Implementation and Evaluation of a Disaster Response Suggestion System

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Abstract

In this study, I conducted experiments of a disaster information acquisition method using a content centric network and moving routers, and verified the usefulness of information acquisition by using moving routers and caches in the event of a natural disaster. In a field experiment using moving routers by constructing a small-scale network assuming a local natural disaster, I measured the data acquisition time of disaster information acquired from the publisher and cache. In addition, in a simulation experiment by constructing a large-scale network assuming a wide-area natural disaster, I measured the average number of hops and the average data download time. As a result, this study showed the usefulness of information acquisition in cache utilization in both field experiments and simulations.

Keywords : Disaster Response Suggestions, Emergency Response Headquarters, Natural Disasters, Information Sharing

1. INTRODUCTION

Every year in Japan, natural disasters, such as torrential rains, typhoons, and earthquakes, occur, some affecting wide geographical areas. The major natural disasters in Japan over the past 3 years include the following:

- Typhoon Haishen No. 10 brought extreme winds to the Kyushu region in September 2020.
- Heavy rains occurred in July 2020 in the Kyushu region, centered on Kumamoto prefecture.
- Typhoon Krosa No. 10 delivered record heavy rainfall in the Kanto, Koshin, and Tohoku regions in October 2019.
- In North Kyushu, torrential rain hit a wide area including Nagasaki prefecture, Saga prefecture, and Fukuoka prefecture in August 2019.
- The Hokkaido Eastern Iburi earthquake occurred in September 2018.

Additionally, such disasters have often developed into complex multifaceted emergencies, such as river flooding due to torrential rain and liquefaction due to earthquakes [(1) (2) (3) (4) (5)].

As a result of surveys conducted by our research group in various municipalities, the problem of delays in disaster responses became clear. The response to a new emergency should be based on information about disasters and disaster responses that occurred in the past. Unfortunately, this information is not stored in digital databases readily accessible by a computer-based system. The core question of this research derived from this problem is “Can emergency response headquarters improve the efficiency and effectiveness of their disaster response and share information promptly, and can we address this question by developing a computational disaster response suggestion system?”

We have developed a method and system to suggest effective disaster responses, including recommendations regarding staffing needs and relief supply allocation. The system bases its decision-making on information such as past disaster response records and regional disaster response plans. By using this system, quick decision-making and information sharing can be expected from the emergency response headquarters. For the basic data in the prototype, we used the disaster response information [(6)] from the Chiba Prefecture in its response to Typhoon Faxai No. 15 and Typhoon Hagibis No. 19, which both occurred in 2019. We built digital databases using this information where none had existed prior.

2. RELATED WORKS

Few works used AI in disaster information systems. Inaba et al. [(7)] proposed an evaluation formula for the level of disaster response according to the amount of damage caused by natural disasters and constructed a disaster response assumption model that enables an understanding of the time-series changes in disaster responses. With this model, it was possible to manage the progress of response work in the event of a disaster and to support appropriate staffing in that disaster response. However, the potential for different types of disasters varies widely among municipalities throughout Japan. This model has not yet reached a level that can be applied to any local government because the characteristics of each region are complexly related to the appropriate disaster response.

Numada et al. [(8)] constructed a disaster response framework consisting of 48 types of response measures on the basis of an analysis of local government responses during the 2011 Great East Japan Earthquake and 2016 Kumamoto Earthquake. This framework was used to realize effective disaster response measures

to be employed by local governments in the event of a natural disaster. Numada et al. showed that this disaster response work framework could also be applied to the disaster response for flood damage caused by the heavy rains in the Kanto and Tohoku regions in 2015. However, various other types of natural disasters, such as typhoons and volcanic eruptions, have not been verified using this disaster response framework.

