Study on IoT Evacuation Support System in Event of Disasters*

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Abstract

In this study, we implemented an Internet of Things (IoT) evacuation support system using beacons that supports evacuees during disasters. This system realized quick and accurate registration of safety information and management of evacuation centers without requiring special equipment by using a mobile device such as a smartphone and a beacon. Additionally, through safety information registration, this system also supports vulnerable people such as the elderly and children by implementing a proxy safety information registration function. Safety information registered at evacuation centers is collected into a regional disaster prevention information/safety information management system managed by the emergency response headquarters. Furthermore, this system also provides regional information and disaster prevention information during normal use. To evaluate the IoT evacuation support system, we evaluated the system usability scale and the operability, relevance, and effectiveness of each function and many of the functions received high evaluation scores.

Keywords: Disaster Management System, Safety Confirmation System, Evacuation Center Support, Beacon, Information Sharing

1 Introduction

The Great East Japan Earthquake of March 11, 2011, caused damage due to both the earthquake itself and the resulting tsunami. This was particularly true in Iwate, Miyagi, and Fukushima prefectures, which saw severe damage, more than 15,000 deaths, and more than 25,500 people missing [2]. Severe building damage, including complete or partial destruction, also occurred in these areas. In addition, the accident at the Fukushima No. 1 nuclear power plant forced many residents to evacuate for a long time. At the peak on the third day after the disaster, there were approximately 470,000 evacuees nationwide, and more than 2,000 evacuation centers were established nationwide one week after the disaster [3]. An evacuation center is a facility that accommodates evacuees when evacuation becomes necessary due to a natural disaster or when it becomes impossible to live at home. Each municipality has specified public facilities such as schools and public halls as evacuation centers in regional disaster prevention plans [13]. However, after the Great East Japan Earthquake, city hall buildings and evacuation centers were damaged in some areas, and evacuation center operations were extremely disrupted. Lifesaving efforts and emergency personnel such as paramedics are given top priority immediately after a disaster. Therefore, it is necessary to operate evacuation centers with a minimal staff, mainly consisting of local government personnel, as the number of volunteers would be small. Under these circumstances, many municipalities use paper-based methods to manage evacuation centers. For this reason, human resources and time are spent on managing evacuees. Information related to the occurrence of natural disasters is complicated; therefore, management of evacuation centers and evacuation lists is a heavy burden for local government staff.

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In our previous research [9, 8], we implemented an integrated safety confirmation system using the IC card. This system quickly gathers evacuees' information at evacuation centers in the time of wide-scale disaster and provides safety information to the emergency response headquarters. We envisioned the use of an individual number card equipped with an IC chip based on the social security number program. However, the ratio of issued individual number cards to the population is less than 20% [12].

Therefore, our proposal system aims to collect and aggregate safety information quickly by using beacon terminals. This proposal system realizes rapid and accurate registration of safety information and entrance/exit management of evacuation centers without the need for special equipment by using tablet terminals such as smartphones.

Previously, we described the evacuee information management function of the Web application and the evacuee information registration function of the proposed system in a conference paper [7]. In this article, we described disaster information notification function and CSV file management function in addition to evacuation information management function of Web application. And, we described the evacuation center map function and navigation function in addition to the evacuee information registration function of the mobile application. Furthermore, we showed the SUS evaluation results and the evaluation results of operability, relevance, and effectiveness of each function of the proposal system.

The rest of the article is organized in the followings way. The related work are descried in section 2. The research objective is descried in section 3. The system configuration is descried in section 4. The web application and mobile application of IoT evacuation support system are described in section 5 and 6, respectively. Section 7 evaluates the IoT evacuation support system and, finally we conclude our findings in section 8.

2 Related Works

Yoshino et al. [19] conducted an experiment to create a disaster prevention map using the Akari Map evacuation support system. Akari Map has an offline route guidance function to enable navigation to evacuation centers, a function for browsing evacuation center information, an evacuation center information editing and registration function that uses gamification, a registrant ranking function, and a user page browsing function. In the evaluation experiment, collaborators obtained new discoveries about evacuation information in the area through the gamification function. However, elderly experiment collaborators who have resistance to smartphones needed support to use the system.

Usui et al. [18] developed a safety confirmation system that manages evacuation centers and evacuation lists using electronic data. The residents used the proposed system during disaster drills with explanation sheets and QR codes distributed to the residents in advance. However, although the proposed system smoothed the safety confirmation process, information that can be registered was limited to ”name”, ”sex”, ”address”, and ”injury and house situation.”

Naka et al. [10] proposed a method to confirm quickly the safety of evacuated residents by conducting facial recognition. However, this proposed method requires that dedicated facial recognition equipment be installed at the evacuation center. In addition, it is necessary to build a resident database containing facial image information in advance.

Amano [4] developed a flood hazard map application for smartphones using open data and national land information. However, this system is specialized for evacuation of residents during disasters and evacuation support at evacuation centers has not been studied.

Nishimoto et al. [11] developed a safety information registration system to quickly identify victims and share information during disasters. This system enables registration of safety information by agents such as volunteers through smartphone applications. When victims register safety information, they can also register whether that safety information can be disclosed. However, this system does not yet

interoperate with existing administrative services and other systems.

Passarella et al. [14] proposed an information technology-based approach for disaster mitigation in Indonesia using geofencing and a mobile ad hoc network (MANET). In this system, an administrator defines an area where a disaster is likely to occur and a notification is transmitted when a terminal enters the area. In a disaster, this system prompts users to evacuate to safe points and provides route guidance. Additionally, this system can spread information even in disaster areas without internet connectivity using MANET. However, this system has not been studied for evacuation support at evacuation centers.

Suwal at el. [16] designed and developed an Android-based application named D-Fencing. This application uses the user's location retrieved from the mobile phone's GPS or GPRS service to determine whether the user is inside or outside the geofence. Users can also receive notifications if their location is within a defined geofence. However, this application has not been studied for evacuation support during or after evacuation.

Fajardo et al. [5] developed a disaster management system that facilitates the logistics of rescue activities during a disaster. This system enables volunteers and others to check the optimal route to the rescuer's location to facilitate rescue activities in a disaster. However, the optimal route is connected by a straight line between the rescuers and the route guidance function has not been implemented.

Yuze et al. [21, 20] developed a safety confirmation system for students at Japan's Shizuoka University. This safety confirmation system can handle earthquakes as well as viral pandemic information, and uses a cloud computing architecture. However, this system is exclusively for students and cannot be used by other residents.

Rahman et al. [15] developed a location-based disaster early warning and evacuation support system. This system determines whether a user is in a disaster-prone area based on that user's location information. Users receive disaster warning messages through the Android application and use the route guidance function to a safe place. However, this system has not been studied for evacuation support after evacuation.

3 Research Objective

In this study, we implement an Internet of Things (IoT) evacuation support system that uses beacons to provide regional information and disaster prevention information in normal times and support evacuation of residents during disasters.

The safety information registration systems in the related research can quickly register evacuee safety information using QR codes and face authentication technology. However, these systems must have QR codes and facial recognition equipment prepared in advance.

