Implementation of an Evacuee Support System for Distributed Evacuation by Visualizing the Congestion Status of Evacuation Shelter

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Abstract

We implemented an evacuee support system in this study. This system consists of evacuee's safety information registration, evacuation shelter management, and evacuation shelter congestion status visualization systems. By implementing these three systems, a disaster response headquarters can manage the evacuees at each evacuation shelter accurately and quickly. Additionally, residents who are considering evacuating to evacuation shelters can browse the visualized congestion status of each evacuation shelter and move to vacant evacuation shelters. We evaluated the operability, readability, functionality, necessity, effectiveness, the applicability of the entire system, effectiveness and operability of the safety information registration system, readability and effectiveness of the evacuation shelter congestion status visualization system, and functionality and effectiveness of the evacuation shelter management system. We conducted evaluation experiments on 30 subjects and obtained a high evaluation in each evaluation item.

Keywords: Visualization, Congestion Status, Evacuees Support, Safety Information, Evacuation Shelter.

1 Introduction

Several natural disasters that occurred in Japan in recent years are as follows: the Kumamoto earthquake (Japan Meteorological Agency, 2016 and Kumamoto Prefecture, 2019), which recorded a seismic intensity of seven on April 14, 2016, causing damage to houses and large-scale landslides, 2019 Boso Peninsula Typhoon (Japanese Cabinet Office, 2020a, and Chiba Prefecture, 2019), which caused damage due to storms in various places in September 2019, 2019 East Japan Typhoon (Japanese Cabinet Office, 2019, and Miyagi Prefecture 2019), which caused damage due to flooding of rivers in a wide area of eastern Japan, and heavy rain in July 2020 (Japan Meteorological Agency, 2020, and Gifu Prefecture, 2020), which caused damage due to river flooding and sediment-related disasters. From the above scenarios, it can be seen that large-scale natural disasters occur yearly, causing enormous damage to various parts of Japan.

However, due to the influence of the coronavirus (COVID-19), disaster response at disaster response headquarters and evacuation shelters is under pressure to respond to new issues. In 2020, the Cabinet Office published "Points for disaster response based on the new coronavirus infection" (Japanese Cabinet Office, 2020b). However, few local governments have been able to thoroughly study the operation of evacuation shelters with measures against infectious diseases in the event of a large-scale

natural disaster. Thus, the importance of distributed evacuation is increasing.

In 2020 Typhoon No.10 (Japanese Cabinet Office, 2020c), some residents were hesitant to vacate the evacuation shelter because they were worried about the COVID-19 infection at the evacuation shelter. Disseminating COVID-19 measures at evacuation shelters and the capacity of evacuation shelters based on social distance will lead to residents' peace of mind when evacuating to evacuation shelters. Thus, the importance of proactively disseminating and publicizing the evacuation shelter situations is increasing. When Typhoon No. 10 occurred in 2020, some local governments used homepages, disaster prevention emails, disaster prevention applications, disaster prevention radios, etc., to inform and publicize the status of evacuation shelters and congestion. As a means to prevent evacuees from concentrating on a specific evacuation shelter, it is crucial to inform residents of the congestion status of evacuation shelters via the Internet or the like (Japanese Cabinet Office, 2020e). However, few local governments provide the real-time congestion status of evacuation shelters.

The rest of the article is organized as follows: Section 2 describes related works. Section 3 describes the purpose of our research. Section 4 explains the system configuration of our proposed evacuee support system. Section 5 describes the evacuee support system. Section 6 evaluates the evacuee support system, and finally, Section 7 concludes our findings.

2 Related Works

Nakada et al. (Nakada, 2021) developed Shelter Navi, an application that avoids the formation of dense areas in evacuation shelters using the self-help of residents. This application manages the location and degree of congestion of evacuation shelters and displays them on a map, thus informing residents to avoid crowding by enabling them to evacuate in a distributed evacuation system in the event of a disaster.

Akasaka et al. (Akasaka, 2017) developed an evacuation shelter management system called Refuge Management System. This system collects evacuees' information using information and communication technology in the event of a large-scale disaster, quickly creates and disseminates evacuees' lists (including relief needs), and manages the evacuees' admission status. Evacuees' information can be registered from various information terminals equipped with a web browser on devices, such as personal computers and smartphones.

Numada et al. (Numada, 2016) developed an evacuation shelter information-sharing system called COCOA to support information sharing between each evacuation shelter and the disaster response headquarters; this is to implement efficient evacuation shelter management. This system gathers the number of evacuees at each evacuation shelter in real-time and efficiently creates a list of evacuees, thus enabling efficient evacuation shelter operation in response to changing circumstances.

Nishimoto et al. (Nishimoto, 2016) attempted to convert a paper-based evacuee list at an evacuation shelter into data to quickly identify and share information with victims in the event of a disaster. In the event of a disaster, residents register their safety information themselves using smartphones to share information with local community organizations.

Naka et al. (Naka, 2017) developed a safety confirmation system that uses facial recognition; this allows residents to register safety information without carrying special equipment.

Aoki et al. (Aoki, 2013) developed a safety confirmation system that allows users to register their safety information in the safety confirmation server and to confirm the safety information of others by

inquiring with the safety confirmation server.

Nakajima et al. (Nakajima, 2007) developed a disaster evacuation guide system using cellular phones with GPS functions. Nakajima et al. performed the augmented experiment to guide subjects and evacuation agents by using a multi-agent simulation.

Sasaki et al. (Sasaki, 2021) developed a navigation system that supports the activities of users during normal times and disasters by integrating augmented reality and web geographic information systems. This system effectively provides users with information on sightseeing spots, tourism-related facilities, and disaster support facilities.

Katayama et al. (Katayama, 2019) developed an evacuation guidance support system using agent-based multi unmanned aerial vehicles (UAVs). In this system, the software agent generates an evacuation guidance plan for UAVs and derives the safest evacuation guidance route.

3 Research Objective

In this study, we implement the following three systems:

☐ Evacuees safety information registration system that registers evacuees' information on the Internet for safety information registration via Bluetooth low energy (BLE) beacon, near-field communication (NFC) tag, and quick response (QR) code.

☐ The evacuation shelter management system that manages evacuees' information about each evacuation shelter is registered on the evacuees' safety information registration system.

☐ An evacuation shelter congestion status visualization system that displays the congestion status of evacuation shelters in real-time from the number of evacuees in each evacuation shelter, which is integrated into the evacuation shelter management system.

Based on the evacuees' information about each evacuation shelter registered on the evacuees' safety information registration system, the disaster response headquarters can manage evacuees from each evacuation shelter in real-time using the evacuation shelter management system. This leads to the distribution of relief supplies based on the actual situation of the shelter. Additionally, based on evacuees' information about each evacuation shelter registered via the evacuees' safety information registration system, residents who are considering evacuating can move to vacant evacuation shelters using the evacuation shelter congestion status visualization system. This leads to distributed evacuation of residents.

4 System Configuration

Figure 1 shows the flow of the entire proposed system. This system consists of evacuees' safety information registration, evacuation shelter management, and evacuation shelter congestion status visualization systems. To register safety information, the evacuees access the evacuees' safety information registration system via the BLE beacon, NFC tag, and QR code. The disaster response headquarters can obtain the safety information of each registered evacuation shelter through the evacuation shelter management system. Furthermore, residents who have not moved to evacuation shelters can view the congestion status of each evacuation shelter via the evacuation shelter congestion status visualization system.
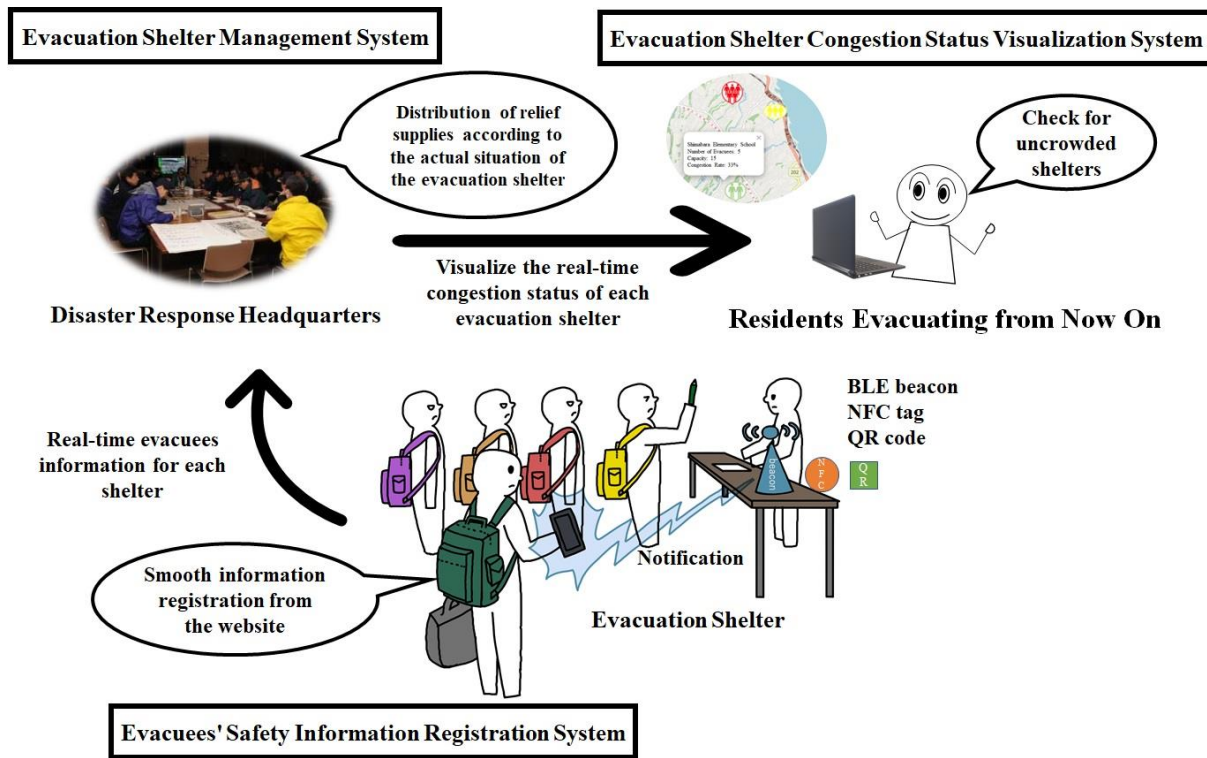
Figure 1. Flow of the Entire Proposed System

