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Designing Interactive Web-GIS Dashboards for Data-Driven Emergency Management in Smart Cities

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Abstract. In the context of smart cities, emergency management is an important area to improve the safety and quality of life in cities by responding to the occurrence of unpredictable emergency situations. This research designed interactive Web-GIS dashboards to support smart city emergency management decisions. User-centered and agile UX approaches defined key features aligned with response personnel's information needs during crisis situations. The resulting prototypes integrate real-time city data feeds and CCTV footage into a visualized map interface that could effectively provide emergency responders with the information they needed. UI design was improved through heuristic usability testing for users within the actual emergency response organization. The dashboards enable data-driven collaboration and coordinated response by emergency managers. It is expected that the dashboard designed in this study can be utilized to improve the efficiency of the smart city emergency management system and the ability to respond to emergency situations.

Keywords: Dashboard, Emergency Management, Emergency Decision Making, Web-GIS dashboard, Smart City, Emergency Response, Heuristic Usability Test

1. Introduction

Emergency means an event that occurs suddenly, such as fire, earthquake or terrorist attack, that causes or is likely to cause serious injury and death, property loss, ecological damage, and social harm (Liu et al, 2016). These emergency situations share a common characteristic of high complexity, uncertainty, and dynamic unfolding, resulting in various kinds of loss or damage (Fu et al, 2021). Emergencies are often long-standing and recurring problems in cities, but as cities grow in size, their impact and influence are also changing significantly (Kontokosta and Malik, 2018).

Emergency management in large cities is a key area where a smart city approach can be leveraged (Romano et al, 2016). Smart cities have the ability to solve urban problems through a combination of physical systems, IT systems, and infrastructure, and to improve the safety and quality of life of cities (AlAbdulaali et al, 2022). However, in the context of smart city management, emergencies are inevitable and unpredictable. In addition, in the high-density urban environment of smart cities, people and economic activities are largely concentrated, making it vulnerable to confusion caused by emergency situations, so the need for smart city emergency management systems has emerged (Beg et al, 2021).

Smart city initiatives have been developed in many cities around the world that address multiple aspects of emergency detection, alerting, response, and mitigation (AlAbdulaali et al, 2022). Various studies have been conducted on emergency management systems in smart cities that have embraced IT technologies such as sensors, Internet of Things (IoT), Big Data, Artificial Intelligence (AI) and Machine Learning (ML) to make cities more sustainable, safe, and resilient. Over the past decade, many solutions have been developed to address urban challenges in the context of smart cities, but prior studies have focused on detecting, warning, or mitigating emergencies based on independent capabilities and services under well-defined goals (Costa et al, 2022). For example, there were image-based classification algorithms for disaster detection (Asif et al, 2021), algorithms for detecting crisis in video (Khatoon et al, 2022), disaster situation subject classification (Imran et al, 2013; Imran et al, 2016), research on capturing useful disaster-related information in social media text (Essam et al, 2021). Studies such as intelligent detection, identification, and classification of disaster information are very important, and the results are of great help in identifying the nature of disasters and the context of events, which are required in the emergency response process. However, there is a lack of contributions in existing research on visualization of smart city information to help emergency decision-making during emergency response, and intuitive user manipulation methods for users to retrieve necessary information in a Web-GIS environment. From an emergency management perspective, it is counterproductive not to efficiently provide the information needed for emergency decision-making in a way that can be used by decision-makers during an emergency response.

This research paper aims to design real-time interactive Web-GIS dashboards for smart city data-driven emergency management. The dashboard system aims to strengthen command, coordination, and control through efficient monitoring and frontline sharing of key information during emergency response. A user-centric design approach was applied to design an interactive dashboard with heterogeneous data visualization and intuitive user interaction that can help emergency decision-making in the process of responding to various emergency situations. The objectives of this study were to

- Explore the different types of data needs within a city to develop emergency management dashboards.
- Explore visualization options for data attributes such as CCTV footage, digital data, images, audio, architecture, drawings, etc.
- Explore key features (how users interact with them) of interactive dashboards to make them more interactive.
- Design and prototype Web-GIS dashboards using a user-centric design approach.

This research paper build on previous research on cyber-physical systems and data collection, pre-processing, and analysis methods for emergency detection, alerting, and response through technologies such as artificial intelligence and machine learning. Based on various advanced IT technologies, this study focuses on the response process after abnormal signs and emergency situations are detected. This research paper is organized as follows: Section 2 reports related works, Section 3 presents the methodology and findings, Section 4 discusses the results, and Section 5 concludes with conclusions and future work.

2. Related Works

2.1. Dashboard: History, concept, and the need for interactive dashboards for emergency management

A dashboard is an effective way to communicate information by displaying different types of visual data in one place. The term "dashboard" comes from the automotive instrument panel, which allows drivers to see a variety of information at a glance. The point of a dashboard is to simplify the work environment and provide solutions to get the right answers at the right time (Lata et al, 2022). The main goal of the dashboard is to communicate and clearly present important information to busy individuals in a timely manner, developed primarily for decision-makers in business organizations.

The concept of digital dashboards stems from the concept of decision support systems that emerged in the 1970s (Zagorecki, 2012). Digital dashboards are specifically focused on data visualization for decision support. Data visualization is a method of presenting data in a visual form to make it easier for users to understand and analyze. Data visualization technology is a combination of various disciplines, including computer graphics, image processing, computer vision, and user interface design (Balzer et al, 2020). Dashboards integrate data from various sources using data visualization tools such as graphs, charts, and tables, and the visualization tools depend on the type of data the user is trying to display. Digital dashboards are important because they provide a platform for people to make better informed data-driven decisions.