Therefore, in this study, we realize quick safety information registration using beacon notification at evacuation centers using devices such as smartphones. At present, registration of safety information at evacuation centers during disasters is performed using paper. Therefore, with this system, we realize quick and accurate registration of safety information and management of evacuation centers without needing special equipment. In addition, we support registering the safety information of vulnerable people such as the elderly and children by implementing a proxy safety information registration function. Safety information registered at evacuation centers is collected in the regional disaster prevention information/safety information management system operated by the emergency response headquarters. This information can also be registered in the safety information of disaster message boards provided by communication carriers. In addition, it is also possible to register on the joint site "J-anpi" [6], which can search the safety information of disaster message boards provided by communication carriers as well as that collected by each company and organization.

It is difficult to use a dedicated application during a disaster unless that application is used regularly.

Therefore, this system also provides regional information and disaster prevention information from the local government during normal use. Using this system during normal times means that residents can more easily use this system during disasters.

4 System Configuration

Fig. 1 shows the system's information flow. During normal times, users can browse regional information, disaster prevention information, maps visualizing evacuation centers, and route guidance to evacuation centers via a mobile application, and can register basic information to register safety information in advance. During a disaster, users can browse disaster information from local governments, map information visualizing evacuation centers, and route guidance to evacuation centers, and can register safety information at evacuation centers. This system also provides users with disaster prevention information from the Japan Meteorological Agency [1]. When the user evacuates to the evacuation center, the registration notification of safety information is automatically obtained from the beacon installed at the evacuation center. Additionally, the safety information registered by evacuees is collectively managed by the emergency response headquarters, and safety information is registered in J-anpi (a service that can search for safety information and messages from disaster victims).

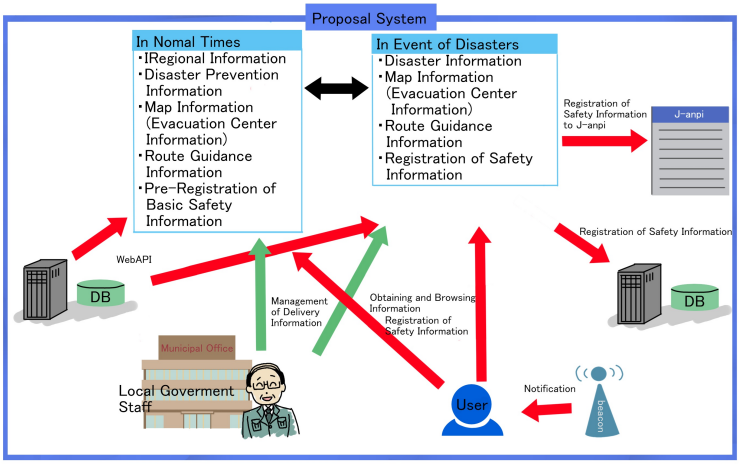


Figure 1: IoT evacuation support system information flow

Fig. 2 shows the configuration of the IoT evacuation support system. The IoT evacuation support system consists of the regional disaster prevention information/safety information management agent, the local residents/evacuees agent, the regional disaster prevention information/safety information management server, and the regional disaster prevention information/safety information database server.

4.1 Regional disaster prevention information/safety information management agent

The regional disaster prevention information/safety information management agent consists of local government staff (e.g., emergency response headquarters staff), and manages the entire system via the regional disaster prevention information and safety information web application. The agent transmits regional information and disaster prevention information to the local residents/evacuees agent. Such information is stored in the regional disaster prevention information storage of the regional disaster prevention information/safety information database. The regional disaster prevention information/safety

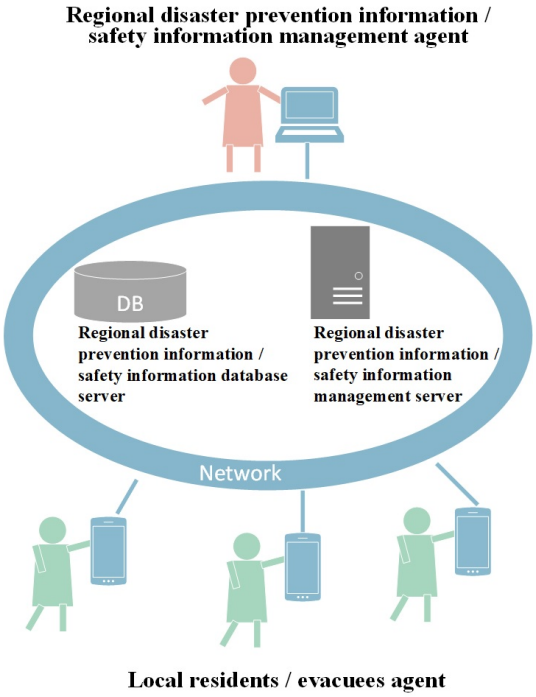


Figure 2: Internet of Things evacuation support system configuration

information management agent also registers evacuation center information for the local residents/evacuees agent so they can use the route guidance function to guide evacuees to evacuation centers during disasters. The evacuation center information is stored in the evacuation center information storage of the regional disaster prevention information/safety information database in CSV format. Furthermore, the regional disaster prevention information/safety information management agent collects safety information from the local residents/evacuees agent during disasters. The collected evacuee safety information is stored in the evacuee safety information storage of the regional disaster prevention information/safety information database.

4.2 Local residents/evacuees agent

The local residents/evacuees agent consists of local residents (or evacuees in the event of a disaster), and receives, from the regional disaster prevention information/safety information management agent, regional information and disaster prevention information during normal times and disaster information and evacuation center information during disasters. The local residents/evacuees agent also uses the route guidance function to travel from their current location to an evacuation center and obtains safety information registration function during disasters.

4.3 Regional disaster prevention information/safety information management server

The regional disaster prevention information/safety information management server acts as an intermediary between the regional disaster prevention information/safety information management agent, the local residents/evacuees agent, and the regional disaster prevention information/safety information database server. The regional disaster prevention information/safety information management agent stores regional information, disaster prevention information, evacuation center information, and evacuee safety

information in the database through this management server. Moreover, the local residents/evacuees agent receives the information stored in in the database using this management server and registers their own or their family's safety information during disasters.

4.4 Regional disaster prevention information / safety information database server

The regional disaster prevention information/safety information database server consists of the local disaster prevention information storage, the evacuation center information storage, and the evacuee safety information storage. The local disaster prevention information storage stores regional information, disaster prevention information, and evacuation center information during normal times, and disaster information and evacuation center information during disasters. The evacuation center information storage stores evacuation center information specified by each local government. Furthermore, the evacuee safety information storage stores safety information of evacuees registered by the local residents/evacuees agent in event of a disaster.

5 Web Application for Management of Regional Disaster Prevention Information and Safety Information

Fig. 3 shows the login screen of the web application for regional disaster prevention information and safety information management. This web application can register and edit all functions provided by the mobile application except for the map function. Local government staff (hereinafter referred to as administrators) enter the user ID and password on this screen and collate them with the administrator information database to transition to the top screen of the web application.