Suzuki et al. [9] [10] developed a disaster response management system after conducting questionnaire-based surveys with a sample of local government employees to extract shared information that is effective for disaster mitigation. This system supports effective information sharing and disaster response work, and the researchers are conducting experimental studies of the system in Mitsuke City, Niigata Prefecture. However, although this system incorporates a mechanism that allows content to be tagged according to its importance, there are only two types of judgment criteria: urgent or normal. Taking into consideration the enormous amount of work of the emergency response headquarters in the event of a disaster, it is necessary to allow for more detailed importance rankings.

Murakami et al. [11] developed an information collection and sharing system using Web-GIS, a web-based mapping framework, to support disaster prevention activities through public?private collaboration of local residents and local governments. This system can be used for regional inspection maps and disaster map training in normal times and can also be used for collecting, transmitting, and sharing disaster information with residents and governments in an emergency. This system makes it possible to grasp an overall view of disaster information; make judgments about the specific situation, such as spreading fire; and make effective response decisions, such as evacuation advisories.

Nonaka et al. [12] proposed an active decision support method to support quick and reliable disaster countermeasure work and developed a disaster countermeasure navigation system. This system has an event-driven automatic guidance function based on an electronic disaster response manual, an information integration function, a user interface that reflects the decision-making process, and a group work function. Shibayama et al. [13] developed a damage information collection system for sharing disaster information. This system has a function for customizing input information, an extended function for improving information collection efficiency, and a navigation function using GPS. Kubota et al. [14] [15] developed a disaster information sharing system using an open-source GIS for emergency response command centers to collect disaster information quickly and accurately. This system can register photos along with location information from the disaster site so that disaster information can be shared via smartphones. Goto et al. [16] developed an information sharing system that addresses communication issues at the time of a disaster and as the situation changes over time. This system is designed assuming communication failures amid a disaster. Sasaki et al. [17] developed a regional information sharing system for disaster risk reduction, especially related to evacuation measures. This system handles disaster information, evacuation shelter information, and information regarding required support people. Ise et al. [18] developed a disaster information utilization system for municipalities. A major feature of this system is that it supports the diversity of municipalities by enabling flexible UI design changes. However, this system does not manage staffing at disaster sites and evacuation shelters based on the records of past disaster responses.

Kakuzaki et al. [19] organized the issues that local governments should tackle in the event of large-scale natural disasters, such as earthquakes and tsunamis, and constructed a basic municipal disaster management system to address these issues. This system aims to shorten the response process by creating a work breakdown structure by determining the work required for the response from the time of the occurrence of a disaster to regional reconstruction. However, to build a management system, it is necessary to repeat the extraction of necessary tasks, each activity and execution procedure, and the input of workload and necessary resources. Therefore, this system cannot be customized by various local governments according to their regional characteristics.

Li et al. [20] implemented DI-DAP, an efficient and effective disaster information delivery and analysis platform. DI-DAP provides users with a single view of useful and timely disaster information gathered from multiple sources. The information used by DI-DAP for analysis is only real-time information, and the utilization of the accumulated information has not been examined.

3. RESEARCH OBJECTIVE

In this work, we implemented a disaster response suggestion system that proposes appropriate and necessary disaster response measures to be performed by the emergency response headquarters, including the allocation of staff to evacuation shelters and other relief locations and preparing and allocating relief supplies. The prototype we built utilizes data from the disaster response work of the Chiba Prefecture during Typhoon Faxai No. 15 and Typhoon Hagibis No. 19, which both occurred in 2019. The system derives its recommendations using past disaster response data stored in its database corresponding to the type and scale of the disaster, as well as regional governments' disaster response plans.

The disaster response suggestion system is roughly divided into two functions: disaster response registration and accumulation, and the disaster response suggestion functionality. The former allows users to register, i.e., input into the system, several types of information, such as past disaster events, past disaster response measures taken, and regional disaster response plans, and the system stores the entered information in its databases. The suggestion function recommends specific disaster response

measures based on the data accumulated in the databases. Particularly, this work aims to improve the efficiency and effectiveness of disaster response command centers and support prompt information sharing by suggesting disaster response measures.