Figure 2 shows the configuration of the evacuee support system. This system consists of an evacuation shelter information management agent, evacuees' agent, evacuation shelter congestion status visualization agent, application server group (a safety information management server, an administrator information management server, and an evacuation shelter information management server), database (DB) server group (a safety information DB, an administrator information DB, and a shelter information DB), and a map information provision API.

4.1   Evacuation Shelter Information Management Agent

The evacuation shelter information management agent is intended to be operated by a staff of the disaster response headquarters or a local government staff assigned to the evacuation shelter. This agent manages evacuees' information of each evacuation center via the administrator's web system, and it is possible to register, delete, and edit the evacuation shelter information.

4.2   Evacuees Agent

The evacuees' agent is intended to be operated by evacuees who have moved to the evacuation shelter. This agent is guided to the safety registration website via a BLE beacon, QR code, and NFC tag. The information obtained from the safety registration website is stored in the safety information and shelter information DBs.
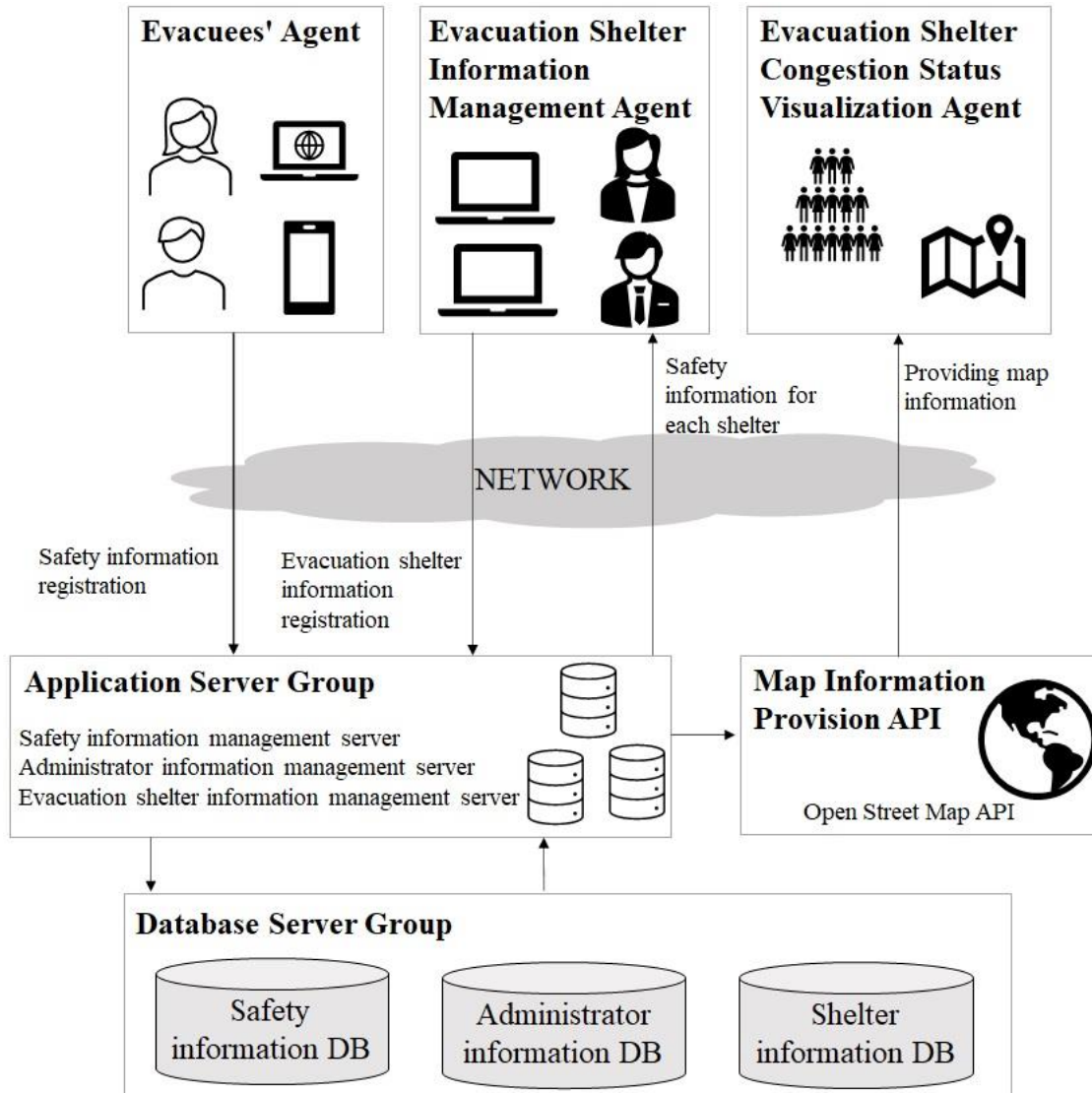
Figure 2. Evacuee Support System Configuration

4.3   Evacuation Shelter Congestion Status Visualization Agent

The evacuation shelter congestion status visualization agent is intended to be viewed by residents before evacuation. The number of evacuees in each evacuation shelter registered by the evacuees' agent is aggregated by the application server, and the real-time congestion status of each evacuation shelter is visualized on Web-GIS. This promotes the distributed evacuation of residents in the event of a disaster. Furthermore, it ensures the safety of residents and reduces the risk of infectious diseases.

4.4   Application Server Group

The application server group consists of safety information management, administrator information management, and shelter information management servers. The safety information management server manages the safety information registered by the evacuees' agents and aggregates the number of evacuees at each evacuation shelter. Next, this server provides the congestion status of each evacuation shelter in real-time to the evacuation shelter congestion information visualization agent via the map information provision API. Additionally, the administrator information management server

manages the administrator information, which in turn manages the information about each evacuation shelter. Furthermore, the evacuation shelter information management server manages the designated evacuation shelter information in the local government.

4.5   Map Information Provision API

The map information provision API uses the Open Street Map API (Open Street Map, 2022). The congestion status of each evacuation shelter is visualized on a map based on the number of evacuees in each evacuation shelter, which is collected from the evacuees' agents and the information on the designated evacuation shelters registered by the evacuation shelter information management agent.

4.6   Database Server Group

The database server group consists of safety information, administrator information, and shelter information DBs. The safety information DB stores the safety information of evacuees registered by the evacuees' agents. Additionally, the data of the shelter information management agent is stored in the administrator information DB. Furthermore, the evacuation shelter information DB stores the designated evacuation shelter information in the local government, which is registered by the evacuation shelter information management agent.

