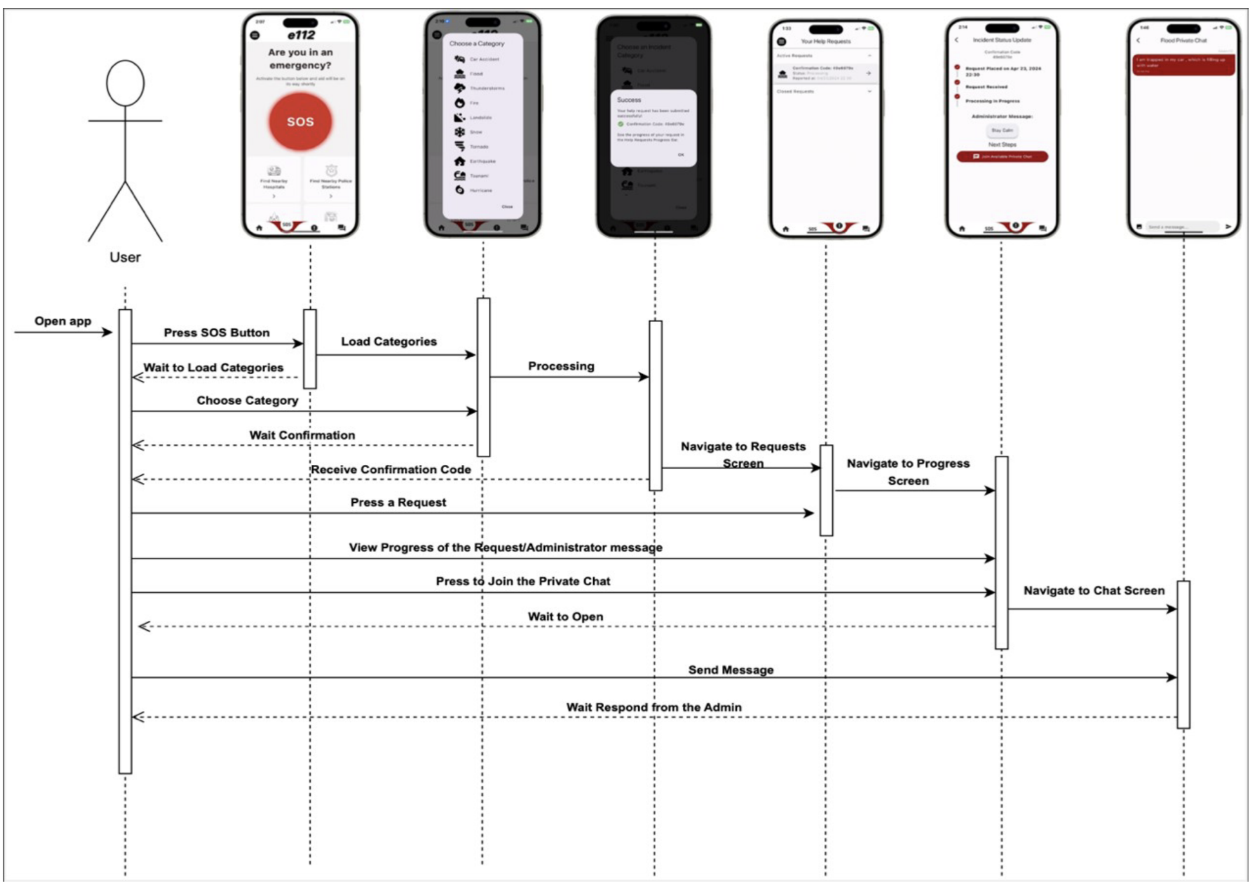

Figure 2: UML Interaction diagram derived from customer-journey analysis of a use-case where a user in danger seeks help through the e112 app; the interaction diagram (bottom) is mapped to the respective app's GUI screens (top).

design (Følstad and Kvale, 2018) provides a structured view of the stages users go through, highlighting critical touchpoints for the design of the application's interactivity (see Figure 1). The purpose of empathy maps is to capture what users see, hear, think, feel, say, and do at each stage of application use, thereby informing the design process by revealing their underlying motivations, frustrations, and needs (Lewrick et al., 2018). For example, in a wildfire scenario, journey mapping clarified the sequence of actions (receiving an alert, navigating to a shelter), while empathy mapping revealed stress, confusion, and the need for reassurance that could hinder decision-making. We consolidated the customer-journey analysis in UML interaction diagrams (see Figure 2).