Meanwhile, the properties of a dashboard are determined by the nature of the problem, organization, user, and data analysis objectives to be addressed (Wilbanks and Langford, 2014). Since emergencies are commonly complex, uncertain, and dynamic, many decision-making processes are required for rapid response under time pressure and incomplete information (Fu et al, 2021; Ergu et al, 2016). Decision-making for emergency response involves assessing the situation, determining priorities, sharing and collaborating on information, and allocating resources. However, emergency decision making is very difficult due to time pressure, limitations in evaluation methods, lack of existing examples, information uncertainty, and incomplete planning (Liang et al, 2019). In addition, recent urban emergencies have become more diverse and large-scale, making the task of emergency response organizations more complex every year. Emergency response is characterized by the fact that it is carried out by multiple organizations that do not routinely work together (various stakeholders such as firefighters, police officers, government officials, and healthcare providers). Therefore, emergency management requires a ‘common operating picture’ for communication, information sharing, collaboration, and effective coordination between ‘multiple organizations’. The term ‘multiple organizations’ refers to environments with multiple data sources that are not connected to each other (Zagorecki, 2012). This means importing data from various fields, and since the spatial and temporal scales of data are incompatible and the format standards are not unified, how to realize the integration of emergency data becomes an urgent and necessary key issue (Wu et al, 2017). The information provided by the platform plays an important role in the user's decision, so the information must be complete and highly accessible (Jeong et al, 2023). Therefore, developing an emergency management dashboard requires data science activities that extract and integrate data from various sources, and find new insights and design visualizations through data utilization (Matheus et al, 2020). In addition, for the 'common operation picture', it is important to perform effective coordination, communication, and collaboration between stakeholders by responding to emergency situations with data-based decision-making based on a common platform. Therefore, the key to developing an urban emergency management dashboard is not only to simplify the work environment, but also to provide a solution that allows decision makers to get the right answer in a timely manner by utilizing large amounts of data collected from various sources (Lata et al, 2022).

However, traditional static dashboards are difficult to meet increased requirements in environments requiring multi-dimensional and complex data analysis, such as urban emergency management (Nadj et al, 2020). Static dashboards limit updates and interaction with real-time data, which limits emergency management in complex modern urban environments. Smart city emergency management utilizes a variety of urban data and includes key activities such as collection, analysis, and visualization. In smart cities, large amounts of data can be collected and analyzed to identify abnormal patterns or emergencies due to advances in computers, sensors, the Internet of Things, and network environments. Emergency management organizations are leveraging machine-readable data to significantly improve the efficiency and speed of emergency management through automated data collection, analysis, and visualization. As data grows larger and more complex, visualization techniques that can be used to discover patterns in unstructured data have become important. In the context of smart cities, the use of dashboards for urban emergency management can display a variety of visual data in one place to help decision makers gain deeper insight into critical information and find actionable answers (Nadj et al, 2020). Against this backdrop, research on interactive dashboards that allow users to drill down, roll up, or filter information is gaining attention. An interactive dashboard is a data management tool that tracks, analyzes, monitors and visually displays key information while allowing users to interact with data, allowing them to make the right decisions based on data.

2.2. Adoption of Web-GIS dashboards in city management

In the context of urban management, Web-GIS dashboards were introduced to solve problems such as increased complexity of urban systems, the need for real-time spatial reference information, and data accessibility of various users. Web-based dashboards are ideal for urban emergency management because they allow users to update, integrate, and display real-time data regardless of time or location. GIS dashboards are particularly useful in situations where large amounts of geolocation data are processed, requiring rapid decision-making based on the latest information such as disaster response and recovery, disease outbreak management, transportation and infrastructure management, and environmental monitoring. In available literature, GIS-based dashboards have been created for a variety of purposes. Johns Hopkins University's COVID-19 dashboard (Johns Hopkins University, 2023), a user-friendly GIS dashboard for evaluating urban resilience in the earthquake-affected town of Camerino, Italy (Villani et al, 2023), a dashboard created in New South Wales, Australia to monitor spatiotemporal changes in bushfire hotspots over 100 years (Visner et al, 2021), and an interactive complex disaster data dashboard that collects and presents complex disaster information, including social media data, in a user-friendly way to improve emergency response decision-making (AlAbdulaali et al, 2022). Previous studies show the spread of infectious diseases in real time, such as COVID-19 dashboards, but they do not provide complex emergency response or decision support capabilities. In addition, the GIS dashboard, which focuses on earthquake damage recovery, is limited to specific situations, making it difficult to apply to various emergency situations. The Australian bushfire monitoring dashboard is useful for identifying long-term bushfire trends, but it has limitations when it comes to responding to real-time fire events. On the other hand, multi-modal dashboards that utilize social media data provide a lot of information in a user-friendly way, but they rely excessively on social media in the entire process and have fundamental problems such as the quality, accuracy, privacy issues, and the limitations of real-time analysis of large-scale data. On the other hand, commercial software such as Tableau, Sisense, and JMP provide data visualization tools, but do not offer interactive plots specific to emergency response. Therefore, research is needed to develop a dashboard that can comprehensively respond to various emergencies and has a user-friendly interface that considers user requirements and goals.