5 Evacuee Support System

The left of Figure 3 shows a screen when a user accesses the safety information registration website using a mobile terminal and selects an evacuation shelter. On the evacuation shelter selection screen, the user can select any evacuation shelter from the evacuation shelter list registered in the evacuation shelter information database. Additionally, since this system allows the input of safety information without requiring user registration, it is also possible to input evacuees who do not have a mobile terminal. When the evacuees' safety information registration is normally completed, the navigation bar notifying the completion of user registration is displayed, as shown on the right of Figure 3.
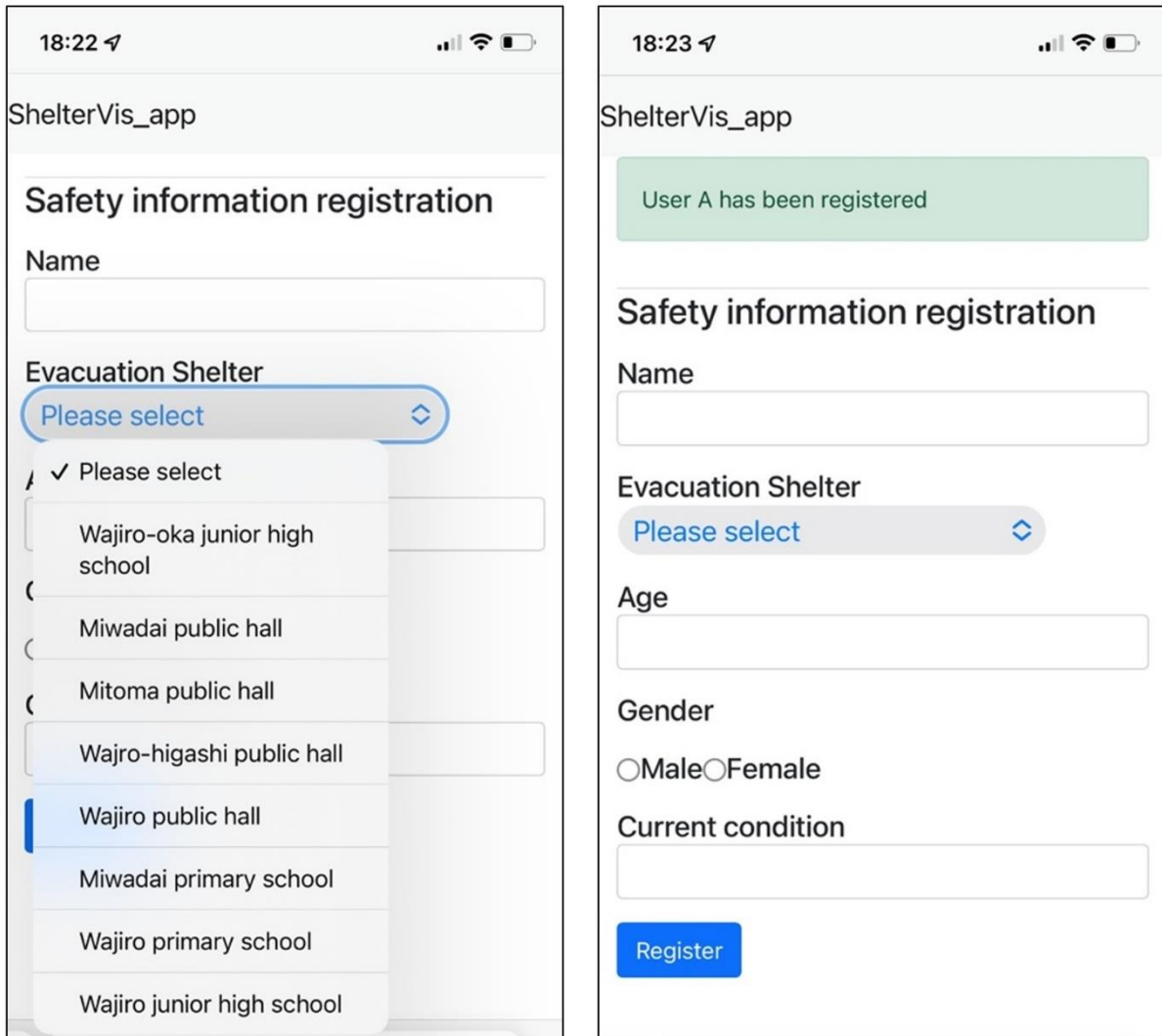
Figure 3. Evacuation Shelter Selection Screen (left) and Safety Information Registration Completion Screen (right) when Entering Safety Information

The evacuation shelter management system can be accessed when the administrator logs into the administrator login system. In the evacuation shelter management system, the evacuation shelter list, evacuee information management screen, new evacuee registration, and log out can be accessed from the menu bar. The default page of the evacuation shelter management system is the shelter list screen. Figure 4 shows the evacuation shelter list screen. When a user selects the evacuation shelter name on the evacuation shelter list screen, the screen transitions to the evacuation shelter detail screen. Figure 5 shows an evacuation shelter detail screen. On this screen, it is possible to check the latitude and longitude of the evacuation shelter and the updated date and time of the evacuation shelter information.
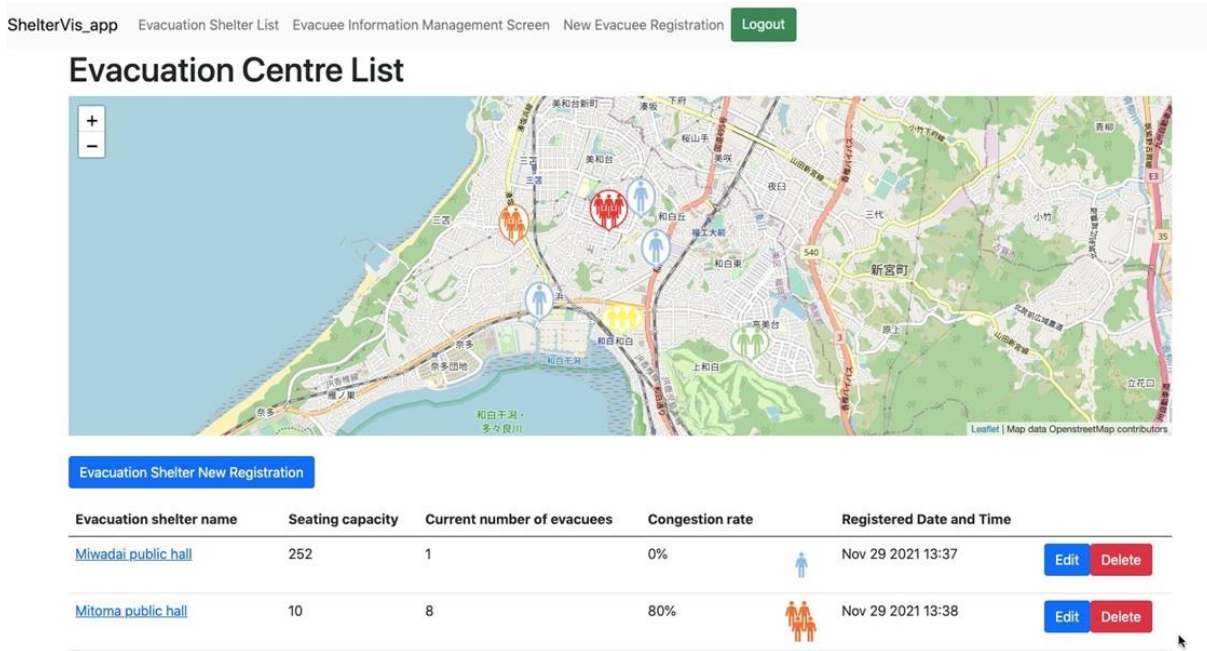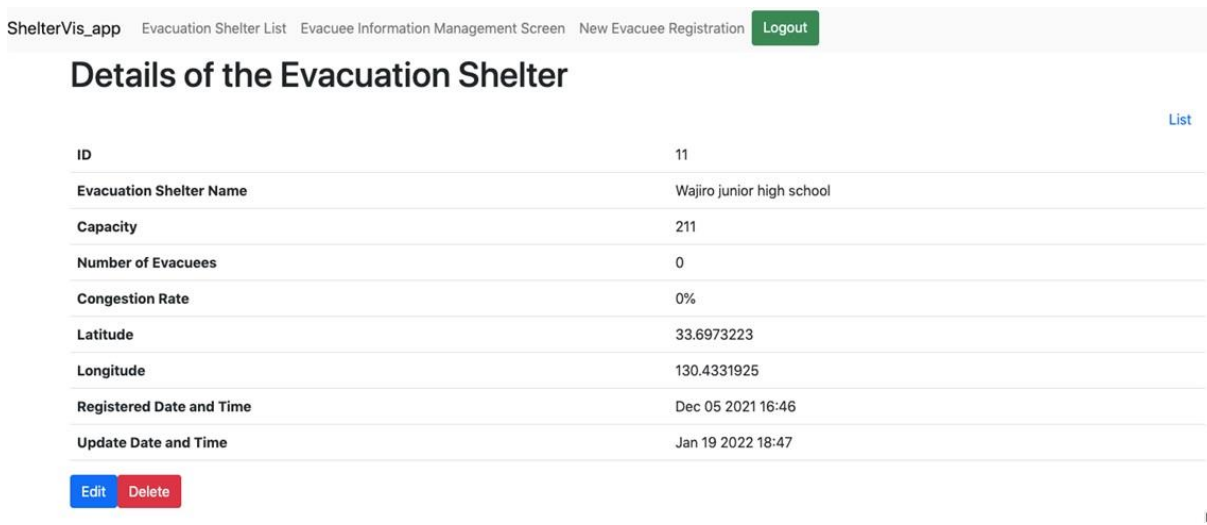
Figure 4. Evacuation Shelter List Screen