Through the UX analysis approach we established the following key functionalities for the e112 mobile application:

- *Emergency Alerts' Dissemination*: The system delivers alerts and situational updates in real time to people,

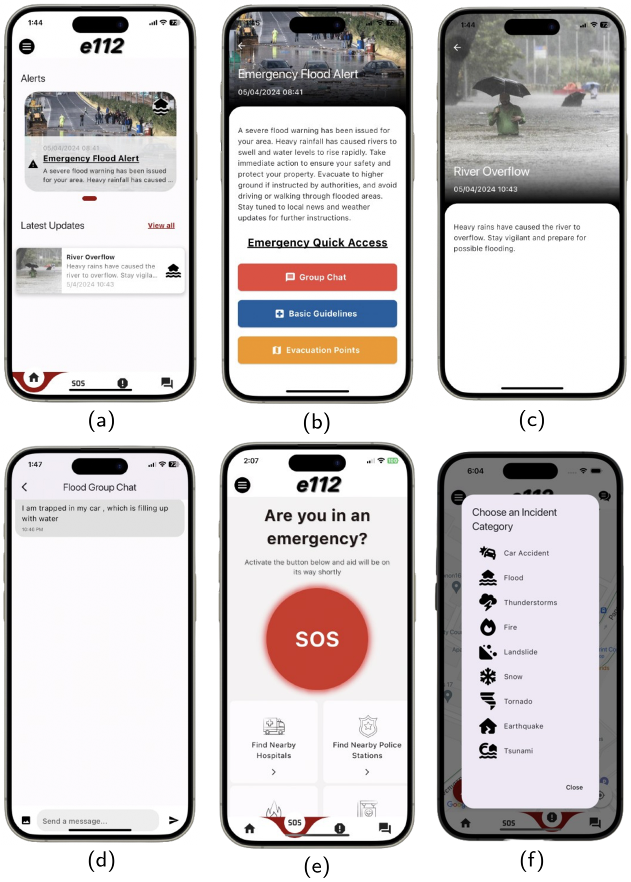

Figure 3: e122 mobile app functionality and interfaces.

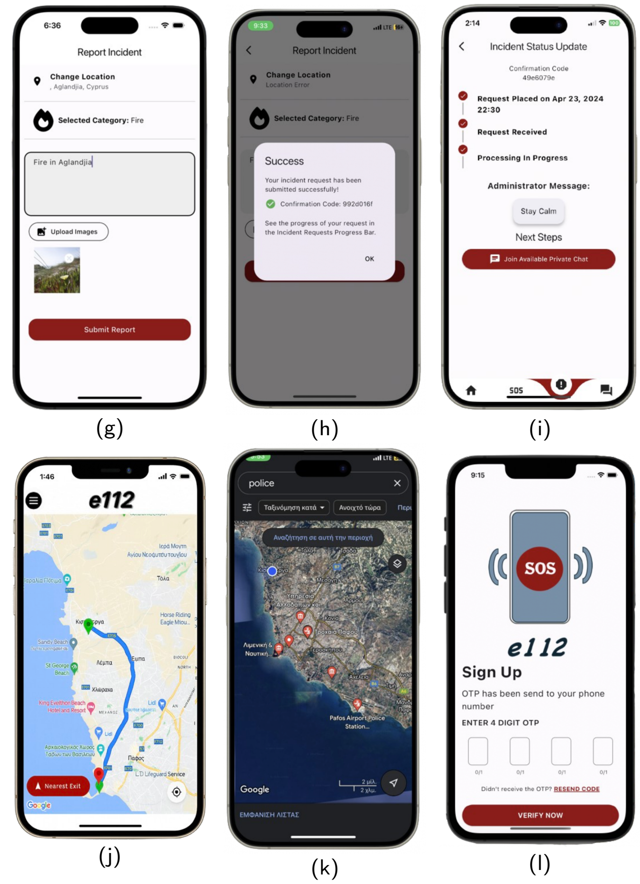

Figure 4: e122 mobile app functionality and interfaces (ctd').

based on their location, thereby minimizing delays and reducing call-center overload during emergencies (see Fig. 3.a). Upon receipt of an alert, users are able to immediately find simple instructions posted by emergency authorities on what to do (see Fig. 3.b,c) or seek help from people in the area from a localized chat-group (see Fig. 3.d).