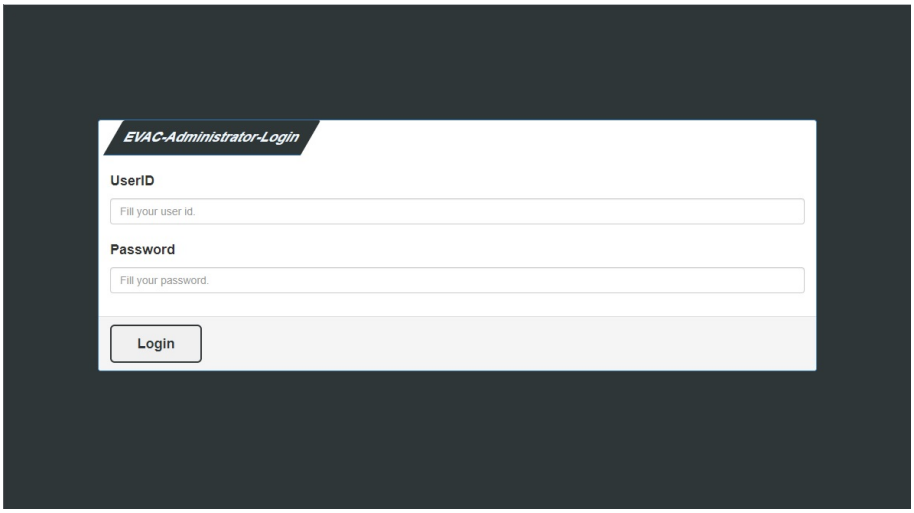


Figure 3: The login screen of the web application for regional disaster prevention information management

Fig. 4 shows the main screen of the web application. The main screen is for registration of regional information and regional disaster prevention information that is expected to be frequently used by administrators. Administrators can register the information to be delivered to the mobile application using the regional information and regional disaster prevention information registration function. During normal times, regional information and disaster prevention information are distributed, but during disas-

ters, evacuation center information and evacuation advisory information are distributed. The most recent information input by the administrators is delivered to the mobile application.

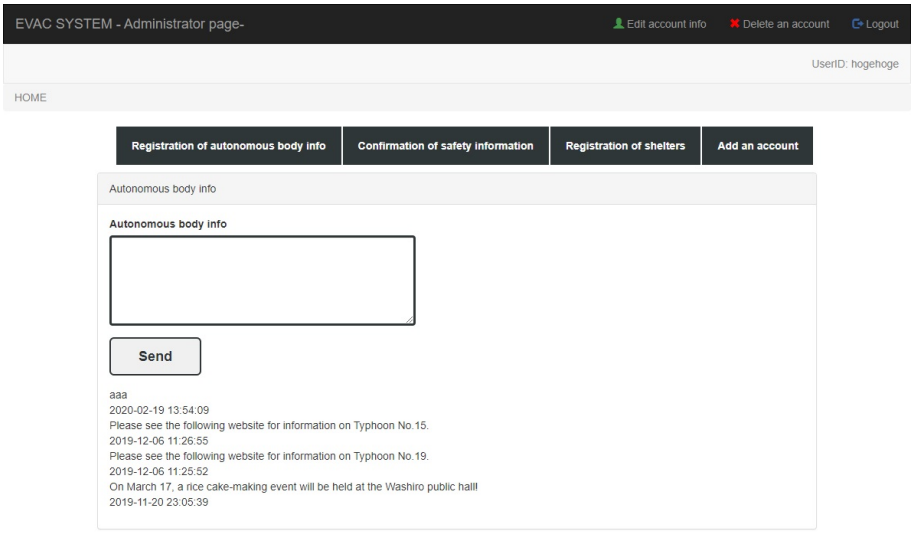
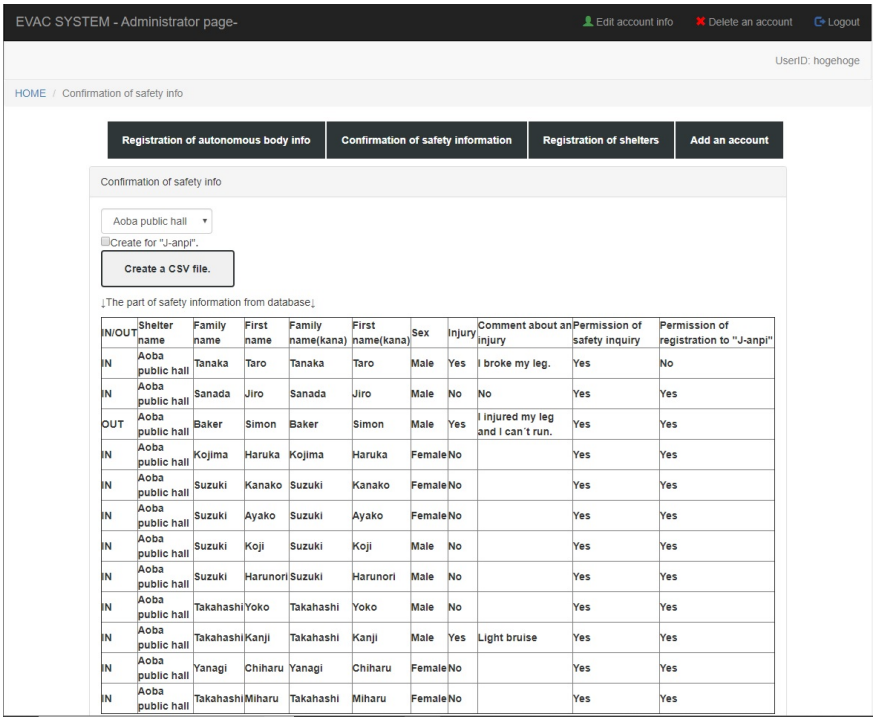


Figure 4: The main screen of the web application (registration screen for regional information and regional disaster prevention information)

Fig. 5 shows the safety information confirmation screen. A portion of the safety information registered from the mobile application can be confirmed using this screen.



IN/OUT	Shelter name	Family name	First name	Family name(kana)	First name(kana)	Sex	Injury	Comment about an injury	Permission of safety inquiry	Permission of registration to "J-anpi"
IN	Aoba public hall	Tanaka	Taro	Tanaka	Taro	Male	Yes	I broke my leg.	Yes	No
IN	Aoba public hall	Sanada	Jiro	Sanada	Jiro	Male	No	No	Yes	Yes
OUT	Aoba public hall	Baker	Simon	Baker	Simon	Male	Yes	I injured my leg and I can't run.	Yes	Yes
IN	Aoba public hall	Kojima	Haruka	Kojima	Haruka	Female	No		Yes	Yes
IN	Aoba public hall	Suzuki	Kanako	Suzuki	Kanako	Female	No		Yes	Yes
IN	Aoba public hall	Suzuki	Ayako	Suzuki	Ayako	Female	No		Yes	Yes
IN	Aoba public hall	Suzuki	Koji	Suzuki	Koji	Male	No		Yes	Yes
IN	Aoba public hall	Suzuki	Harunori	Suzuki	Harunori	Male	No		Yes	Yes
IN	Aoba public hall	Takahashi	Yoko	Takahashi	Yoko	Male	No		Yes	Yes
IN	Aoba public hall	Takahashi	Kanji	Takahashi	Kanji	Male	Yes	Light bruise	Yes	Yes
IN	Aoba public hall	Yanagi	Chiharu	Yanagi	Chiharu	Female	No		Yes	Yes
IN	Aoba public hall	Takahashi	Miharu	Takahashi	Miharu	Female	No		Yes	Yes

Figure 5: Safety information confirmation screen

The administrator can export the registered safety information into a CSV file by pressing the ”Create

a CSV File" button on the safety information confirmation screen. Fig. 6 shows an example of CSV file output.