4. DISASTER RESPONSE SUGGESTION SYSTEM CONFIGURATION

Fig.1 shows the configuration of the disaster response suggestion system. The environment consists of emergency response headquarters agents (humans) and, on the system side, an Application Server group and a Database Server group.

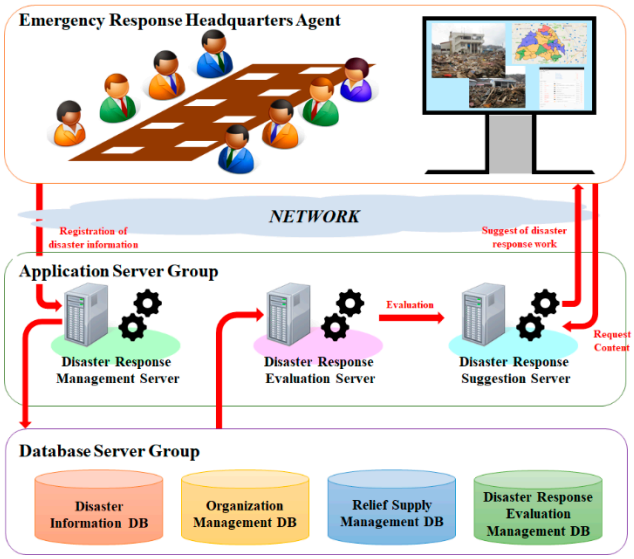

Fig. 1, Configuration of proposed disaster response suggestion system.

4.1 EMERGENCY RESPONSE HEADQUARTERS AGENTS The emergency response headquarters agents, i.e., people at the command center, register regional disaster response plans and past disaster response records. These data are stored in the appropriate database. Additionally, agents are able to browse disaster responses according to the type of disaster.

4.2 APPLICATION SERVER GROUP The Application Server group consists of a disaster response management server, a disaster response evaluation server, and a disaster response suggestion server. These are described in the following subsections, respectively.

4.2.1 DISASTER RESPONSE MANAGEMENT SERVER The disaster response management server manages disaster information, the numbers of disaster response staff, past disaster response records, damage information, and relief supplies information. It allows emergency response center agents to register and edit data in the disaster information database, organization management database, and relief supply management database.

4.2.2 DISASTER RESPONSE EVALUATION SERVER The disaster response evaluation server derives the ideal disaster response in terms of staffing and relief supplies based on the type and intensity of the current disaster, current damage status, information about past disasters, and the historical records of prior disaster response measures taken. This server passes the derived disaster response that the emergency response headquarters should take to the disaster response suggestion server.

4.2.3 DISASTER RESPONSE SUGGESTION SERVER Based on the evaluation server's results, the disaster response suggestion server visualizes for agents the disaster response measures that the emergency response headquarters should take. The emergency response headquarters then make decisions on the basis of these recommendations.

4.3 DATABASE SERVER GROUP The Database Server group consists of a disaster information database, an organization management database, a relief supply management database, and a disaster response evaluation management database. These are described in the following subsections.

4.3.1 DISASTER INFORMATION DATABASE The disaster information database stores regional disaster response plans and past disaster response records, which are managed by the emergency response headquarters agents via the disaster response management server.

4.3.2 ORGANIZATION MANAGEMENT DATABASE The organization management database stores organizational information, such as relevant departments and divisions of the local government. The prior disaster response records stored in the disaster information database are linked to the respective departments or divisions in charge.

4.3.3 RELIEF SUPPLY MANAGEMENT DATABASE The relief supply management database stores information on disaster relief supplies, such as food, power sources, bedding, and blankets for evacuation shelters, portable toilets, sandbags, and other disaster response necessities.

4.3.4 DISASTER RESPONSE EVALUATION MANAGEMENT DATABASE The disaster response evaluation management database stores the disaster response recommendations derived by the disaster response evaluation server. This is the main result of the disaster response suggestion system, specifying the actions to be taken by the emergency response headquarters.