- *Reporting to and Communication with Authorities*: The system shall enable users to engage in trusted communication with authorities, requesting assistance under personal duress (see Fig. 3.e), reporting incidents (see Fig. 3.f, 4.g), getting confirmation receipt (Fig. 4.h), monitoring status updates, and obtaining follow-ups (see Fig. 4.i). The design of the application's graphical user interface and interaction must adapt to the user' anticipated level of stress, with a minimum number of clicks required to ask for help when in personal danger (see Figure 3.e,f). To this end, information about the location of the user and/or the reported emergency can be retrieved directly from the smartphone and/or by using its GPS and camera (see Figure 4.g).

- *Information Resources and Presentation*: The application must present information clearly and accurately in visual and textual formats, including annotated maps and landmark images, while minimizing cognitive load under high-stress conditions. The application shall provide intuitive navigation to quickly locate critical resources such as safety guidelines, shelters, protected spaces, hospitals, and police stations (see Fig. 4.j,k).

- *Group Communication*: The system shall allow users affected by the same emergency in the same location to join moderated chat groups that are dynamically established by the platform's operator at the onset of an incident . Group chat will enable individuals to exchange information and advice, help each other even before the arrival of rescue teams, and coordinate activities within a channel monitored by emergency services (see Fig. 3.d). Moderation and monitoring will ensure that authorities maintain up-to-date situational awareness, are able to deliver targeted guidance and coordinate corrective action remotely, while protecting the integrity of the information exchange from malicious information attacks.

- *Secure Accessibility*: The system shall facilitate registration through verifiable, non-anonymous credentials (e.g., identifiable mobile numbers or third-party authenticated accounts - see Fig. 4.l) to ensure accountability and prevent spam or disinformation attacks.