Based on the above mentioned points, it is necessary to introduce Web-GIS based interactive dashboard for emergency management in cities, especially in smart cities. Dashboards should provide real-time data, map-based information, and visual representations of cities, allowing emergency managers (especially decision makers) to make quick and accurate decisions based on the insights on specific situation. It is of great significance to provide efficient and intuitive visual information to emergency response organizations based on effective information science, helping them share information, collaborate, and support emergency decision-making. This is because the improvement of emergency decision-making methods for emergency situations means that the possibility of securing golden time and protecting citizens' lives and property in the emergency response process increases.

3. Designing interactive Web-GIS dashboards

This study designed and evaluated interactive Web-GIS dashboards that display information about the stages of emergency response. Figure 1 shows the steps in a user-centered design approach. First, the emergency management process steps were categorized and defined. Second, through informal surveys with actual stakeholders, each stage's achievement goals and major missions were defined. Third, the city data, metadata, and essential features for decision support during response phases were examined. Finally, a High-fidelity prototype of dashboards were implemented and refined using an Agile UX approach (Steve, T., 2022). Agile UX, a concept that emerged in late 2011, is a design and development approach that combines Agile software development principles with design principles. This is to overcome the linear work structure that starts collaborating with the development department after the design is completed, the lack of a culture of collaboration with the development department during the design process, and to modify the concept and process flow of design to better align the process of design development with the process of software development to increase the efficiency of the overall work (Colfelt et al, 2010). Agile UX takes a more integrated approach by keeping the UX design and development processes in constant communication with each other and encouraging continuous feedback and improvement. Integrating Agile UX into the product creation process can create a feature-rich, easy-to-use product that users will like (Cheung, 2023). Two dashboards' designs and implementations are described in detail in Chapter 4.

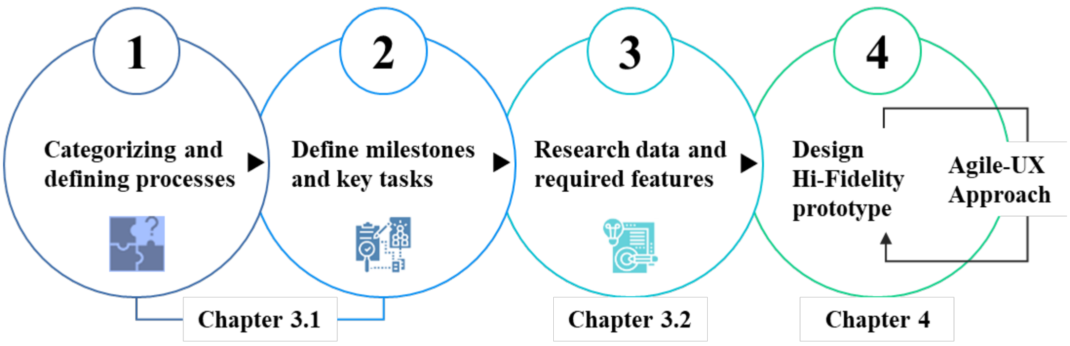


Fig. 1: Methodology for designing smart city emergency management interactive Web-GIS dashboards

3.1. Categorizing the emergency management process: objectives, missions and key data

In this section, prior to the UX/UI design of the emergency management dashboards, the process is classified into five stages according to the actual emergency management procedures. Objectives, missions, and relevant data were presented for each stage. This was done through relevant literature and surveys of real users (3 municipal officials).

Step 1: Monitor urban environments and detect anomalies

The first stage is monitoring urban environments and detecting abnormalities. The main goals are to detect changes in the urban environment in real-time, and to detect anomalies such as risks and threats that can lead to emergencies as quickly as possible. In order to detect and respond to emergency situations early, abnormal signs must be quickly recognized and related information must be displayed on the dashboard.

- **Key response personnel:** Integrated control center resident police and monitoring personnel
- **Primary mission:** detect smoke, odor, flame, heat, seismicity, traffic congestion, rising water levels, building shaking, etc.
- **Key data:** temperature/humidity, air quality, weather conditions, traffic patterns, social media, CCTV footage, etc.

Step 2: Emergency detection

The second stage is detecting whether an emergency has occurred. The main goals are to determine whether an emergency has occurred based on visual information such as automatic detection through the system and real-time CCTV footage around the area where abnormal signs occurred in the first stage or footage taken by dispatched drones. This includes quickly identifying emergencies, determining their location and scale, and which areas need prioritization, so that decisions can be made for faster and more effective notification and decision-making for response.

- **Key response personnel:** Integrated control center resident police and control personnel, Firefighting personnel
- **Primary mission:** Identification of various emergency situations in the city, such as fires, earthquakes, floods, typhoons, landslides, traffic accidents, injuries, deaths, building collapses, explosions, etc.
- **Key data:** CCTV footage, drone shooting footage, social media, etc.

Step 3: Alerts and notifications

The third stage is sending alerts and notifications related to the occurrence of emergency situations. The main goals are to alert the appropriate emergency response organizations to act quickly based on the type and magnitude of the emergency, and to quickly inform the public within the affected area about the emergency so that they can take evacuation actions.

- **Key response personnel:** Integrated control center public officials and control personnel, Firefighting personnel
- **Primary mission:** Send SMS and siren alerts through the system

Step 4: Emergency responses

The fourth stage is performing response activities to emergency situations. The main goal is for decision makers within the emergency response organization to take actions to mitigate the impact of an emergency, such as deploying emergency response personnel to the scene and allocating resources. Effective communication and cooperation between emergency managers are important, and emergency situations should be responded to through proper placement and coordination of resources.