5. DISASTER RESPONSE SUGGESTION SYSTEM

Fig.2 shows the first screen of the disaster response suggestion system. The user can navigate to the disaster response registration and storage system and the disaster response suggestion system from this screen.

Fig. 2, Top screen of the disaster response suggestion system.

When the user selects “Evaluation/Suggestion” at the top of the screen, the Evaluation/Suggestion menu screen shown in Fig.3 is displayed. By selecting items “Past Disaster Response Work Evaluation,” “Disaster Response Work Suggestion,” and “Disaster Response Work Suggestion Evaluation” at the bottom of this screen, the user can, respectively, browse past disaster response evaluations, view future disaster response suggestions, or navigate to the screen that permits the user to enter his or her own evaluations of the suggestions provided by the system.

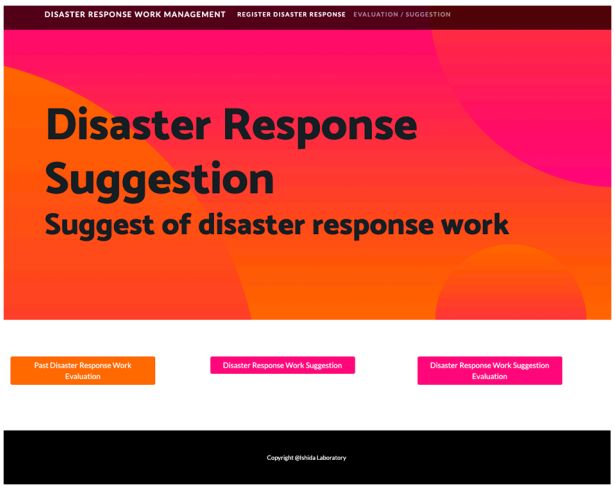

Fig. 3, Evaluation/suggestion menu screen.

5.1 PAST DISASTER RESPONSE WORK EVALUATION BROWSING FUNCTION When the user selects “Past Disaster Response Work Evaluation” on the Evaluation/Suggestion menu screen, the system transitions to the screen shown in Fig.4, which displays a list of past disaster events that have been registered in the system and stored in the databases.

The user can then select a specific disaster by clicking on its corresponding “disaster response evaluation” link to view the evaluation of the response to that disaster. Fig.5 shows an example in which the past disaster response rates very high scores in all categories of relief supplies and the level of the response by specific relief organizations.

Fig. 4, Past disaster response evaluation browsing screen.

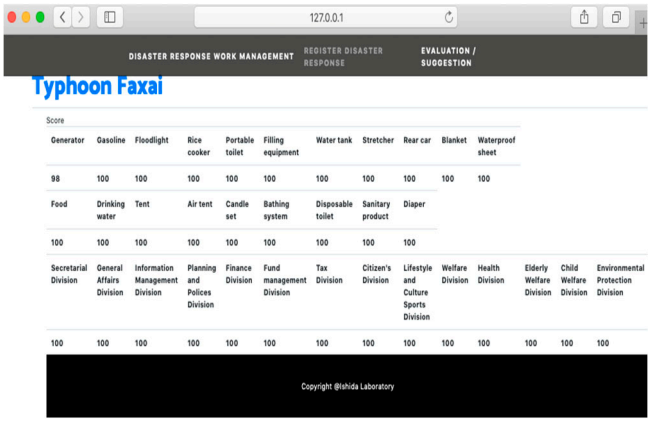

Fig. 5, Evaluation scores for a specific past disaster response.

5.2 DISASTER RESPONSE SUGGESTION BROWSING FUNCTION When the user selects “Disaster Response Work Suggestion” on the Evaluation/Suggestion menu screen shown in Fig.6, the screen transitions to the Disaster Response Work Suggestion browsing screen as exemplified in Fig.7. Again, the screen presents a list of past disaster responses to choose from.