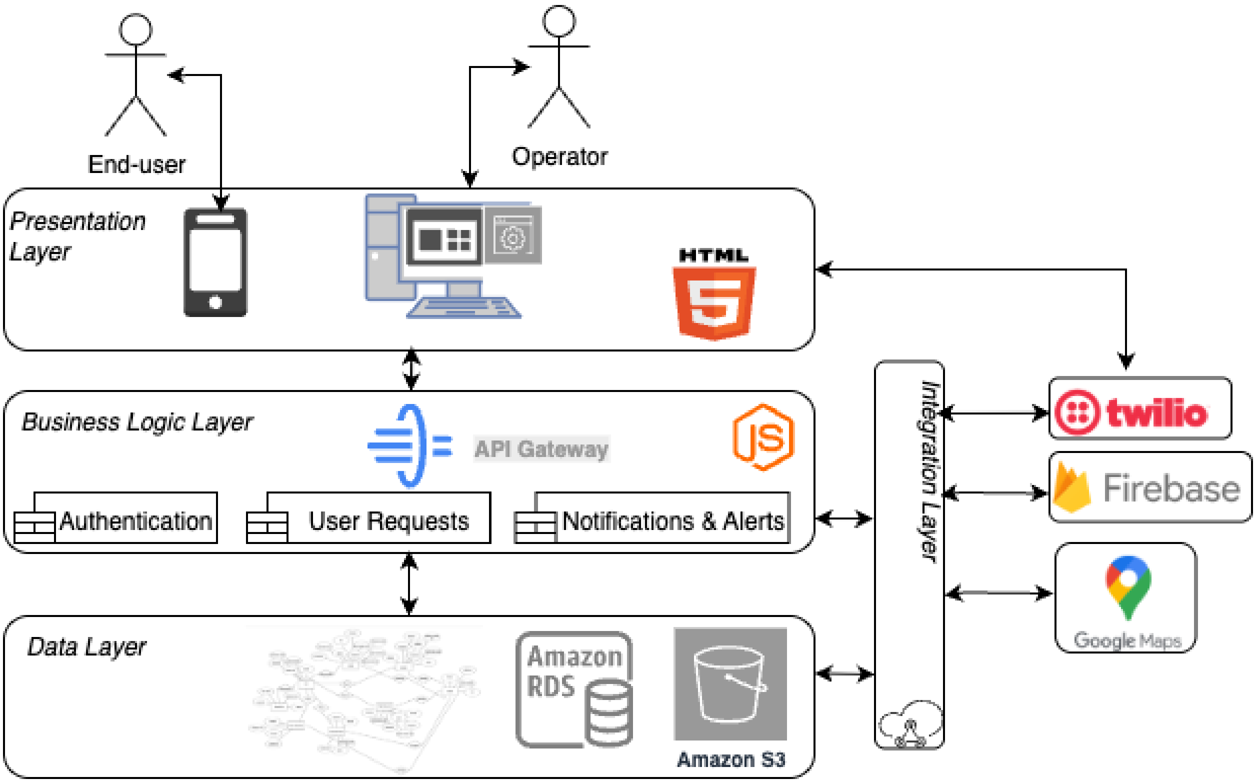

Figure 5: e122 System Architecture.

- *Interface Responsiveness*: The application shall adapt seamlessly across devices and screen sizes to ensure a consistent user experience.

Additionally, for the graphical user interface (GUI) of the mobile application, we adopted a color scheme chosen to balance urgency with usability under stressful conditions, and facilitate navigation decisions under duress. The primary color is dark red, symbolizing emergency and urgency, and used in elements such as ”SOS” and group chat buttons, to reinforce critical actions. Red highlights affected areas on the evacuation map, while dark green is applied to safe zones, providing an intuitive visual contrast that directs users toward safety. Dark blue is reserved for basic guidelines, conveying reliability and calmness, and dark yellow is used for evacuation points, combining visibility with caution. By employing darker tones of each color, the design reduces visual strain and enhances legibility, ensuring that users can quickly interpret essential information even in high-stress disaster scenarios

4. System Architecture and Technology Stack

The system architecture of the e112 follows the principle of separation of concerns, splitting the functionality to independent layers for presentation, business logic, data management, and integration, so that each layer cannot affect another and system modules can be implemented as cloud micro-services (Trihinas et al., 2018). This makes the platform easier to scale and troubleshoot.

- The presentation layer comprises the Web dashboard used by e122 operators to log in, monitor incoming alerts, manage group communications, and issue official updates (see Fig. 6), and the e122 application which runs on end-user smartphones and provides reporting and communication functionalities to citizens (see Fig. 3). Both dashboard and app communicate with the backend through e112’s API, which is implemented in the business-logic layer. The e112 mobile application was implemented with Flutter (Google, 2025a), a software framework for developing native-quality mobile apps across Android and iOS from a single code-base.

- The business-logic layer comprises the e122 API and is developed with the Express-node.js framework. This layer is responsible for managing the main operations of the system including authentication, user requests, generation and dissemination of alerts, and communication with the data layer. This layer handles requests from both the mobile app and the operator’s dashboard.

- The data layer is responsible for the persistent storage and retrieval of all information required by the system to operate effectively. We designed an entity–relationship model to capture core e112 entities and their attributes, including users, alerts, incidents, help requests, chats, and evacuation routes, along with their interrelationships. We implemented