- **Key response personnel:** Integrated control center control personnel, public officials, firefighters, medical staff, resident police, citizens, etc.
- **Primary mission:** Fire suppression, prevention of the spread of hazardous substances, evacuation assistance, provision of medical services, etc.
- **Key data:** Wind direction/speed, precipitation, weather, temperature, nearby CCTV footage, video from dispatch vehicles, building information, hazardous material concentrations, etc.

Step 5: Recovery

The fifth step is restoring normal operations and services after resolving the emergency situation. The main goals are to enable individuals and communities affected by the emergency to resume normal operations and restore services. In the recovery stage, long-term efforts can also be used to address economic, social, and environmental impacts. Effective recovery requires close coordination and cooperation among emergency managers, government agencies, and community organizations.

- **Key response personnel:** Emergency managers, government agencies, and community organizations
- **Primary mission:** Restoring infrastructure, repairing damaged facilities, and supporting affected individuals and communities.
- **Key data:** Information about past emergencies, the extent of physical damage, geographic information, etc.

Since the main achievement goals and tasks of each stage of the emergency management process are different, it is necessary to define the functions and implement the system considering the requirements of each stage of emergency management of response organization during design and implementation of the Web-GIS dashboard. The first four steps in the emergency management process are primarily focused on taking immediate and decisive action in the face of an emergency crisis. These are the steps that require immediate response and should focus on saving lives, preventing further damage in the affected area, and managing the immediate aftermath of an emergency. The "recovery" phase, on the other hand, requires a long-term approach and involves navigating the complex process of restoring normalcy after the initial crisis has abated. Complex and multifaceted solutions may be required, addressing not only physical restoration but also psychological and socioeconomic impacts. Since this study aimed to design a real-time interactive Web-GIS dashboard that enables rapid response through emergency decision support within the context of smart city management, the provision of information to help in the 'recovery' phase was excluded from the scope of the study.

3.2. Investigating data and essential functions to support decision-making in response phases

Data and detailed functions were configured to provide key information in a timely manner for each response stage (excluding ‘recovery' stage). This was done through relevant literature review and in-depth interviews and consultations with real users (3 municipal officials). The main data available for the emergency management process in cities are CCTV footage installed by local governments for various purposes, data collected by IoT sensors, and public data provided by the Open Government Data Portal (www.data.go.kr) established and operated by the minister of interior and safety of the Republic of Korea. Metadata collected throughout the entire emergency management process basically includes information such as anomaly and type of emergency, location of occurrence, time, date, and reporting time.

After initially selecting public data based on its usefulness, availability, and accessibility, the type of linked data was finally determined through a user research. Data visualization measures (display type, screen position, etc.) were derived in consideration of the properties of linkage information, the purpose of achieving each emergency response step, and tasks. In the case of dashboard essential functions, UX/UI was designed in consideration of user convenience such as inquiry (reading), update, and generation of information necessary for users to achieve the purpose of the task based on emergency response scenarios. Major functional requirements were finally classified according to the aspects of ‘data linkage’ and ‘construction of an interactive environment’ as shown in Table 1 and Table 2. In Tables 1 and 2, ‘●’ indicates data and functions required for tasks that support the main task, and ‘○’ indicates data and functions that are utilized as auxiliary.

Table 1. Key data requested by smart city emergency response personnel

Key data needed for each phase of emergency response	① Urban environmental monitoring & anomaly detection	② Emergency Detection	③ Alerts and notifications	④ Emergency response
Weather, temperature, humidity, wind direction/speed, precipitation	●			○
Fine particulate matter, ultrafine particulate matter, yellow dust, ozone, nitrogen dioxide, carbon monoxide	●			○
Multipurpose CCTV footage(video) in city	●	●		●
Real-time drone location		●		●
Type and real-time location of dispatch vehicles				●
Emergency history and response information				●
Video(footage) from dispatch vehicles and drones				●
Firefighting object, water, and hazardous materials/things information				●
Building information (floors, floor plans, fire safety, survey information, etc.)				●
General 2D maps, 3D maps, aerial maps, and road views	○	○	○	○
Life safety facilities such as pharmacies, AEDs, health centers, heat shelters, nucliear relief centers, etc.	○	○	○	○

Table 2. Key features requested by smart city emergency response personnel

Key data needed for each phase of emergency response	① Urban environmental monitoring & anomaly detection	② Emergency Detection	③ Alerts and notifications	④ Emergency response
On/Off map layers: Weather, Atmospheric, and Life Safety Information (Urban flood maps, landslide risk maps, forest fire history, landslide history, earthquake history)	●			○
Change the type of map(2D/3D/Aerial/Road views), zoom in/out of map size, rezone area, rezone radius, select area	○	○		○
Automatic abnormal pattern and emergency detection based on artificial intelligence and machine learning algorthms (Smoke, electricity leakage, fire, crisis, water level rise, seismic)	●	●		
CCTV control(Pan, Tilt, Zoom) around the location of abnormal signs/emergencies	●	●		●
Alert and disseminate emergency information (SMS, voice alerts via siren)			●	
Dispatch orders to emergency response personnel			●	
Real-time video pop-up display when clicking on dispatch vehicle and drone icons on the map		●		●
Playback of surrounding CCTV and road video tracking according to location of dispatch vehicle				●
Telescopic surveillance and circular surveillance of CCTV footage (display at least 5 CCTV videos simultaneously)	●	●		●
Display various building information of the building when selecting a building				●
Displays emergency type, location, time, duration, hospital arrival		●		●
Hospital arrival notification function				●
Search function for information related to emergency occurrence history and response				●

