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Assessing the Impact of Communication Failures on Disaster Victims using a Communication Emulator

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Abstract - This paper analyzes the prediction of communication failures and their impact on information communication during a flood event using a communication failure emulator. Damage estimates related to communication in the event of a disaster are indicated by the number of disrupted lines. However, this method does not allow disaster victims to know when they will not be able to use the system and what kind of situation they will be in. In these days when information communication has become commonplace, such a situation could have a tremendous impact on the damage. Therefore, we propose a system that emulates communication failures in the event of a disaster and analyzes the impact from the user's perspective. We have performance study for our system with communication failures emulator and discuss its impact.

Keywords: flood disaster, communication failure, federation system

1 INTRODUCTION

1.1 Background

The number of disasters and the number of human casualties is steadily increasing in the world due to the complex intertwining of changes in the global climate system and global warming caused by greenhouse gases[1] [2]. Urban populations are expected to reach over 6 billion by 2050, with 68% of that population concentrated [3] in urban areas at risk of disaster. In particular, flood disasters have the highest number of human casualties, with about 3.39 million affected in 2018 [4], and the projections show further increases in these numbers.

Smart city technology is expected to realize resilient cities. Smart city technology uses Internet of Things (IoT) sensors to collect various data on cities, such as traffic flow, people flow, and weather, and uses AI to determine and predict the supply and demand of people living in cities in real time [5].The aim of smart cities is to create resilient cities that make our lives in cities with high disaster risks better.

Advances in cyber-physical systems, IoT, cloud computing, and other software technologies are actively contributing to the development of smart cities. Smart cities offer the basic capabilities of integrating sensors, actuators, and other devices into the physical environment of the city through a variety of technologies and computational techniques. Especially, simulation technology, one of the basic technologies of smart cities, playing an important role in service demand forecasting in physical spaces and prediction analysis in virtual spaces.

1.2 Motivation

Simulation is a traditional fundamental technology for imitating real-world events. Simulation techniques can be broadly classified into physical simulations (i.e., that physically model actual objects or physical phenomena) and logic simulations (i.e., that approximate state changes with continuous or discrete modeling). Case study application of simulation technologies is contributing to the study of production process management and productivity improvement measures in the supply chain, as well as to the upgrading of agricultural management systems based on weather data in the field of agriculture. These manufacturing and agriculture smart city objectives can be said to be relatively simple simulations and system optimizations. For example, in agriculture, the change in weather can be represented by a physical phenomenon model, and the growth of agricultural products can be represented by a real model given conditions. In other words, these objects and phenomenon can be described by physical simulation.

By contrast, in the field of disaster researches, various types of simulations are required to explain complicated phenomena. The magnitude of disaster damage is determined by the disaster phenomena and the vulnerability of elements, such as urban spatial structure and human behavior, against them. Therefore, in order to extend the smart city to the field of disaster prevention and contribute to realizing resilient cities, it is necessary to handle various physical and social phenomena. The problem is that the simulations of each phenomenon to be handled are modeled with different principles. Disaster phenomena are described by a physical model, and human behavior is described by a discrete model such as a multi-agent model. Conventional simulation technology has evolved such as to be specialized for one certain model. That is, these different models and technologies are represented by different simulations and systems. Therefore, in order to realize a cyber-physical system for disaster prevention, dealing with analysis results obtained from different models and technologies in an integrated manner is a major challenge.

2 RELATED WORK

2.1 Literature Review

One of the simulation techniques is physical simulation for reproducing disaster phenomena; for flood damage, this means a flood analysis simulator that estimates the occurrence of flood damage and its expansion process. This is a simulator that derives the flood water value in several-meter grid units by numerical analysis using input data such as precipitation, land use, building coverage, sewer pipes, and manholes. In addition to flood damage, many simulations have been developed to accurately reproduce various disaster phenomena such as tsunami [6] and wildfire [7]. In these simulations, each generation mechanism is modeled by a physical formula and then reproduced on a computer; these simulations are actually used for risk estimation and damage estimation in many regions.