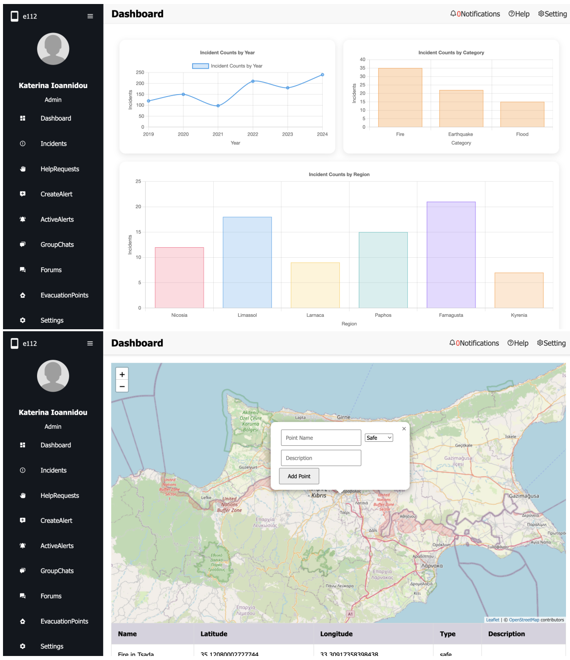

Figure 6: e122 administrator's dashboard: statistics and map-oriented interface.

this model as a relational PostgreSQL database deployed on Amazon RDS, ensuring reliability and scalability for structured data. In parallel, we used Amazon S3 to store multimedia files such as images and videos, providing durable and cost-effective object storage. The data layer interacts with the business logic layer through secure, private communication channels, ensuring both efficiency and data integrity.

- The integration layer connects the business-logic layer with external services, including the Google Maps API (Google, 2025b) for location information, the Twilio API (Twilio, 2025) for mobile phone verification through SMS, and the Firebase API (Firebase, 2025) for real-time push notifications. These services interact also with the business logic layer through restful HTTP endpoints.

We used the Vercel (Vercel, 2025) Platform-as-a-Service (PaaS) cloud to host the presentation and business-logic layers. Vercel provides serverless deployment, automatic scaling, and global distribution.

5. Evaluation

The performance of an emergency application is determined not only by its technical robustness but also by the clarity and efficiency of its user experience, particularly under high-pressure conditions (Mentler et al., 2016). To examine these dimensions in e112, we evaluated its two main components: i) the administrator's dashboard, through which authorized personnel receive, manage, and coordinate alerts, and ii) the mobile application. To this end, we employed a mixed-methods evaluation strategy, combining automated auditing of the administrative dashboard with scenario-based usability testing of the mobile application. This approach was selected to capture both quantitative performance indicators (e.g., page load times, accessibility compliance) and qualitative insights into end-user interaction under simulated emergency conditions.

5.1. Administrator's dashboard

The administrative web interface was assessed using Unlighthouse, an open-source auditing framework that reports on speed, accessibility, code quality, and search engine optimization (SEO) metrics (Wilton, 2025). Using Unlighthouse, we measured the following Core Web Vitals:

- First Contentful Paint (FCP): the time taken to render the first visual element after page load.
- Largest Contentful Paint (LCP): the time at which the main content becomes visible.
- Total Blocking Time (TBT): the cumulative duration during which the main thread is blocked after FCP, delaying user interactions.
- Cumulative Layout Shift (CLS): the extent of unexpected visual shifts during page loading.

Each of these metrics is associated with a recommended threshold for an optimal user experience. Specifically, an FCP $\leq$1.8s is considered good, while values >3s require improvement. LCP $\leq$2.5s is desirable, with values >4s negatively affecting usability. TBT should remain below 200ms to ensure responsive interactions, while a CLS <0.1 is recommended to maintain visual stability during loading. Based on our tests and measurements, the e112 dashboard generally performed well. The recorded FCP slightly exceeded the recommended threshold (1.8s) but remained within the acceptable range (<3s), possibly reflecting the additional time required for font rendering. LCP was measured at 2.8s, marginally above the optimal threshold, likely due to the rendering of large text blocks. In contrast, both TBT and CLS achieved ideal values, demonstrating excellent responsiveness and visual stability.

The audit results further indicate a generally high-quality implementation of the administrative dashboard. The system achieved a performance score of 90/100, placing it within the "good" range of the Lighthouse standard (Google, 2023a). Accessibility achieved 95/100, consistent with WCAG 2.1 guidelines (W3C, 2018). The Best Practices score reached 96/100, confirming adherence to high standards of security and code quality—both critical for systems that process sensitive emergency data (Google Chrome Developers, 2019). By comparison, the SEO score was 82/100, an acceptable outcome but one that highlights the need for improvements in metadata and indexing (Google, 2023b).