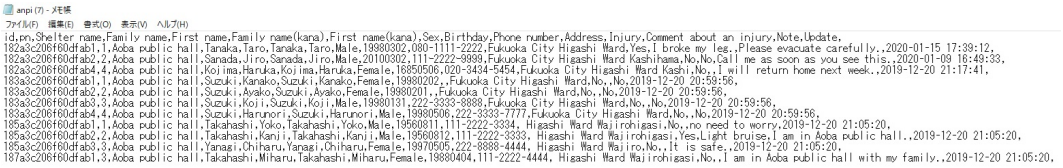

anpi (7) - メモ帳
ファイル(F) 編集(E) 書式(O) 表示(V) ヘルプ(H)
id,pn,Shelter name,Family name,First name,Family name(kana),First name(kana),Sex,Birthday,Phone number,Address,Injury,Comment about an injury,Note,Update,
182a3c206f60dfab1,1,Aoba public hall,Tanaka,Taro,Tanaka,Taro,Male,19980302,080-1111-2222,Fukuoka City Higashi Ward,Yes,I broke my leg.,Please evacuate carefully.,2020-01-15 17:39:12,
182a3c206f60dfab2,2,Aoba public hall,Sanada,Jiro,Sanada,Jiro,Male,20100302,111-2222-9999,Fukuoka City Higashi Ward Kashihama,No,No,Call me as soon as you see this.,2020-01-09 16:49:33,
182a3c206f60dfab4,4,Aoba public hall,Kojima,Haruka,Kojima,Haruka,Female,16850506,020-3434-5454,Fukuoka City Higashi Ward Kashi,No,,I will return home next week.,2019-12-20 21:17:41,
183a3c206f60dfab1,1,Aoba public hall,Suzuki,Kanako,Suzuki,Kanako,Female,19980202,,Fukuoka City Higashi Ward,No,,No,2019-12-20 20:59:56,
183a3c206f60dfab2,2,Aoba public hall,Suzuki,Ayako,Suzuki,Ayako,Female,19980201,,Fukuoka City Higashi Ward,No,,No,2019-12-20 20:59:56,
183a3c206f60dfab3,3,Aoba public hall,Suzuki,Koji,Suzuki,Koji,Male,19980131,222-3333-8888,Fukuoka City Higashi Ward,No,,No,2019-12-20 20:59:56,
183a3c206f60dfab4,4,Aoba public hall,Suzuki,Harunori,Suzuki,Harunori,Male,19980506,222-3333-7777,Fukuoka City Higashi Ward,No,,No,2019-12-20 20:59:56,
185a3c206f60dfab1,1,Aoba public hall,Takahashi,Yoko,Takahashi,Yoko,Male,19960811,111-2222-3334, Higashi Ward Wajirohigasi,No,,no need to worry,2019-12-20 21:05:20,
185a3c206f60dfab2,2,Aoba public hall,Takahashi,Kanji,Takahashi,Kanji,Male,19560812,111-2222-3333, Higashi Ward Wajirohigasi,Yes,Light bruise,I am in Aoba public hall.,2019-12-20 21:05:20,
185a3c206f60dfab3,3,Aoba public hall,Yanagi,Chiharu,Yanagi,Chiharu,Female,19970505,222-8888-4444, Higashi Ward Wajiro,No,,It is safe.,2019-12-20 21:05:20,
187a3c206f60dfab1,3,Aoba public hall,Takahashi,Miharu,Takahashi,Miharu,Female,19880404,111-2222-4444, Higashi Ward Wajirohigasi,No,,I am in Aoba public hall with my family.,2019-12-20 21:05:20,

Figure 6: CSV file output example of registered safety information

Administrators can register evacuation centers from CSV files using the evacuation center registration function. To register the evacuation centers, the administrator first selects the "prefecture" and "municipality" fields from the evacuation center registration screen. Next, the administrator specifies the CSV file column in which the "facility name", "type of evacuation center", "latitude", "longitude", and "notes and comments" fields are registered. Last, the administrator selects the CSV file to be registered and clicks the "Register" button to send the latest information to the mobile application map screen. Fig. 7 shows the evacuation center registration screen.

Figure 7: The evacuation center registration screen

Fig. 8 shows the sequence of each function provided to the user by the disaster evacuation support system management web application.