In this study, the types of emergency situations were classified into four categories: fire disasters, emergency disasters, rescue disasters, and other disasters according to the classification of 119 emergency services, an actual emergency response demand organization. This taxonomy represents a pragmatic approach tailored to achieving the research objectives and is consistent with established response strategies and coordination protocols (personnel coordination and resource allocation) routinely used by professional emergency response organizations. Including a detailed type of emergency as in-system metadata can facilitate and enhance the decision-making process for recovery steps and future policy formulation.

On the other hand, the provision of information that helps in the recovery stage was excluded from the scope of the study. As previously mentioned, the first four steps in the emergency management process are primarily focused on taking immediate and decisive action in the face of an emergency crisis. These are the steps that require immediate response and should focus on saving lives, preventing further damage in the affected area, and managing the immediate aftermath of an emergency. The "recovery" phase, on the other hand, requires a long-term approach and involves navigating the complex process of restoring normalcy after the initial crisis has abated. Complex and multifaceted solutions may be required, addressing not only physical restoration but also psychological and socioeconomic impacts.

In addition, social media was excluded due to problems such as personal information protection, quality, and difficulty in real-time analysis of large amounts of data when collecting and utilizing data. Various city data were considered to build a smart city emergency monitoring platform, but the exclusion of social media data in the final stage was supported by several key factors. First, the cost of collecting, preprocessing, analyzing, and managing social media data in real time is an important consideration for real-world organizations. The extensive resources required to process the vast amounts of social media content generated in real time have posed a significant challenge for emergency response organizations that must operate within limited budgets. Second, it required strict measures to comply with data privacy regulations and protect individual rights. Finally, the quality, accuracy, and reliability of social media data has become a major issue. Ensuring the veracity of data, a critical component of making informed decisions in an emergency, requires sophisticated filtering and validation mechanisms and adds complexity to the data processing pipeline. Given these challenges, this study decided to focus on the integration of other city data sources that can provide reliable, high-quality, and quickly accessible information for emergency decision-making.

4. Implementing interactive Web-GIS dashboard prototypes

In a real-world project to develop real-time interactive Web-GIS dashboards for smart city data-driven emergency management, the end-user (municipality) hoped to strengthen command, coordination, and control through efficient control and front-line field sharing information during emergency response. The user requirements for developing the dashboard were quite numerous and complex, but can be summarized as follows.

1) Linking information needed for emergency response

- Reported information, emergency information, dispatch information, CCTV footage, IoT sensor data, atmospheric information, weather information, life safety maps, and other public data

2) Visualize linked information within the map interface

- Derivation of effective visualization measures considering the characteristics of the aforementioned data and the emergency response process (Icons, GIS layers, Local Navigation Menu, Right Panel Menu, etc.)

- Pop-up window configuration method in map interface based on CCTV type and monitoring method (how to select CCTVs, location, number), display CCTV location and facing direction, etc.

3) Derive and implement intuitive user interactions

- CCTV control (Pan, Tilt, Zoom operation), building and fire safety information inquiry function, current/past data inquiry function (CCTV footage, information of report, emergency, and dispatch, etc.), natural language search function (address, emergency, facility, etc.), etc.

This project took place from April 2022 to November 2022 in Busan, South Korea. 1 product manager, 3 product designers, 3 web-developers, 3 local government officials, 2 control center monitoring personnel, and 2 firefighters participated in the UX/UI design and development process. Based on the information needed at the actual emergency response site, the accessibility of the information, the possibility of implementing the function in the present, and real-user feedback, the functions and UI needed for emergency management were developed and finally implemented. Using an agile-UX approach, project participants discussed user requirements and improvements and draw conclusions through face-to-face or video conferencing in each sprint (A sprint is a period of 1-3 weeks during which a team focuses on a small set of work items and aims to complete it) that were conducted every two to three weeks. Based on the conclusions drawn in each sprint, the product designer produced the prototypes (draft), and in the next sprint, demonstrations of the prototypes were repeated to gather user feedback and improve the UX/UI of dashboards. As a high-fidelity prototyping tool, the most well-known and widely used web browser-based UX/UI creation tool 'Figma' (Figma) was utilized, which was used from the initial prototype to the final UX/UI design. Producing prototypes enables effective communication with developers in the development stage, including screen layouts, buttons, interactions, and user journeys. Real users evaluated the usefulness and effectiveness of the dashboards from their own unique work perspectives, which was used as an important criterion for UX/UI design. 10 design iterations were conducted based on user feedback, and this iterative approach emphasized user-centered design and development, which helped us deliver fast and efficient results.