5.2. Mobile application

For the e112 mobile application's usability study, we recruited 19 participants from 16 to 65 years of age to account for known differences in technology use: older adults often adapt more slowly to new interaction patterns whereas younger users typically complete tasks more quickly and efficiently (Kurniawan et al., 2013; Sonderegger et al., 2016). This approach ensured that the evaluation captured a representative spectrum of usability challenges across diverse user demographics. All participants had prior experience with smartphones and possessed basic digital literacy. For this study, we assumed a simulated flooding disaster scenario to evaluate the application's usability in a high-stress, real-world context. We asked participants to consider they are in the midst of a flood disaster and use the e112 application to submit incident reports and navigate the app's primary features. Following task completion, participants filled a structured questionnaire measuring perceived usability, task difficulty, and overall satisfaction.

We designed the questionnaire to collect meaningful and reliable feedback capturing both quantitative ratings and qualitative perspectives. Our questionnaire using a mix of five-point Likert scales, yes/no questions, and short open-ended items. We asked participants to respond to 16 questions covering a range of aspects of the application: ease of navigation and success in locating desired information; the usefulness of alerts and real-time updates during an emergency; which features they considered most valuable; whether they experienced any difficulties during the reporting process; and how satisfied they were with the response time. We also included items on the ease of posting in the forum, the helpfulness of the evacuation-route tool, the utility of the guidelines feature, and the value of the live chat function. Finally, we asked participants how necessary they believed such an application would be in emergency situations.

After analyzing the responses, we found that participants generally considered the application easy to navigate and reported no major difficulties with the user interface. They also indicated high satisfaction with the response time. An interesting result emerged regarding the live chat feature: participants aged 35–54 viewed it as unnecessary, while those aged 18–34 rated it as highly useful. Overall, we observed high satisfaction with the application, with a mean score of *4.58 out of 5*, and a recommendation score averaging *4.63 out of 5*. Nearly all participants agreed that the existence of such an application is important during emergency situations.

6. Conclusions and Future Work

The increasing frequency and scale of climate-driven disasters, often spanning large geographic regions and populations, place significant pressure on Emergency Services Communication Systems and demand a paradigm shift in how emergency communications are designed and delivered. The widespread adoption of smartphones offers a powerful opportunity to enable context-aware, two- and multi-way interaction that leverages sensors, geo-location, and multimedia reporting. In this paper, we presented the design, implementation, and evaluation of e112, a cross-platform mobile application and cloud-based system supporting SOS requests, incident reporting, evacuation guidance, targeted alerts, and moderated community interaction, alongside an operator dashboard for situational awareness and response coordination.

Our performance assessment and usability studies show that e112 is technically robust, highly usable, and well received across age groups. A lightweight, user-centered mobile platform can significantly strengthen preparedness and response, reducing risk to human life during emergencies. Community-driven features, such as contextualized chat forums, further enhance local coordination, while the use of authenticated mobile identities and moderated channels reduces the risk of misinformation attacks. Moderation that can be further supported by generative AI techniques. The platform's microservice-based architecture and cloud-native implementation also enable scalable deployment, rapid iteration, and seamless integration with third-party services.

Thanks to its modular design and use of HTTP/REST APIs, e112 is positioned to interoperate with next-generation emergency communication standards such as NG112 European Emergency Number Association (EENA) (2024) and NG911 Wikipedia (2025). Both environments rely on IP-native based communication and have provisions for media transport, dynamic location-to-service mapping, delivery of precise geo-location metadata, and multi-modal "total conversation" capabilities (voice, text, image, video).

Several interesting open problems remain, including automated assessment of user vulnerability, reliable integration with legacy emergency services, and the management of high-volume, real-time communication during large-scale crises. Future work focuses on integrating agentic systems to augment human operators by classifying incoming requests, prioritizing incidents, monitoring group communications, and filtering misinformation. Early results with large language models (LLMs) show strong potential for automating report clustering, urgent-case escalation, and conversation summarization, thereby improving response times and enhancing overall emergency service effectiveness.

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