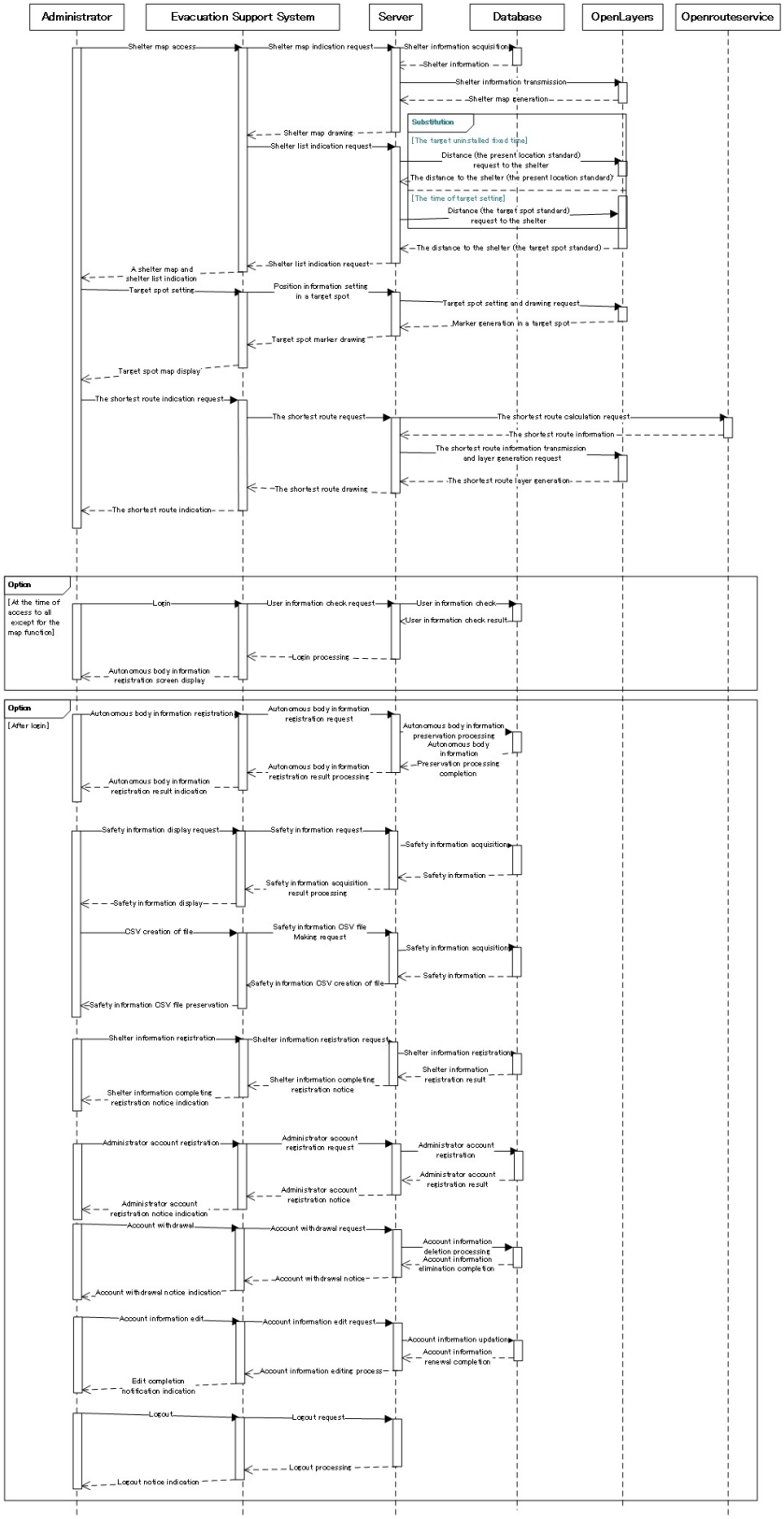


Figure 8: The sequence of the disaster evacuation support system management web application

6 Mobile Application for Browsing Regional Disaster Prevention Information and Registering Safety Information

Residents can use the map function, route guidance function, safety information registration function, and safety information inquiry function through the mobile application. The residents can browse ”facility name”, ”type of evacuation center”, ”remarks”, and ”distance from current location” displayed on the map screen using the map function. Additionally, acquiring location information in the map function requires user permission. Fig. 9 shows the map screen on which evacuation center information and distance to evacuation centers are displayed.

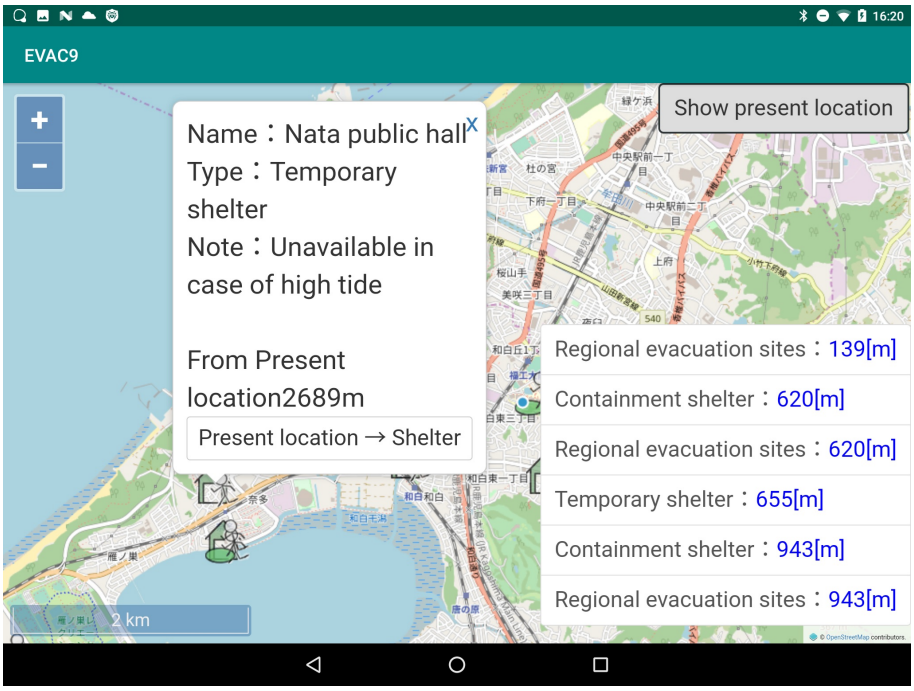


Figure 9: Map screen displaying evacuation center information and distance to evacuation centers

The route guidance function provides the user routes to the evacuation centers registered on the map screen. Fig. 10 shows route guidance information on the map screen.

Users can register their own safety information or that of their family using the safety information registration function. The user registers name, address, phone number, and other information as well as whether they are injured and what type of injury they have on the safety information registration screen as shown in Fig. 11. After that, the user can confirm the registered information on the safety information registration confirmation screen, and tap the ”Register” button. After that, the safety information is registered in the database server.

Fig. 12 shows the sequence of the disaster evacuation support system mobile application.