The smart city emergency management system was finally implemented with a status dashboard as shown in Figure 2 and a Web-GIS dashboard for responding to anomalies and emergency situations as shown in Figure 3. The status dashboard in Figure 2 displays (a) global navigation menu that can be moved between menus, (b) total number of incidents by type within a user-defined time period (days, months, years), (c) the name, date, progress, address, and dispatch status, and (d) location of real-time emergencies. When the user clicks on the emergency list in (c), he/she is directed to the Web-GIS dashboard as shown in Figure 3, which displays various city information necessary for the response to the emergency in a GIS map environment. The Web-GIS dashboard in Figure 3 has organized data, menus, and detailed functions to provide users with important information required for each stage of response in a timely manner in the event of an emergency. (a) is a global navigation menu for moving between menus, and (b) is a local navigation menu that allows searching information by emergency situation, CCTV footages, and addresses. (c) is a layer that displays various city data in a GIS map (General map, aerial map, terrain map) environment, and an area that displays information such as CCTV footage from various sources, dispatch vehicle types and locations. (d) is a right panel menu that provides basic information about the emergency (location, time, details, instructions, dispatch status, etc.), progress, and nearby facilities when a specific emergency is selected. Before selecting a specific emergency, the CCTV video screen in (c) and the area in (d) are not displayed, and all areas except (a) and (b) are displayed as GIS maps.

Fig. 2: Status dashboard configuration; (a) Global navigation menu for moving between menus, (b) number of occurrences by emergency type within a period, (c) real-time emergency information, (d) display location information via map chart

Figure 4 shows the detail menu for the Web-GIS dashboard local navigation menu. In the first tab (Figure 4-(a)), the list of emergencies is displayed in the latest order of occurrence, and only the desired type of emergency can be expressed through the filter function or search through natural language search. When the user clicks on a specific emergency in the list, the right panel menu displays live videos of the five closest CCTVs in the GIS map area and basic information about the emergency. Decision makers in emergency can view and record those orders in the system. Depending on the situation, real-time footage of drones and dispatched vehicles may be displayed. If the integrated control center personnel flies a drone before the dispatched personnel arrives at the site to grasp the situation, the emergency response personnel can reduce the time required to judge the situation after arrival, thereby securing golden time. If the injured person arrives at the hospital, the center and field personnel can report in real-time regardless of the location. The second tab (Figure 4-(b)) is a menu that allows users to view live footage from various devices (CCTV, fire trucks, drones, and mobiles) within the city. The last tab (Figure 4-(c)) is a natural language address search menu that allows users to search for an address and immediately bring up a GIS map of the area, as well as display various urban data layers or view a road view after navigating.