When the user selects the “disaster response suggestion” link next to a specific disaster, the disaster response suggestion screen for that disaster is displayed, as shown in Fig.7; presented on this screen are suggestions for a similar disaster that may occur in the future. The user can view here the system’s recommendations regarding staffing and relief supply requirements, based on the evaluation derived from the past disaster response.

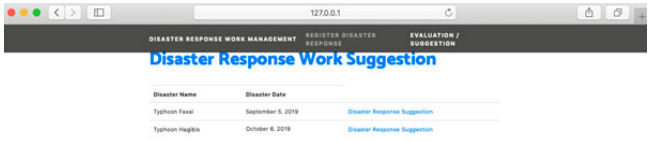

Fig. 6, Disaster response work suggestion browsing screen.

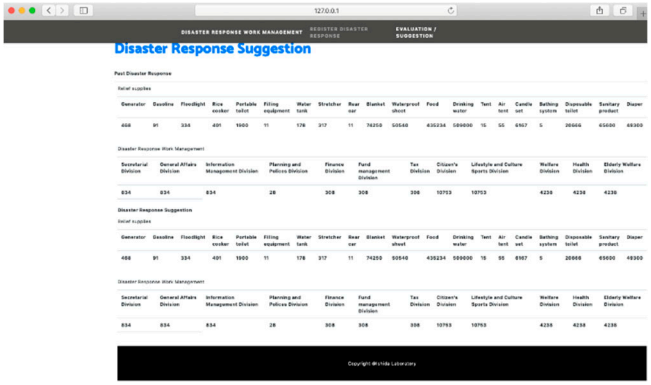

Fig. 7, Disaster response suggestion screen.

5.3 USER EVALUATIONS OF DISASTER RESPONSE SUGGESTIONS As we have discussed, the disaster response suggestion system efficiently learns and makes suggestions regarding the allocation of staffing and relief supplies for future disaster events based on past disaster response work. The system includes the functionality to allow users to evaluate these disaster response suggestions. When the user selects “Disaster Response Work Suggestion Evaluation” on the Evaluation/Suggestion menu screen, the user interface transitions to a screen with a list of the disasters for which the system has derived disaster response suggestions. Fig.8 shows an example of this screen.

The user can select a specific set of suggestions?that is, the suggestions for a specific disaster event?by selecting the “Evaluation” button next to that particular disaster. The system then displays the User Evaluation of Disaster Response Suggestions screen, as shown in Fig.9. Here, the user can provide a fine-grained evaluation of the system’s suggestions by rating multiple individual suggestion points.

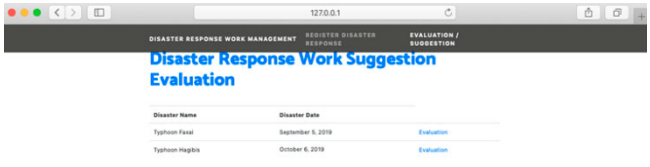

Fig. 8, List of disaster events for which the system has derived disaster response suggestions.

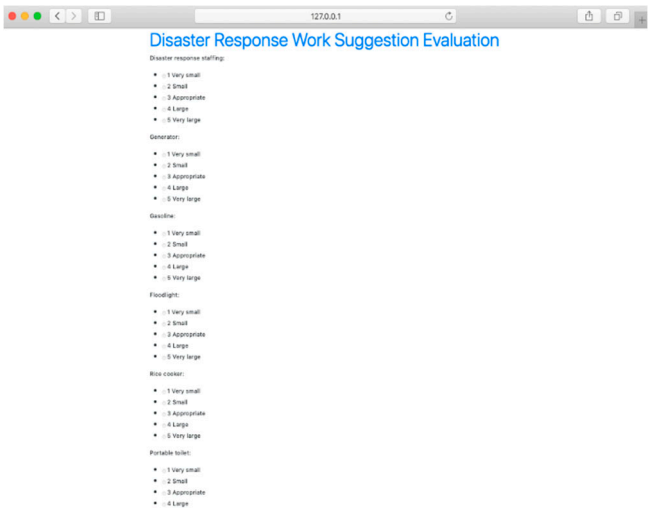

Fig. 9, User evaluation of disaster response suggestions screen.