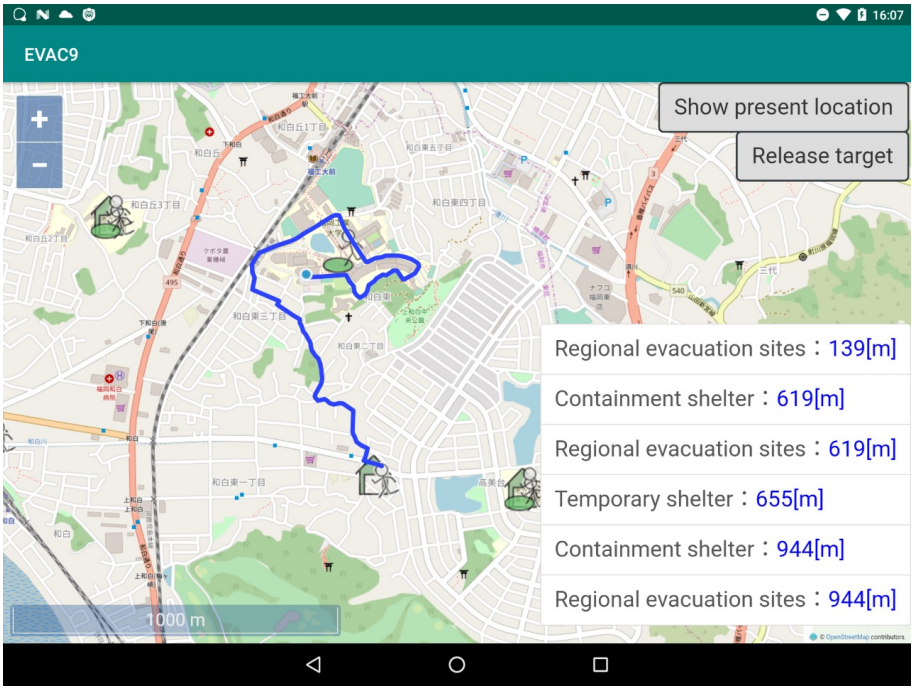


Figure 10: Route guidance to evacuation center

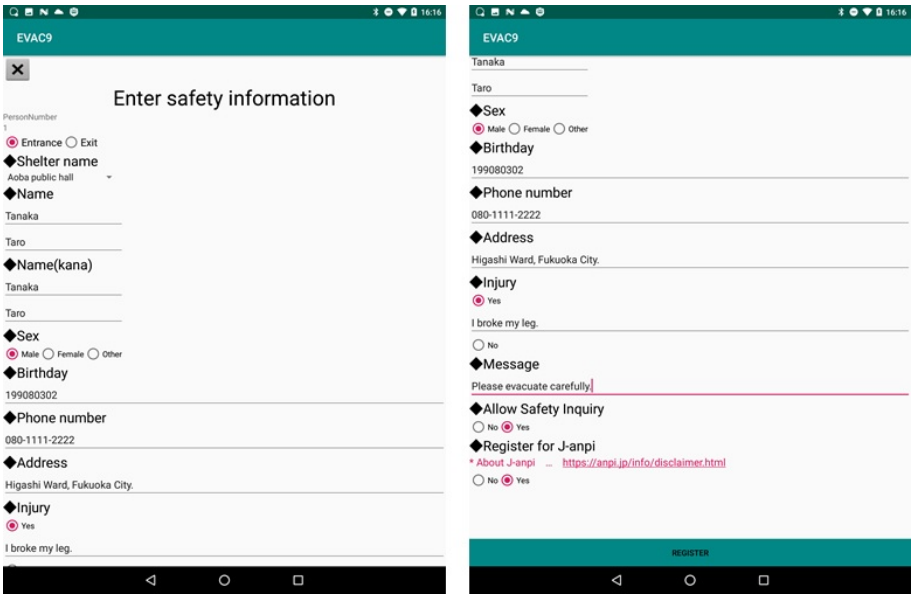


Figure 11: Safety information registration screen (left) and safety information registration confirmation screen (right)

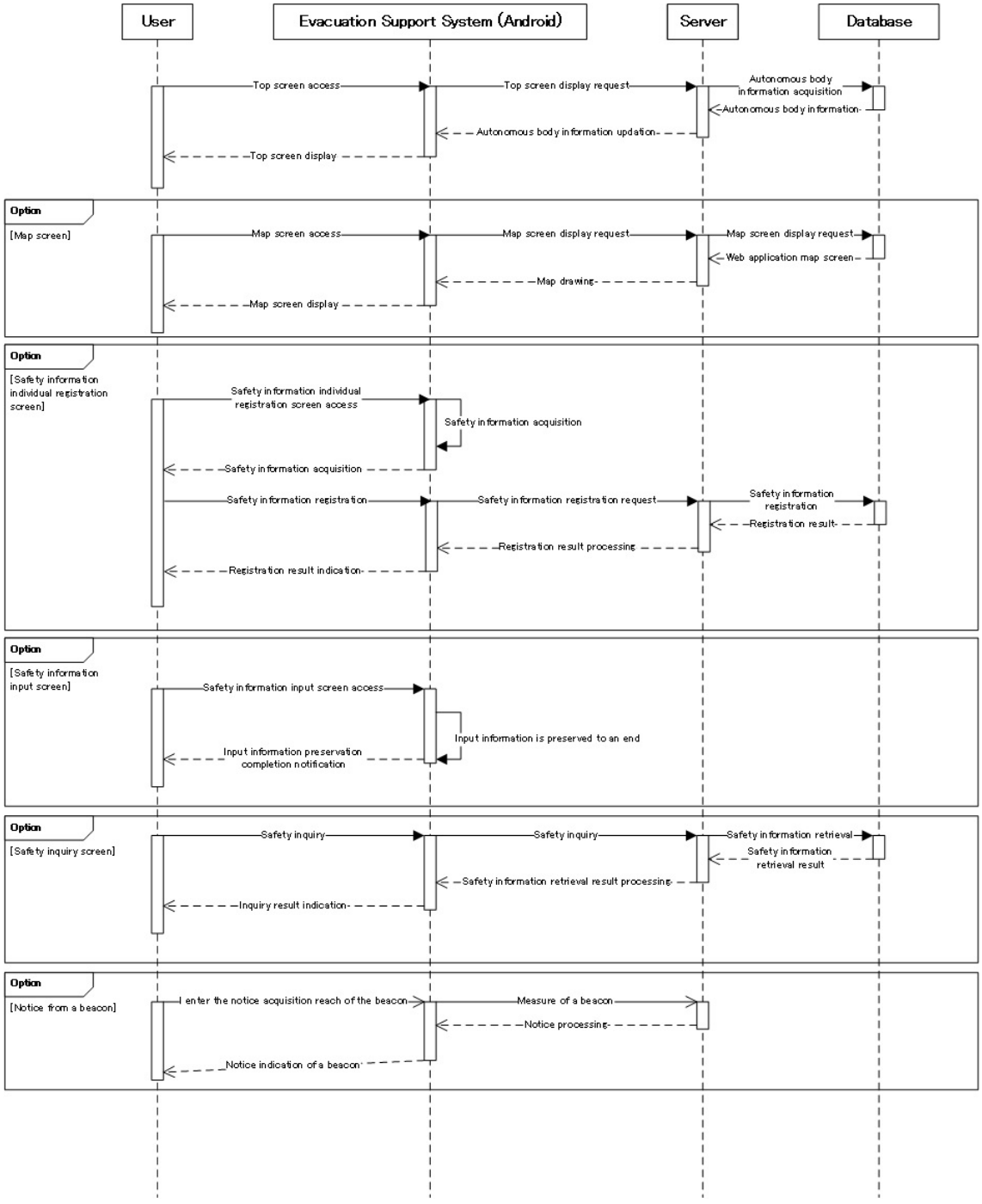


Figure 12: The sequence of the disaster evacuation support system mobile application

7 System Evaluation

To evaluate the IoT evacuation support system, we conducted a system usability scale (SUS) [17] evaluation as well as evaluation experiments on operability, relevance, and effectiveness of the system using 30 subjects. The average score of 10 questions of the SUS evaluation was 72.92 points, which slightly exceeds the standard average score of 68 points. Notably, Q3, Q5, and Q6 scored more than 75 points, demonstrating the system's ease of operation and consistency. In contrast, the Q4 score was 66.67 points, which is lower than the standard average score. This may be due to a need for detailed explanation to enable subjects to use each function.