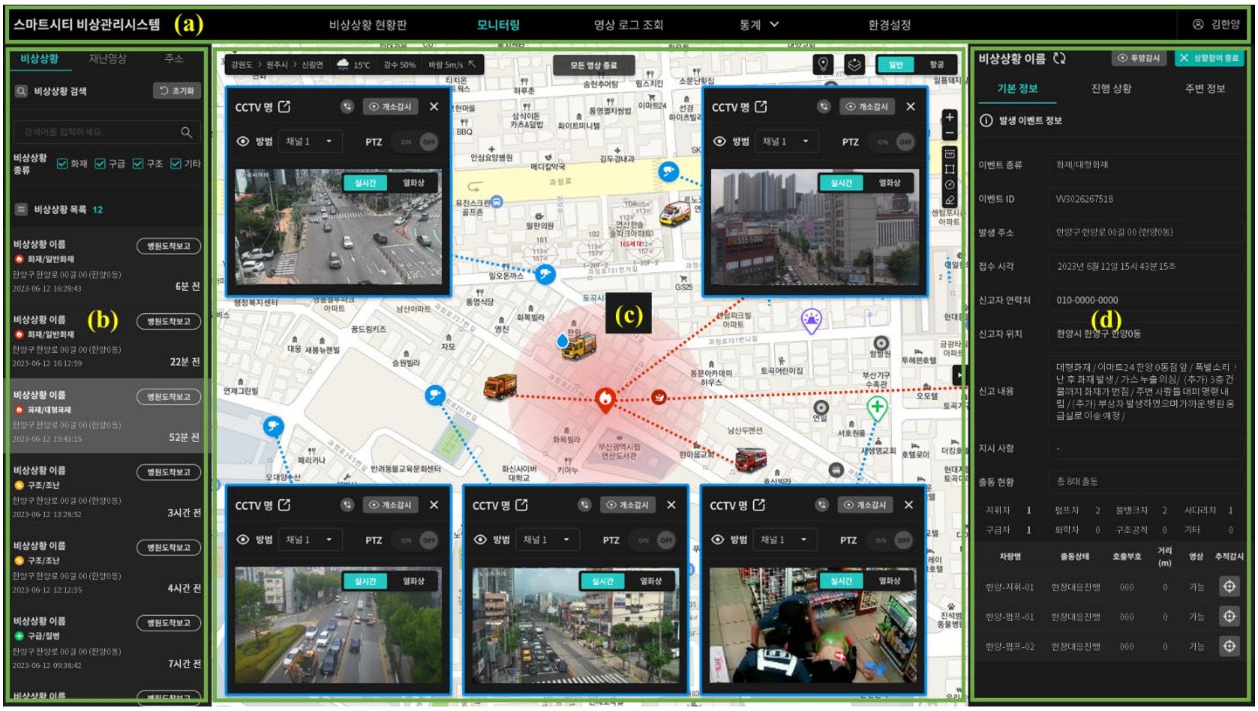
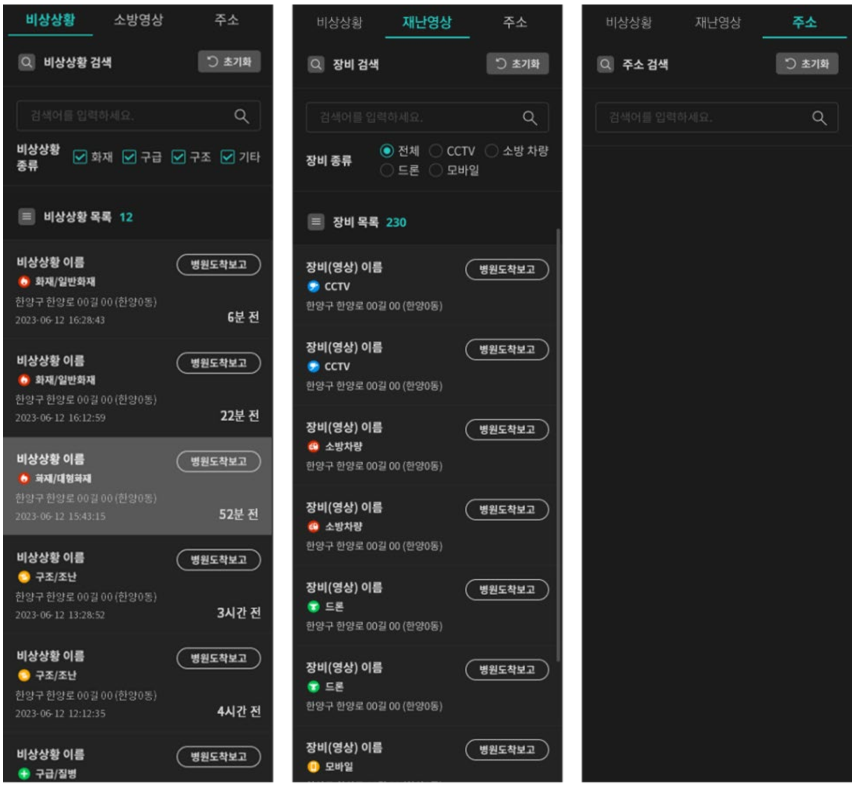
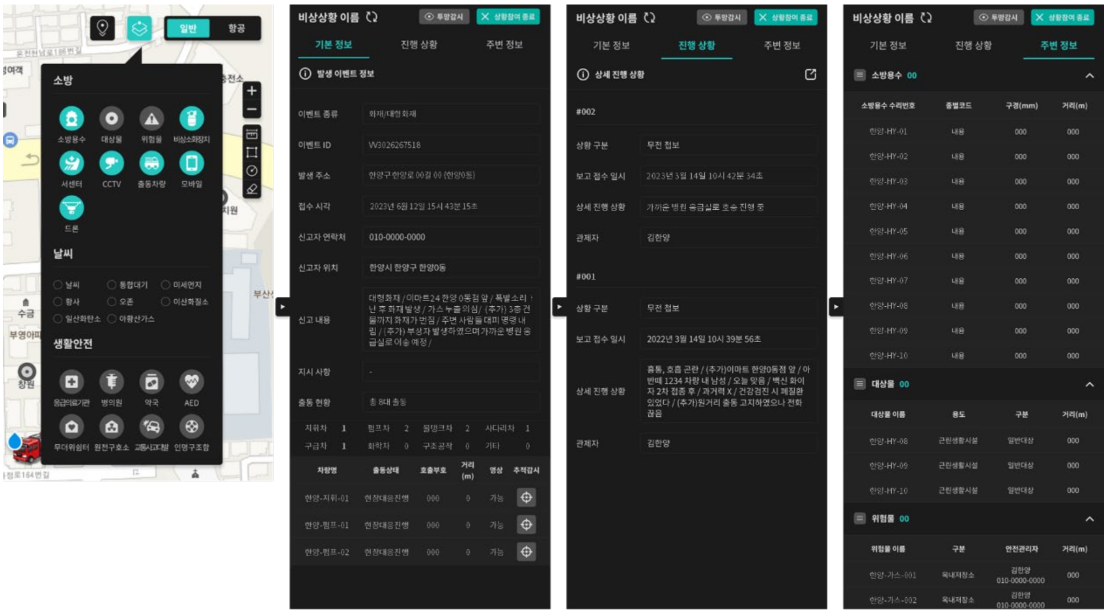


Fig. 3: Web-GIS dashboard configuration; (a) GNM for moving between menus, (b) Local navigation menu for searching emergency, CCTV footage, and address, (c) GIS map information such as emergency location, CCTV footage, and dispatch vehicle location, (d) Right panel menu for searching basic information, progress, and neighborhood information



(a) (b) (c)

Fig. 4: Web-GIS dashboard menu configuration; (a) search for emergency information, (b) view live-videos from various equipment, (c) address search based on natural language



(a) (b) (c) (d)

Fig. 5: Web-GIS dashboard map layer and right panel menu configuration; (a) various city information display layers, (b) emergency basic information, (c) emergency response progress information, (d) nearby facility information

Figure 5 shows the map layer of the Web-GIS dashboard and detailed display items of the right panel menu. Figure 5-(a) shows a feature that allows users to turn on/off firefighting resources (fire water, hazardous materials, emergency fire extinguishers, drones, dispatch vehicles, fire stations, etc.), weather (air quality, hazardous materials, fine dust, etc.), and life safety (emergency medical institutions, hospitals, AEDs, nuclear relief stations, etc.) information in the form of map layers in a GIS environment. Menus (b)-(d) are organized for use by emergency responders based on the stage of the emergency response. In (b), users can write detailed information and instructions when detecting an emergency or receiving a report, and easily identify the dispatch situation (vehicle type, video). In (c), the information can be logged whenever the response situation is updated, and in (d), the function is configured to provide information on major fire fighting facilities around the scene to enable effective resource allocation and response at the scene.