Figure 5. Evacuation Shelter Details Screen

On the evacuees' information management screen, it is possible to manage the evacuees' information input from the evacuees' safety information registration system. Figure 6 shows an evacuees' information management screen. This screen provides a search function through these options: evacuation center, name, age, and gender. Furthermore, it provides a sorting function through the registration date and time options.
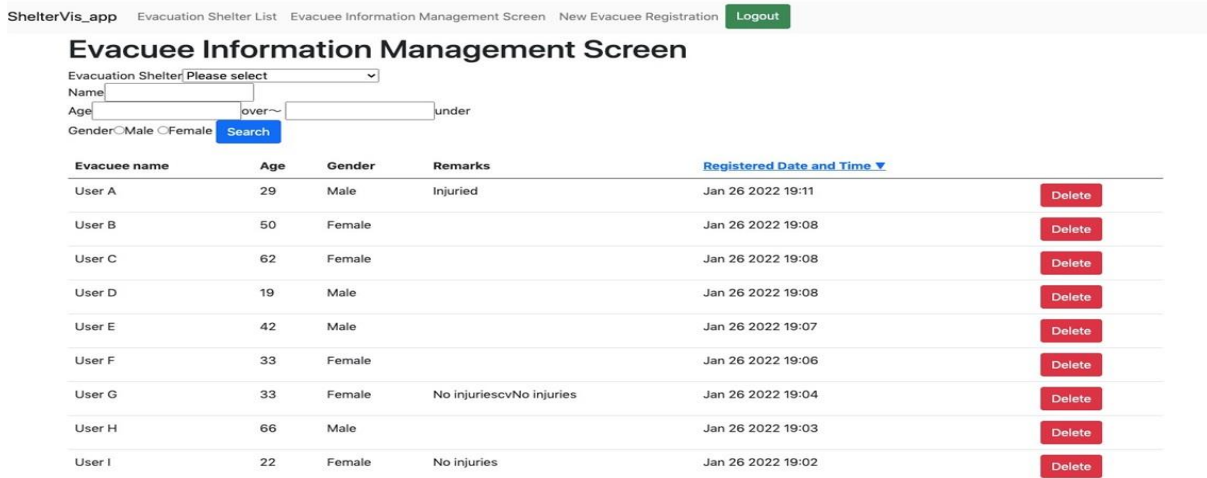
Figure 6. Evacuees Information Management Screen

Figure 7 shows the top page of the evacuation shelter congestion status visualization screen viewed by residents before evacuation. When a user clicks on the "List" button in Figure 7, the screen transitions into another screen that displays the congestion status of each evacuation shelter in a list format, as shown on the right of Figure 8. Furthermore, when the user clicks on the "MAP" button in Figure 7, the screen transitions into another screen that displays the congestion status of each evacuation shelter on the map, as shown on the left of Figure 8. By tapping the marker displayed on the map, the user can check the evacuation shelter name, the current number of evacuees, seating capacity, and congestion rate.
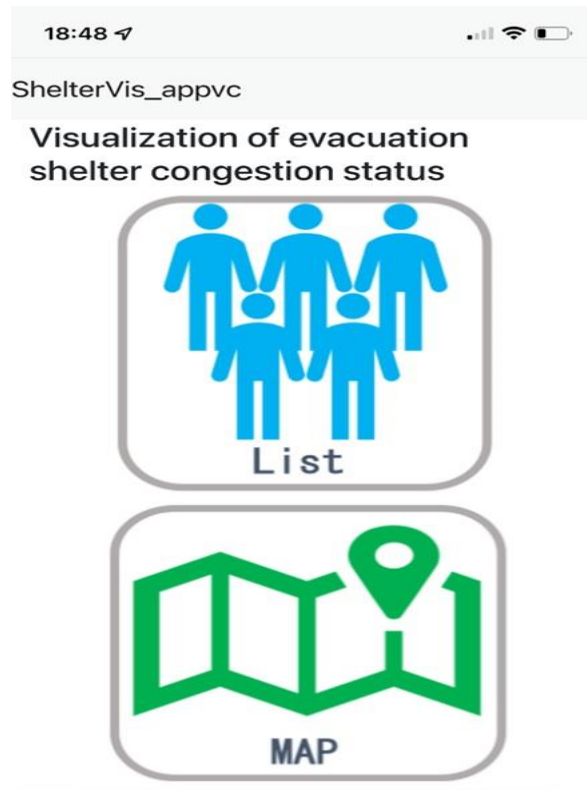

Figure 7. Top Page of the Evacuation Shelter Congestion Status Visualization Screen
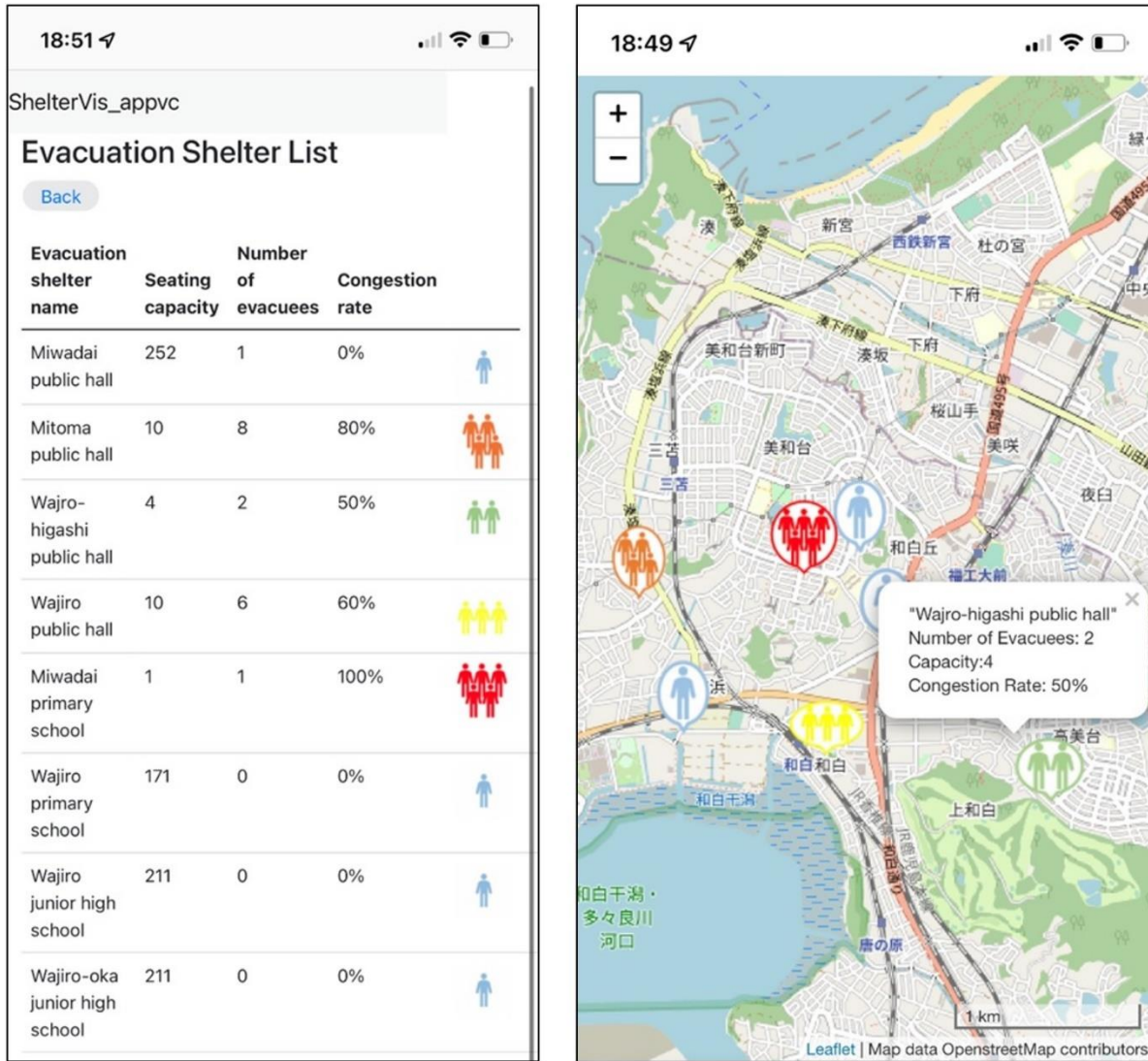
Figure 8. Congestion Status Visualization Screen for Each Evacuation Shelter in List Format (left) and Congestion Status Visualization Screen for Each Evacuation Shelter on the Map (right)

6 Evaluation of Evacuee Support System

In this study, we conducted an evaluation experiment on 30 subjects to evaluate the operability, readability, functionality, necessity, effectiveness, the applicability of the entire system, effectiveness and operability of the safety information registration system, readability and effectiveness of the evacuation shelter congestion status visualization system, and functionality and effectiveness of the evacuation shelter management system.