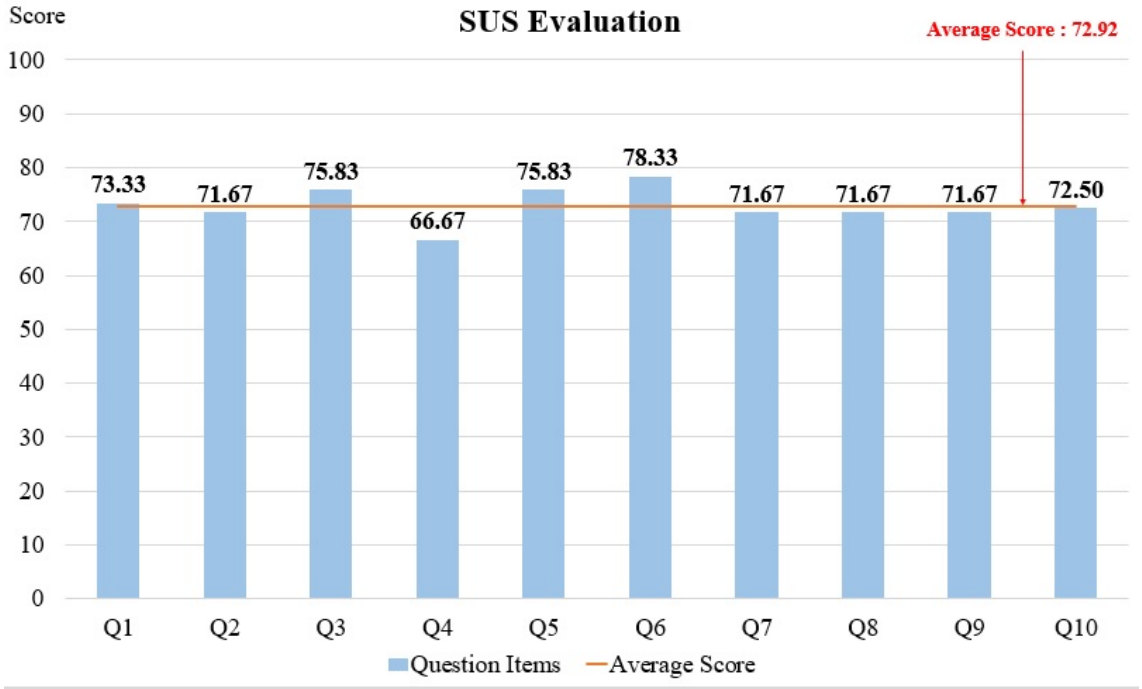


Figure 13: System usability scale (SUS) evaluation scores

7.1 Results of mobile application function operability evaluation

Fig. 14 shows the evaluation results of the operability of the mobile application map and route guidance function, safety information registration function, and safety information inquiry function. When asked about the operability of the map and route guidance function, about 80% of the subjects answered "easy" or "somewhat easy." Additionally, more than 70% of the subjects answered "easy" or "somewhat easy" when asked about the operability of the safety information registration function and the safety informa-

tion inquiry function. From this, we were confirmed the high degree of operability of the three functions. One subject commented on the route guidance function, stating that it needs guidance on roads that cannot be passed due to landslides and other disasters.

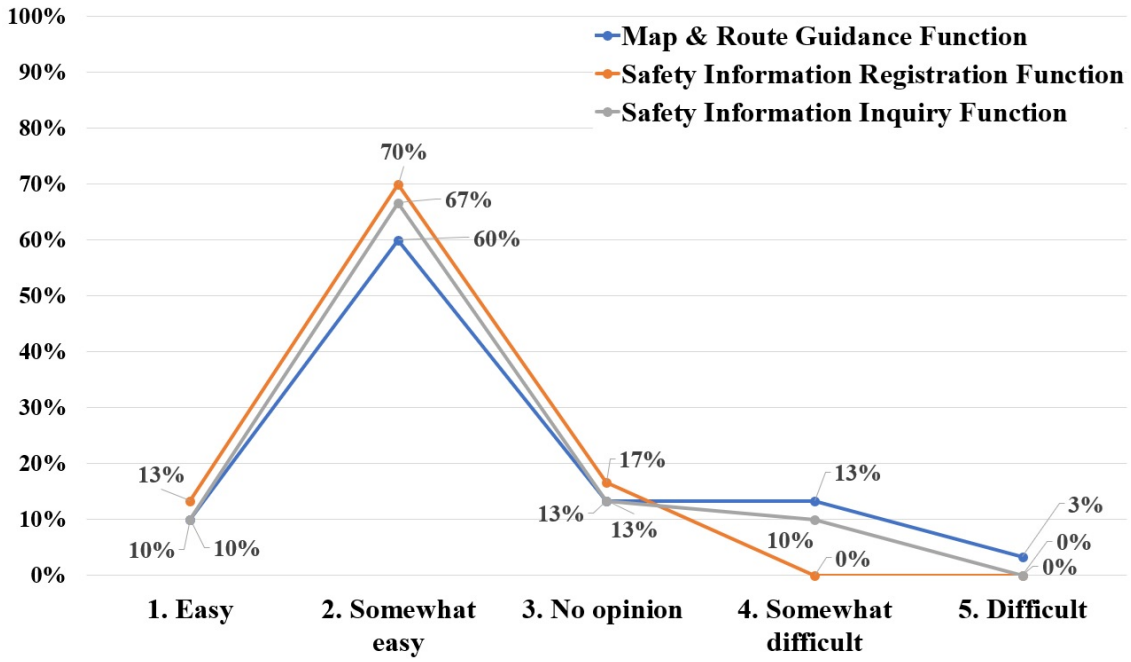


Figure 14: Operability of the mobile application functions in mobile application (n = 30)

7.2 Results of mobile application function relevance evaluation

Fig. 15 shows the results of the evaluation of the relevance of the mobile application map and route guidance function, safety information registration function, safety information inquiry function, and beacon notification. More than 90% of the subjects answered ”relevant” or ”somewhat relevant” when asked about the relevance of the map and route guidance function, safety information registration function, and safety information inquiry function. Additionally, more than 80% of the subjects answered ”relevant” or ”somewhat relevant” when asked about the beacon notification function. From this, we confirmed the high degree of relevance of these four functions.

7.3 Results of mobile application function effectiveness evaluation

Fig. 16 shows the results of the evaluation of the mobile application map and route guidance function, safety information registration function, safety information inquiry function, and beacon notification function effectiveness. When asked about the effectiveness of the map and route guidance function, safety information registration function, and safety information inquiry function, more than 90% of the subjects answered ”effective” or ”somewhat effective.” Additionally, more than 80% of the subjects answered ”effective” or ”somewhat effective” when asked about the beacon notification function. From this, we confirmed the high degree of effectiveness of these four functions.

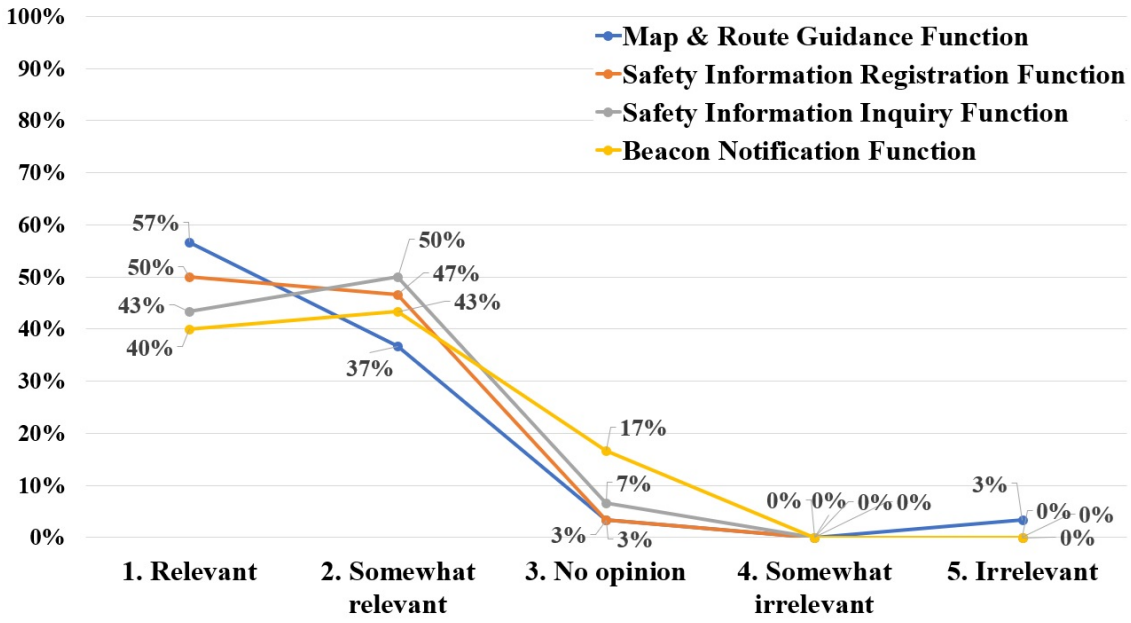


Figure 15: Relevance of the mobile application functions in mobile application (n = 30)