The Web-GIS dashboard implemented based on end-user requirements enables users to support emergency decision-making and efficient emergency management through two-way interaction, such as viewing, creating, and updating necessary data through user-driven operations according to the emergency response stage, rather than unilaterally accepting the information provided. With just a few clicks, users can easily access additional information needed to respond to an emergency, such as CCTV footage around the emergency location, city air quality information, firefighting facilities, building layouts, shelters, life safety facilities, and etc. All visualizations can be interactively interrogated for in-depth information or zoomed in and out in a Web-GIS environment. Since the dashboard of the smart city emergency management system is implemented under the premise of using it in a web environment, the control center and field dispatchers can be provided with various city data to help them respond regardless of time and place during the emergency response process.

The usability of the two developed dashboards' visualization UI was tested with four users from IT backgrounds and real users in a strictly controlled environment using heuristic testing methods. Heuristic testing methods have the advantage of being conducted with a small set of evaluators, but can reveal 75% of the major problems in the interface [25, 26]. The basic point of "heuristic evaluation" (Nielsen, 1994) is to reduce the set criteria to a few, while at the same time making them broadly applicable and generally agreeable, increasing the expertise of the evaluator and consequently increasing reliability (Karoulis and Pombortsis, 2004). All evaluators conducted their evaluations independently to ensure that their opinions were not influenced by each other during the evaluation process. All evaluators rated the severity of each heuristic principle on a scale of 0 to 4 (0 - no usability issues, 4 - usability disaster) and discussed the recommendations and violations found and agreed on how to improve/enhance them. The usability of the visualization UI was tested and found three cosmetic issues, one minor usability issue, and nine other heuristics that were not violated, as shown in Table 3. The end user showed overall positive feedback, and the visualization UI elements with negative results were finally updated according to the improvement and complementary directions derived together.

Table 3. Results of the heuristic usability evaluation of the proposed visualization UI

#	Heuristic	Severity Rating	Violation	Improvement directions
1	Visibility of the system status	0	No violations found	No improvements are needed
2	Match between system and real world	0	No violations found	No improvements are needed
3	Support users' control and freedom	0	No violations found	No improvements are needed
4	Consistency and standards	0	No violations found	No improvements are needed
5	Prevent errors	1	Confirmation messages are missing for some actions	When updating and saving dispatch instructions and current emergencies, there should be a confirmation message asking the user to ensure that they have completed the process.
6	Minimize the users' cognitive load	2	Some tasks are subject to a high cognitive load on the user.	Requires redesign of some icons displayed on the map (dispatch vehicle icon, event type icon)
7	Recognition rather than recall	0	No violations found	No improvements are needed
8	Flexibility and efficiency of use	0	No violations found	No improvements are needed
9	Help users recognize, diagnose and recover from errors	1	It should specify how the user recovers the error.	Error messages should be able to accurately represent problems in plain language without code and provide constructive solutions.
10	Aesthetic and minimalist design	0	No violations found	No improvements are needed
11	Spatial organization and perspective	0	No violations found	No improvements are needed
12	Create, Read, Update, Delete of Data	0	No violations found	No improvements are needed
13	Control the published data	1	No violations found	Some data loading needs to take less time.

5. Conclusion

As modern cities embrace smart ecosystems, developing effective tools for managing unpredictable emergencies becomes increasingly important. This research makes key contributions to smart city systems engineering and emergency management. The interactive Web-GIS dashboards integrate heterogeneous data feeds to enhance situation awareness and coordinated response in a high-pressure emergency situation. The user-centric design approach aligns key features with emergency decision-makers' information needs during time-sensitive, dynamic events. The dashboard prototypes proposed in this research provides an initial smart city system design example and foundation for continued innovation. While refinements remain through real-world implementation, the prototypes represent progress toward next-generation emergency response technologies. Collaborative efforts between researchers, practitioners, and technology partners will be crucial in this complex domain rife with human factors challenges.

In the event of an emergency, participants in the real-world project expect to be able to enhance their command, coordination, and control capabilities through efficient monitoring and frontline sharing of key information via interactive web-GIS dashboards. However, quantitatively measuring the effectiveness of the dashboard's potential usefulness requires continuous performance assessments, such as the time required for each response stage, and improvements in bottleneck stages to ensure citizens' safety. Assessing dashboard performance during future simulated drills would provide vital usability insights. It is also important to ensure flexibility throughout the event, or to include only actually effective urban data feeds in the emergency response process through repeating simulated drills.

On the other hand, the limitations of this study include that there are data and functions excluded from the actual system construction process of local governments due to the data accessibility, the feasibility of implementation by contractors, privacy protection issues and system operation costs. For example, this study excluded the association of social media data due to privacy issues caused by data collection and utilization, data quality, and real-time analysis costs for large amounts of data. However, there are many references to the availability and potential of social media data in existing literature, so future research needs to explore ways to take full advantage of social media data. In addition, in the future, a menu design that can support decision-making in the "recovery" stage, the final stage of smart city emergency management, will be added to complete the implementation of the total five-step response system for smart city emergency management.

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