6.1 Operability, Readability, Functionality, Necessity, Effectiveness, Applicability of the Entire System

Figure 9 shows the evaluation results for the operability of the entire system. Here, 100% of the subjects answered "easy" or "somewhat easy," and we confirmed the high operability of the entire system. Figure 10 shows the evaluation results for the readability of the entire system. Here, 100% of

the subjects answered "easy to understand" or "somewhat easy to understand," and we confirmed the high readability of the entire system. Figure 11 shows the evaluation results for the functionality of the entire system. Here, 100% of the subjects answered "satisfied" or "somewhat satisfied," and we confirmed the high functionality of the entire system. Figure 12 shows the evaluation results for the necessity of the entire system. Here, 100% of the subjects answered "necessary" or "somewhat necessary," and we confirmed the high necessity of the entire system. Figure 13 shows the evaluation results for the effectiveness of the entire system. Here, 97% of the subjects answered "effective" or "somewhat effective," and we confirmed the high effectiveness of the entire system. Figure 14 shows the evaluation results for the applicability of the entire system. Here, 90% of the subjects answered "high" or "somewhat high," and we confirmed the high applicability of the entire system. Regarding applicability, the subjects commented, "I think it is also effective for visualizing the congestion status of restaurants and polling stations."
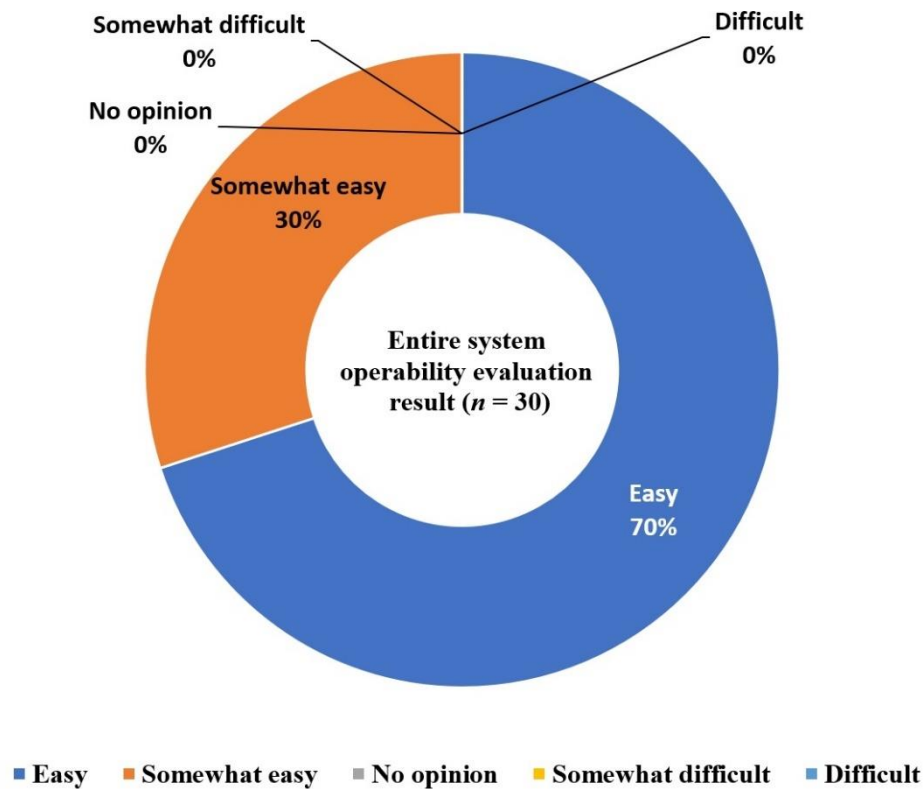

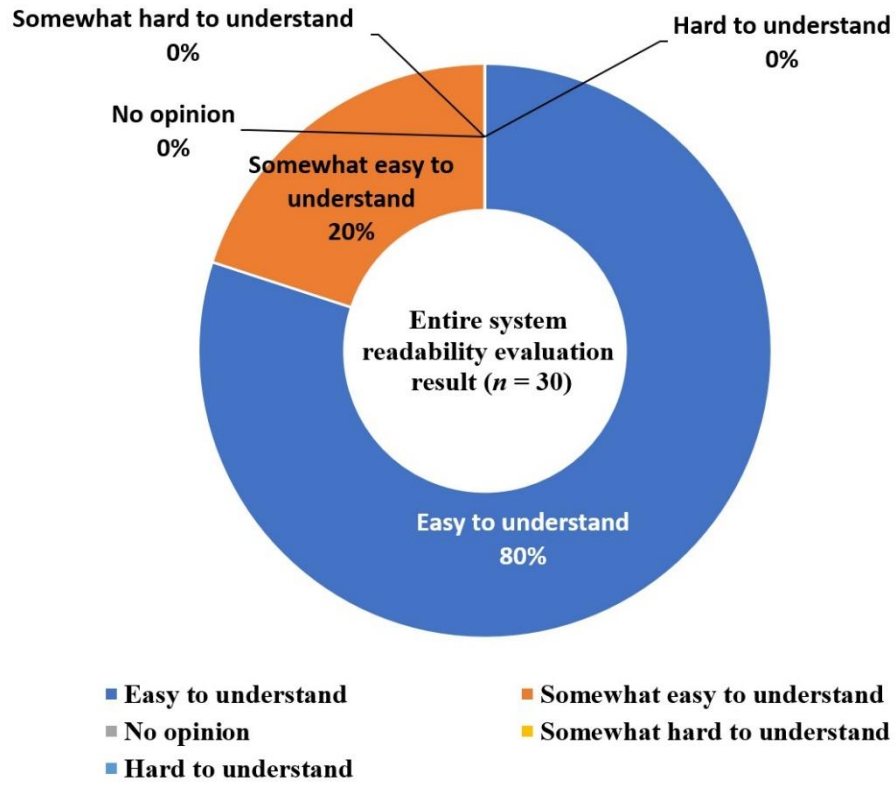Figure 9. The Entire System Operability Evaluation Result (n = 30)

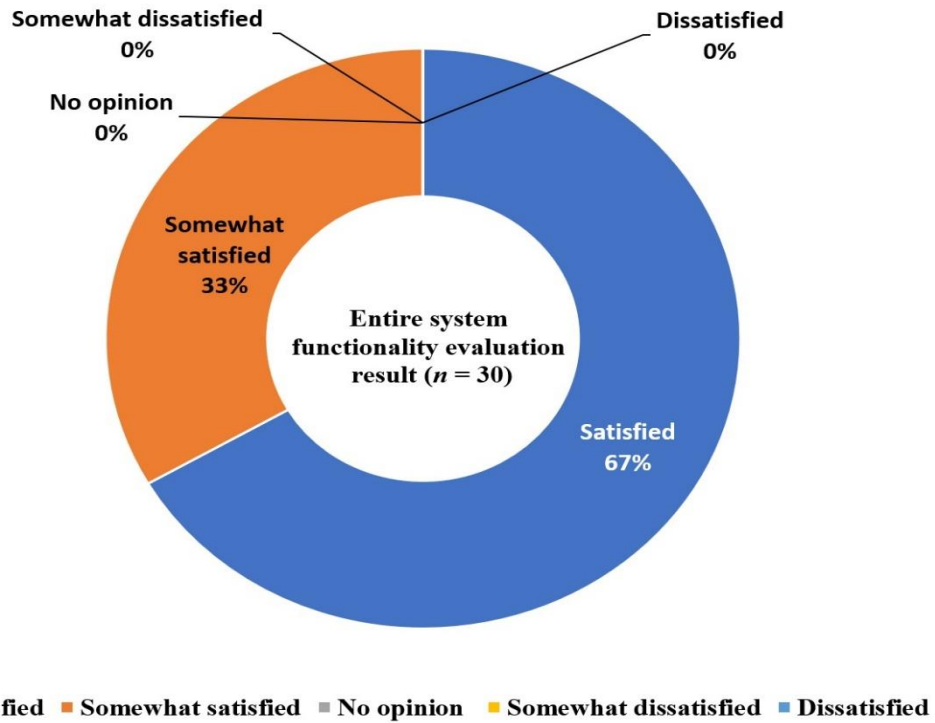Figure 10. The Entire System Readability Evaluation Result (n = 30)