5.4 SEQUENCE DIAGRAM OF THE DISASTER RESPONSE SUGGESTION SYSTEM Fig.10 shows the sequence diagram of the disaster response suggestion system. For example, when the user navigates to the past disaster response evaluation browsing screen and then selects a particular disaster, the system calls the Application Server to retrieve the evaluation score of that past disaster response; the Application Server retrieves the corresponding information via the Database Server and delivers it back to the user interface. The same flow applies to browsing the disaster response suggestions and the user evaluations of disaster response suggestions.

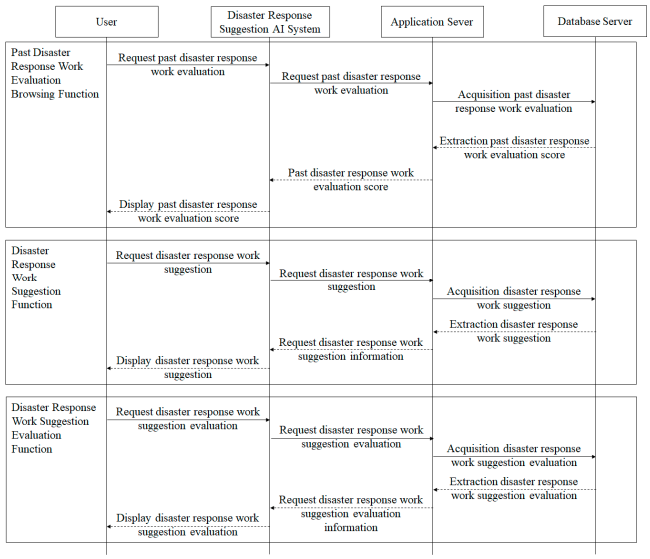

Fig. 10, Sequence diagram of the disaster response suggestion system.

6. USER EVALUATION OF THE DISASTER RESPONSE SUGGESTION SYSTEM

After we implemented the prototype disaster response suggestion system, we conducted an evaluation experiment to obtain user feedback about the system. This study recruited 27 subjects to obtain their judgments of the operability, readability, functionality, necessity, effectiveness, and applicability of the system. In this evaluation experiment, the subjects answered a questionnaire after actually using the disaster response suggestion system.

6.1 OPERABILITY, READABILITY, NECESSITY, EFFECTIVENESS, AND APPLICABILITY OF THE DISASTER RESPONSE SUGGESTION SYSTEM Fig.11 shows the evaluation results for operability, readability, necessity, effectiveness, and applicability. The percentage of respondents who rated each of these elements as "high" or "very high" is as follows: operability, 74% of respondents; readability, 78%; necessity, 81%; effectiveness, 89%; and applicability, 70%. Regarding applicability, feedback from subjects included, "I think this system can be applied not only to emergency response headquarters but also to general operations in local governments" and "I think this system can be applied to hospital operations as well."

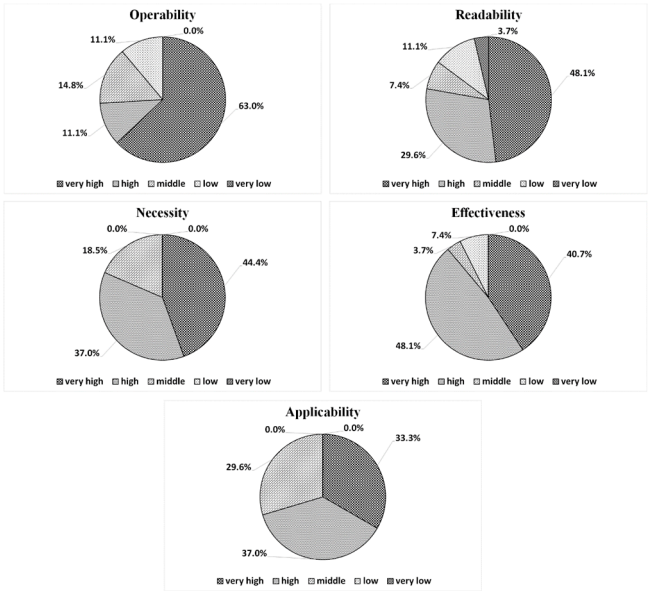

Fig. 11, User ratings of the operability, readability, necessity, effectiveness, and applicability of the disaster response suggestion system (n = 27).