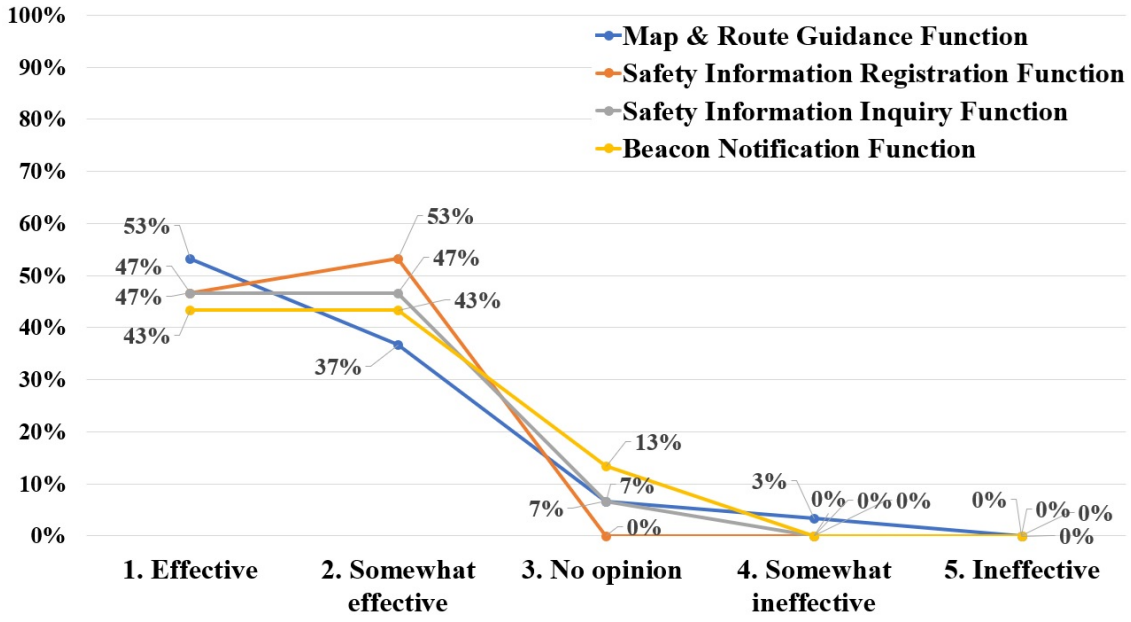


Figure 16: Effectiveness of the mobile application functions in mobile application (n = 30)

8 Conclusion and Future Works

In this study, we implemented and evaluated an IoT evacuation support system with a beacon that consists of a web application and a mobile application. Using the web application, the administrator can confirm and output safety information registered by users, update the evacuation center information using the evacuation center registration function, and register disaster information. Using the mobile application, residents can obtain regional information and disaster prevention information in normal times and obtain disaster information and route guidance to evacuation during a disaster. Additionally, in the event of a disaster, residents can receive notification from beacons installed at evacuation centers and register safety information through the mobile application. Residents can also register basic safety information in advance in the mobile application to prepare for disasters. Because this system consists of a web application and a mobile application, the system can be introduced at a low cost without requiring expensive dedicated equipment for practical use. In the evaluation experiments, we evaluated the SUS as well as each function's operability, relevance, and effectiveness, and obtained high ratings for many items.

Fig. 17 provides an overview of future work. We implemented an IoT evacuation support system using a beacon in this study. The implemented system has a map function that includes route guidance and a regional information/disaster prevention information browsing function. However, there is a concern that roads will be closed due to landslides during an actual disaster. In addition, the regional information/disaster information browsing function requires users to obtain the information themselves actively. Thus, the latest information is not always obtained. Therefore, we will implement a route guidance function that avoids closed roads and a disaster information notification function as future work. The updated route guidance function provides users with safe route guidance based on real-time disaster information provided by the local government and social networking service information posted by residents. Additionally, the disaster information notification function would provide users with real-time disaster information using disaster prevention information XML data provided by the Japan Meteorological Agency.

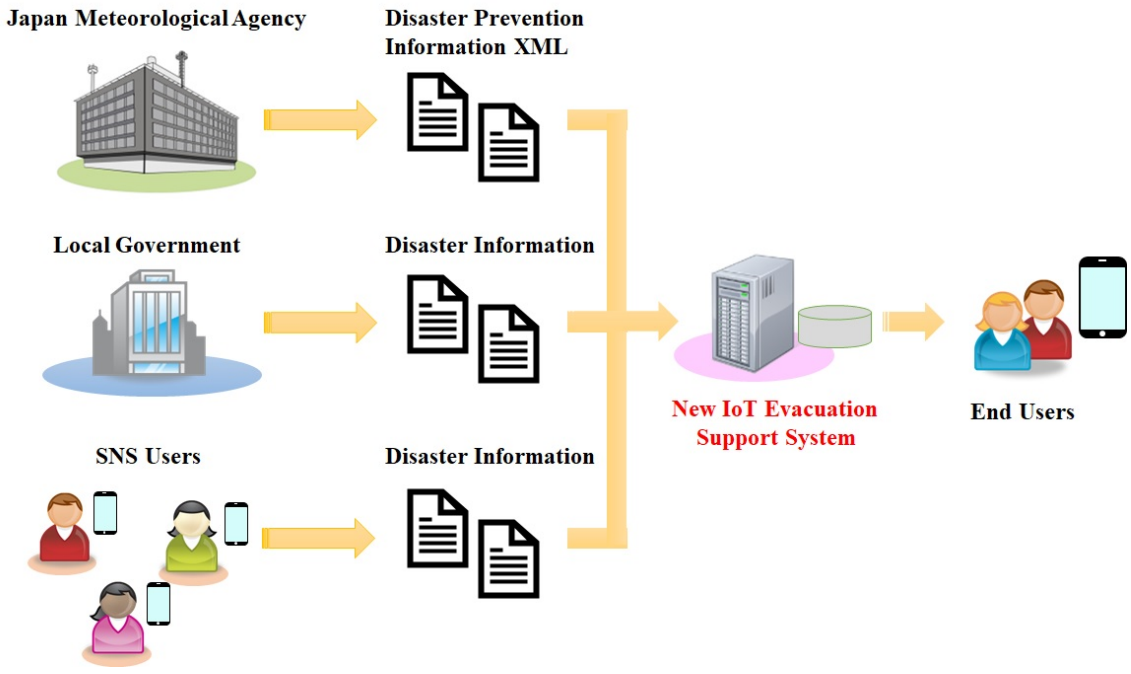


Figure 17: Overview of future work

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