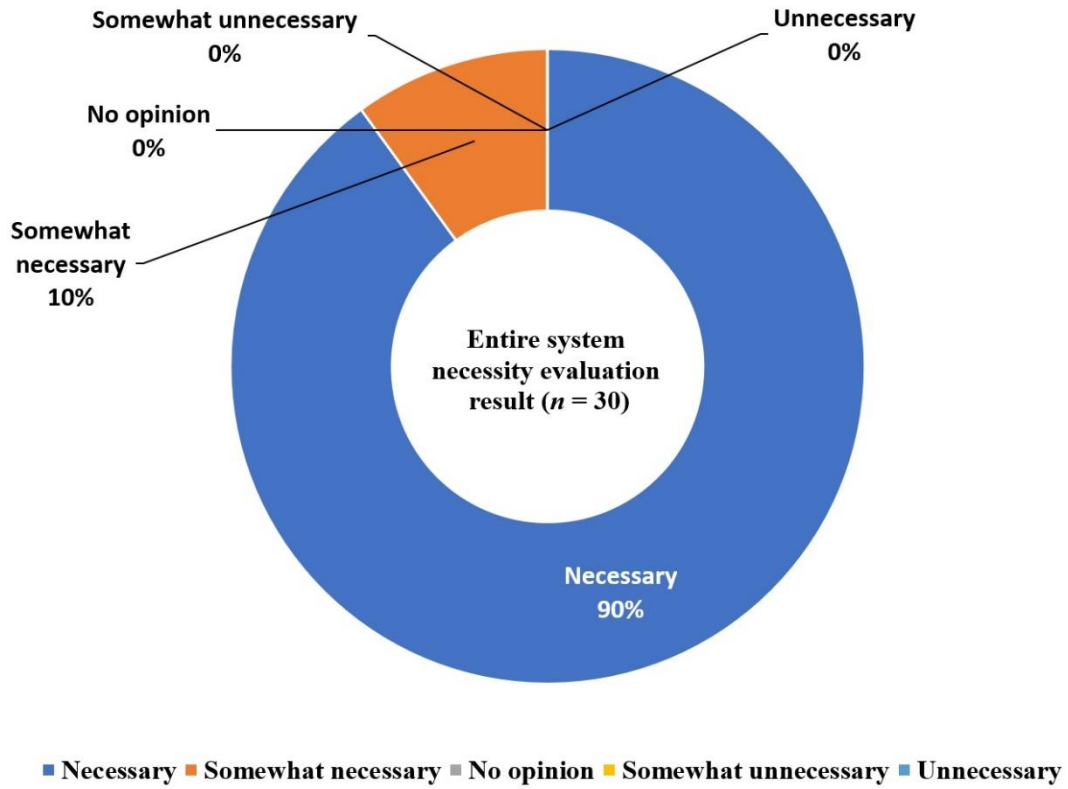Figure 11. The Entire System Functionality Evaluation Result (n = 30)

Somewhat unnecessary
0%

Unnecessary
0%

No opinion
0%

Somewhat
necessary
10%

Entire system
necessity evaluation
result (*n* = 30)

Necessary
90%

■ **Necessary** ■ **Somewhat necessary** ■ **No opinion** ■ **Somewhat unnecessary** ■ **Unnecessary**

Figure 12. The Entire System Necessity Evaluation Result (n = 30)

Somewhat ineffective
0%

Ineffective
0%

No opinion
3%

Somewhat effective
17%

Entire system
effectiveness evaluation
result (*n* = 30)

Effective
80%

■ **Effective** ■ **Somewhat effective** ■ **No opinion** ■ **Somewhat ineffective** ■ **Ineffective**
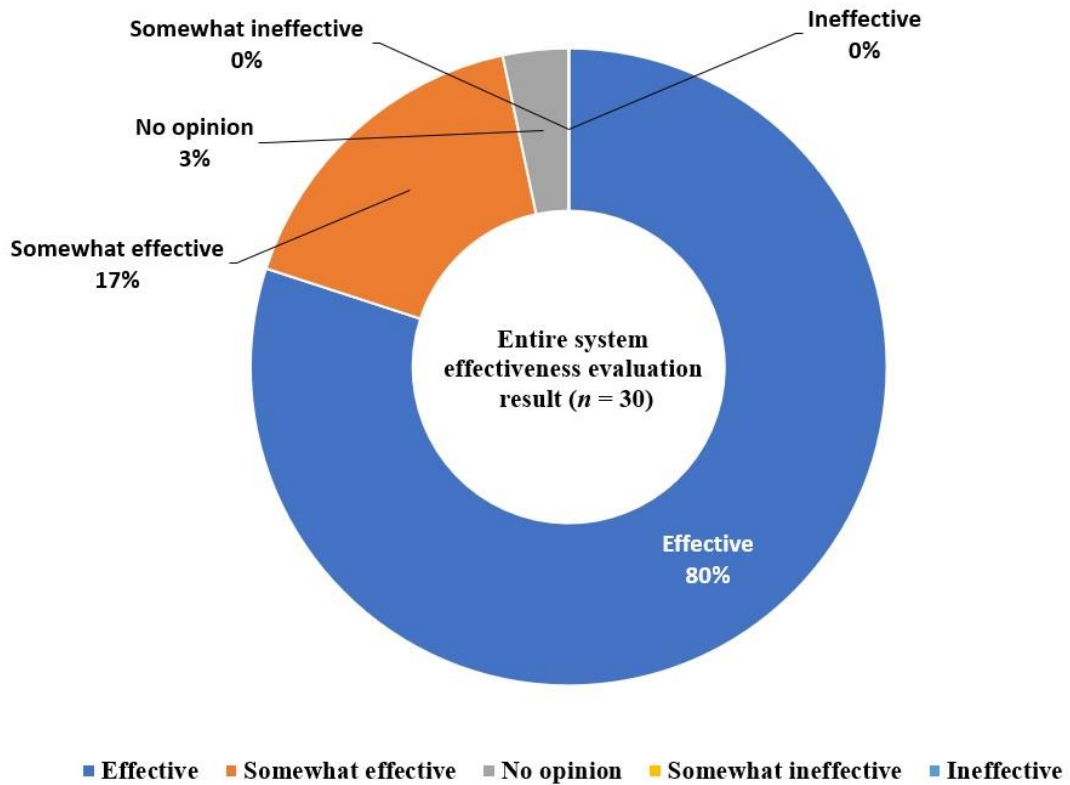
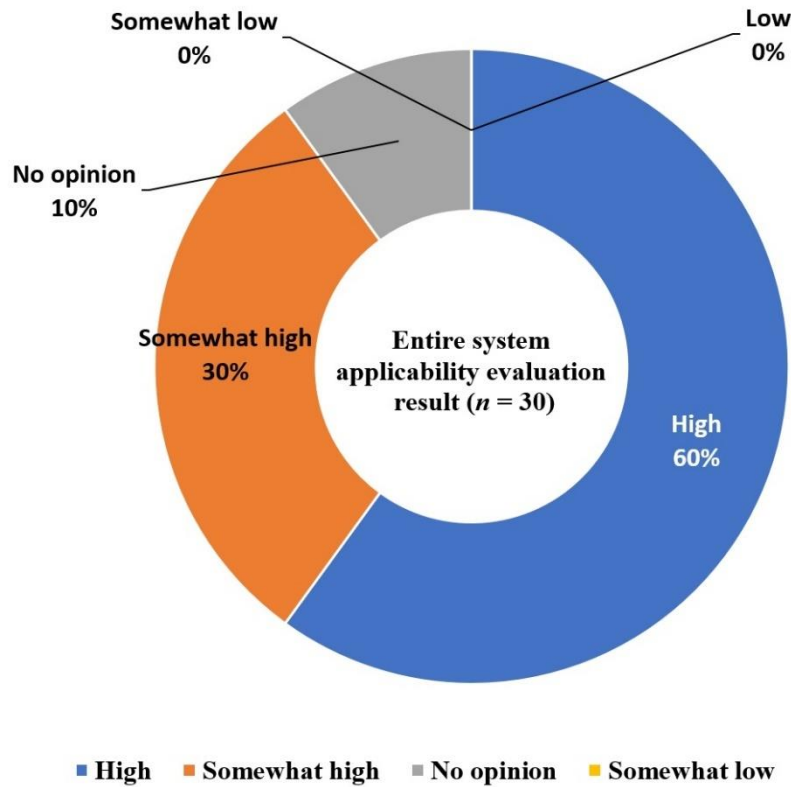Figure 13. The Entire System Effectiveness Evaluation Result (n = 30)

Figure 14. The Entire System Applicability Evaluation Result (n = 30)

6.2 Effectiveness and Operability of a Safety Information Registration System

Figure 15 shows the evaluation results of the effectiveness of guiding the safety information registration system using a BLE beacon, NFC tag, and QR code. Here, 97% of the subjects answered "effective" or "somewhat effective," and we confirmed the high effectiveness of guiding the safety information registration system using the BLE beacon, NFC tag, and QR code. Furthermore, Figure 16 shows the evaluation results of the operability of the safety information registration system. Here, 93% of the subjects answered "easy" or "somewhat easy," and we confirmed the high operability of the safety information registration system.