6.2 FUNCTIONALITY OF THE DISASTER RESPONSE SUGGESTION SYSTEM Fig.12 shows the user evaluation results for functionality. Regarding the past disaster response evaluation browsing function, 63% of the subjects responded "very high" or "high." However, 37% of the subjects answered "middle" or "low." Regarding the disaster response suggestion function, 67% of the subjects answered "very high" or "high." However, 34% of the subjects responded "middle" or "low." And regarding the user evaluation of the disaster response suggestions function, 52% of the subjects answered "middle" or "low." From these evaluation results, it became clear that it is necessary to improve the functionality of the system.

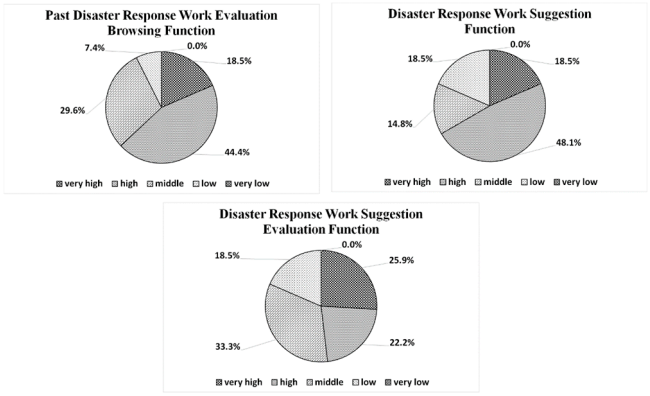

Fig. 12, User evaluations of the functions of the disaster response suggestion system (n = 27).

7. DISCUSSION

We implemented an interactive decision support system to provide suggestions for disaster response measures based on information such as past disaster response reports, the organizational structure of the groups involved in disaster relief, and regional disaster response plans. The system uses a deep learning model to derive suggestions. We evaluated the system in a study involving a sample of users and the system was highly rated in terms of operability, readability, necessity, effectiveness, and applicability. Clearly, users appreciated and saw value in many aspects of this work. Conversely, low evaluations were found regarding functionality. The following two points can be considered as factors for the low evaluation:

- Since the prototype system uses only the disaster response data from the Chiba Prefecture regarding Typhoon Faxai No. 15 and Typhoon Hagibis No. 19 in deriving the disaster response suggestions regarding disaster response staffing and the prediction of the amounts of relief supplies required, the accumulated data of the prototype are overwhelmingly insufficient.
- Visualization of evaluation scores and disaster response suggestions for past disaster response work is complicated.

Therefore, we need to enhance the accumulated data, further expand the functions of the system, and improve the user interface.

8. CONCLUSION

In the work reported in this paper, we implemented a disaster response suggestion system to improve the effectiveness of disaster

response measures and organizations and promptly share information to improve the efficiency of the emergency response headquarters. The disaster response system supports the decision-making of the emergency response headquarters staff by accumulating regional disaster response plans, past disaster response records, various disaster information, and organizational responsibilities in the event of a disaster, and presenting staffing and relief supply suggestions for disaster responses. To evaluate the operability, readability, functionality, necessity, effectiveness, and applicability of the system, an evaluation experiment was conducted with 27 users. The system obtained high evaluations in terms of operability, readability, necessity, effectiveness, and applicability, but there remain issues related to functionality. In the future, we plan to broaden the accumulated data, extend the functionality of the system, and improve its user interface.

ACKNOWLEDGMENTS

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