6.3 Readability and Effectiveness of the Evacuation Shelter Congestion Status Visualization System

Figure 17 shows the evaluation results for the readability of the evacuation shelter congestion status visualization system. Here, 100% of the subjects answered "easy to understand" or "somewhat easy to understand," and we confirmed the high readability of the evacuation shelter congestion status visualization system. Furthermore, Figure 18 shows the evaluation results for the effectiveness of the evacuation shelter congestion status visualization system. Here, 100% of the subjects answered "effective" or "somewhat effective," and we confirmed the high effectiveness of the evacuation shelter congestion status visualization system.
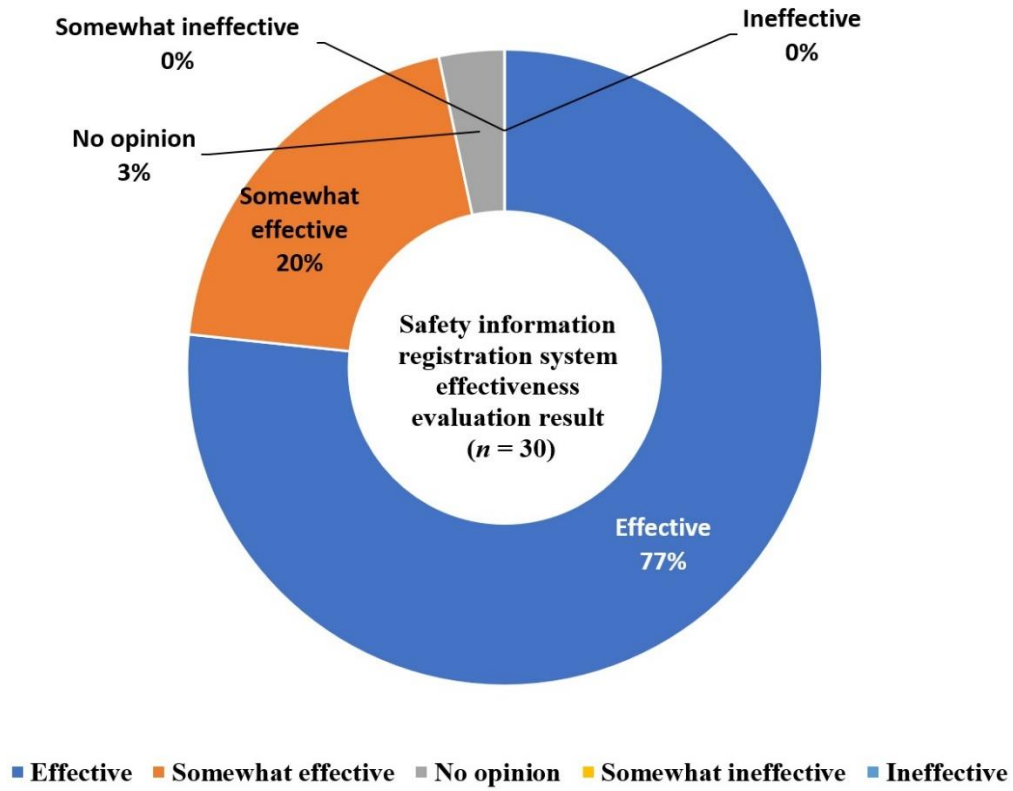
Figure 15. Safety Information for the Registration of System Effectiveness Evaluation Result (n = 30)
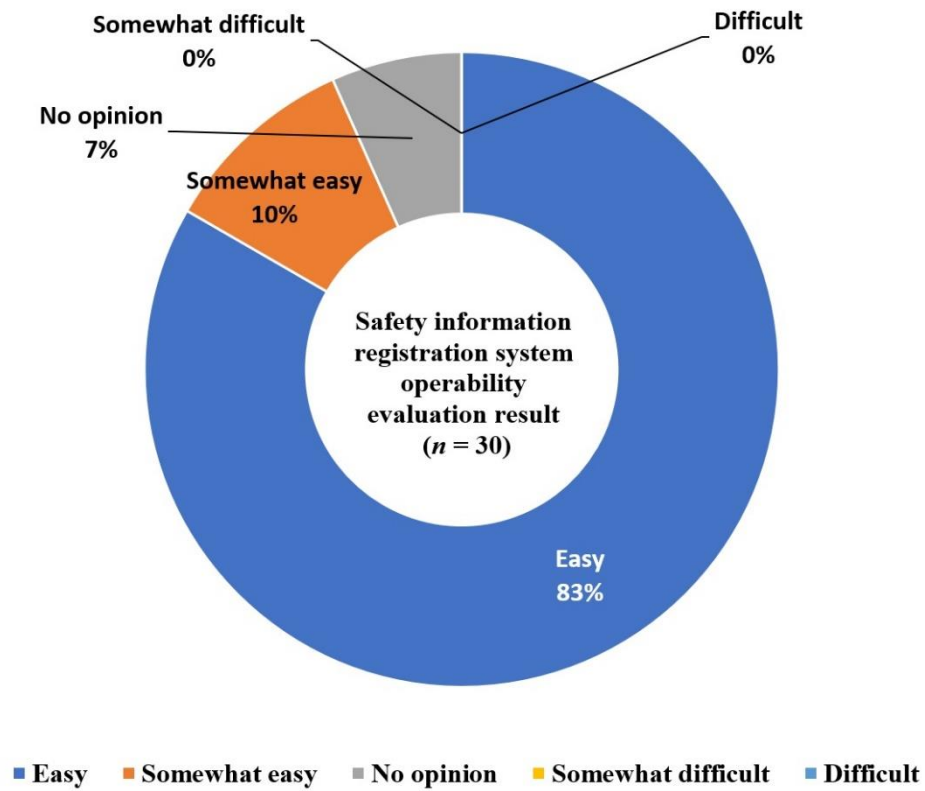

Figure 16. Safety Information for the Registration of System Operability Evaluation Result (n = 30)
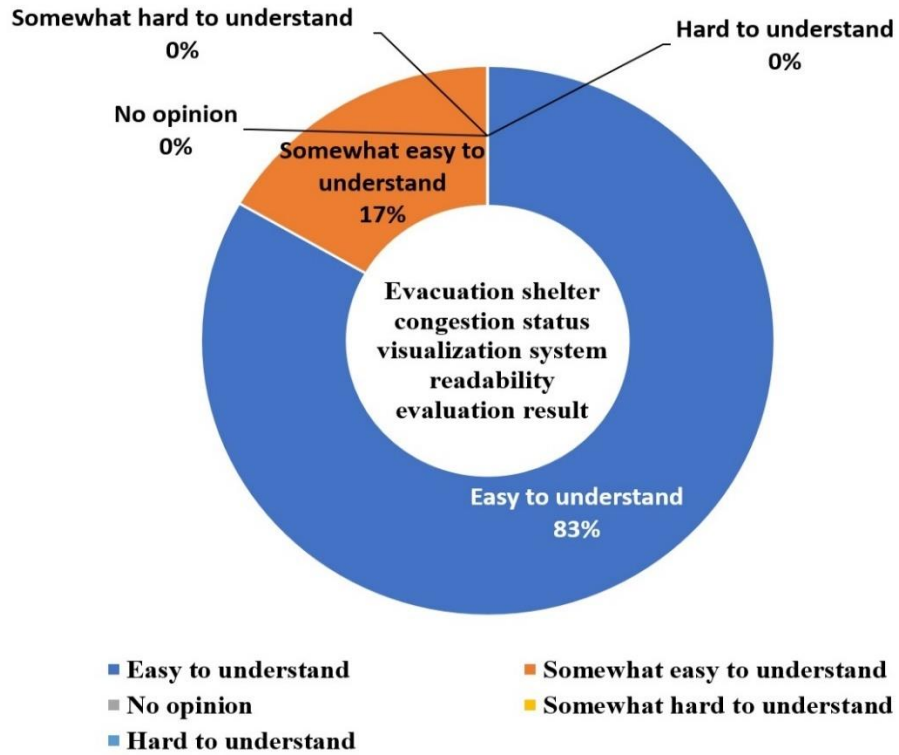
Figure 17. The Evacuation Shelter Congestion Status Visualization System for Readability Evaluation Result (n = 30)
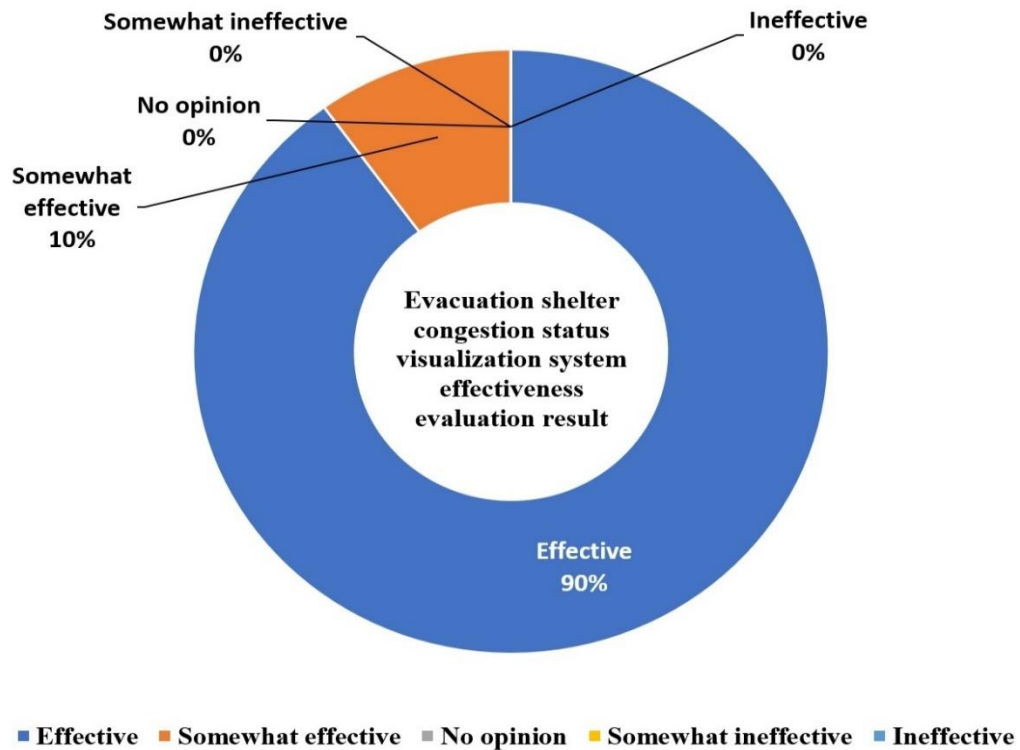

Figure 18. The Evacuation Shelter Congestion Status Visualization System for Effectiveness Evaluation Result (n = 30)

6.4   Functionality and Effectiveness of the Evacuation Shelter Management System

Figure 19 shows the evaluation results for the functionality of the evacuation shelter management system. Here, 100% of the subjects answered "satisfied" or "somewhat satisfied," and we confirmed the high functionality of the evacuation shelter management system. Furthermore, Figure 20 shows the evaluation results for the effectiveness of the evacuation shelter management system. Here, 100% of the subjects answered "effective" or "somewhat effective," and we confirmed the high effectiveness of the evacuation shelter management system.
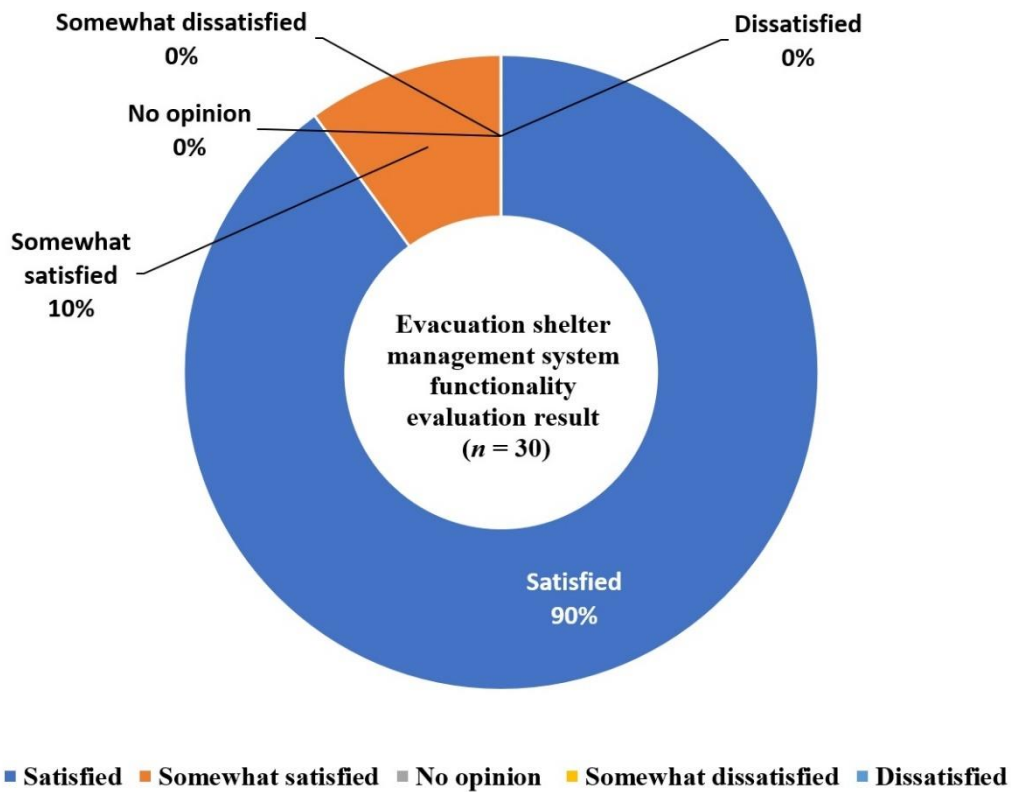
Figure 19. The Evacuation Shelter Management System Functionality Evaluation Result (n = 30)
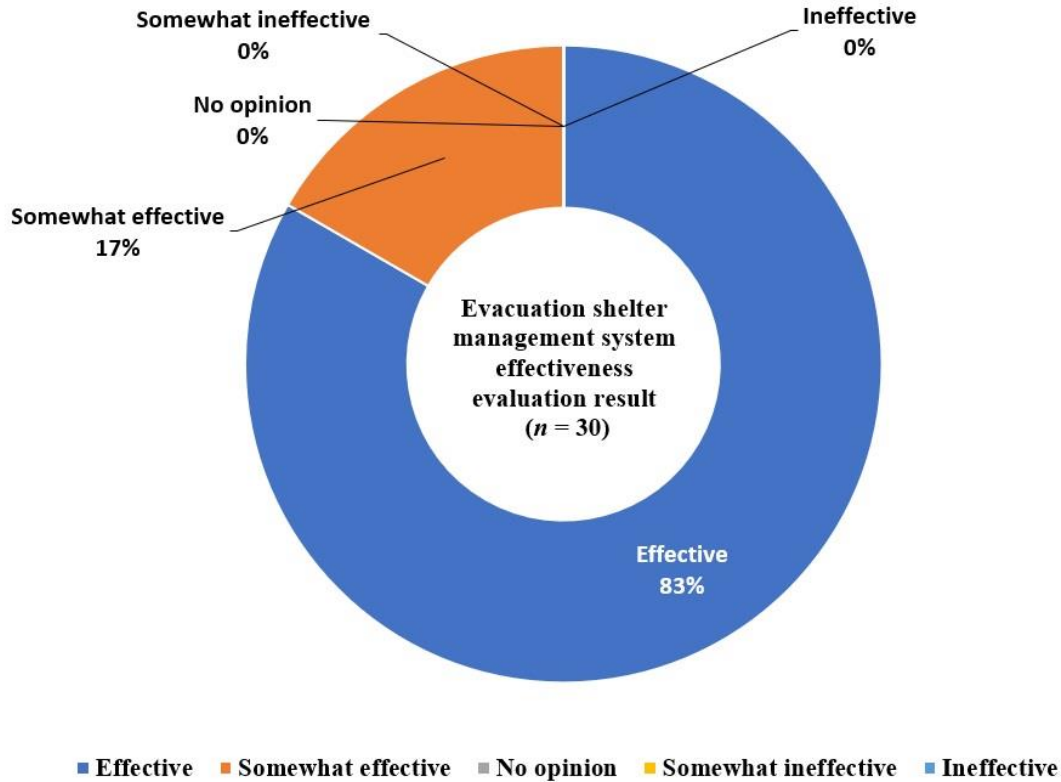
Figure 20. The Evacuation Shelter Management System Effectiveness Evaluation Result (n = 30)

7 Conclusion and Future Works

In this study, we described an evacuee support system. This system realizes accurate and prompt management of evacuees in evacuation shelters by enabling the disaster response headquarters to understand the situation of each evacuation shelter and distribute relief supplies based on the actual situation of the evacuation shelters. Furthermore, this system enables residents to select evacuation shelters by displaying the real-time congestion status of each evacuation shelter. Our purpose is to ensure the safety of residents and reduce the risk of infectious diseases by realizing distributed evacuation of residents. Additionally, this system was implemented as a web application with a flexible design that is independent of the user's operating system or terminal environment. Thus, we have created a system with high usability that guides evacuees to the web application for registering safety information using multiple methods. To evaluate this system, we conducted an evaluation experiment on 30 subjects and obtained a high evaluation of 90% or more for each item.

In future works of this research, we plan to implement an evacuation shelter entry/exit function via login/logout of the evacuees and a BLE beacon reception function on iOS terminals. Although we implemented the login/logout function exclusively for the administrator in the evacuation shelter management system, we did not implement the login/logout function of the evacuees' safety information registration system because of the convenience of safety information registration. However, when considering long-term operation at evacuation shelters, it is crucial to implement the login/logout function for the disaster response headquarters to obtain accurate entry/exit information of evacuees in real-time. Although we implemented an evacuees' safety information registration system that registers evacuees' information on the web application for safety information registration

via BLE beacon, NFC tag, and QR code, terminals that can receive notifications from BLE beacons are limited to Android users. Therefore, considering the practical application in evacuation shelter management, we must implement a mechanism that allows iOS users to receive notifications from BLE beacons.

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