Another approach is a social simulation that models the behaviors that can be taken by evacuees. An evacuation simulator reproduces evacuation behavior in various situations, such as when a disaster event occurs. There are several approaches to behavior modeling, including an empirical approach and an agent-based approach [8]. A number of models have been developed, including an evacuation model that dynamically selects destinations [9], an indoor evacuation model that considers collisions between evacuees [10], an evacuation model that considers evacuation behavior affected from nearby evacuees [11], and a crowd evacuation model [12]. Nguyen et al. [13] used an evacuation simulation in disaster phenomena, considering the behavior of smoke diffusion during a fire and providing directions to evacuees, and discussed its use in formulating efficient evacuation plans.

A new approach in the concept of the cyber physical system is a simulation that models physical elements of the real space onto the virtual space. Virtual Singapore produces an urban space model that integrates terrain information, buildings, and social infrastructure information throughout Singapore onto a virtual space [14][15]. Furthermore, a simulation environment is being constructed by integrating various real-time data (traffic information, car / people location information, etc.) into that urban space model. Behind these technologies is the evolution of technologies developed for various applications, such as IoT. Cyber-physical systems extend the IoT concept further to facilitate the interaction of the smart city's cyber and physical spaces. Ref. [16] attempted to detect landslide using IoT concept, Refs. [17]-[19] adopted their cyber physical system to disaster response. In disaster prevention, construction of an elaborate urban structure model means that disaster phenomena can be reproduced with high accuracy, which can improve the usefulness of feedback to the physical spaces. This is because the parameters of the physical model used for the physical simulation of disaster phenomena are defined based on the data of the urban space model. Moreover, the collection of real-time data by the IoT has the potential to improve the accuracy of both disaster phenomena simulation and social simulation.

The goal of handling different models and technologies in an integrated manner is achieved by a strategy to develop a large framework that incorporates these simulations and systems as a single function. Integrated Emergency Response Framework (iERF) [20] is such an integrated framework. This was proposed as a framework to integrate various tools used in emergencies such as simulation and visualization. High Level Architecture (HLA) is an approach to standardize different simulators/systems for distributed simulation, used when developing a simulation for a larger purpose by combining several simulations [21]. HLA develops a distributed simulation by providing various services such as data distribution and time synchronization through middleware. Dahmann et al. [22] have achieved the interoperability of various simulations by examining the specifications of a common technical architecture for simulations using HLA. The architecture was implemented as a prototype to interoperate multiple simulators, including evacuation, information provision systems, and emergency operations, in an earthquake disaster [23]. In addition, a distributed simulation platform has been constructed for evacuation simulation in the event of fire disasters caused by earthquakes [24].

2.2 Limitations and Contributions

Although the abovementioned integration strategies provide theoretical support for coordination between different models to represent complex real spaces, there remain several issues to be improved. First, it is necessary to realize information communication environment in virtual space. Considering the feedback of the prediction results, actual information communication needs to be simulated, but this has rarely been discussed in disaster response terms. Second, while ensuring scalability, the cost of system improvement for synchronization with new simulations and systems should be reduced. This is due to reducing obstacles to quickly adopting new observation systems and prediction technologies created by feedback from the virtual space of a cyber-physical system. Third, social simulation depends on information and decision making. In order to reproduce human behavior in a disaster situation more precisely, a cyber-physical system needs to incorporate accessibility to disaster information as a parameter of the simulation.

A federation strategy using the information bus was proposed in our previous paper [25] to solve the problems above. The contributions of the federation strategy are summarized as follows:

- Federation technology is achieved by implementing functions of data exchange and processing timing control between simulations / systems in a cyber-physical system. These functions mean that simulations representing virtual spaces can be integrated together to create a more elaborate physical space. In addition, the components themselves can be exchanged between virtual space and physical space via federation, and application to various test beds can be expected. We named this progressive simulation.

- Our platform also supports the behavior of computer networks that affect the accessibility of information, and it evaluates the damage mitigation effects of that behavior. We define the technique that imitates the behavior of computer networks as computer emulation. Computer emulation automatically verifies computer network outages or destruction due to disasters and can more accurately reproduce physical space events caused by complex factors.

This paper proposes a system that uses this federation strategy to create scenarios that include the impact of communication failures in floods.

3 PROPOSAL OF DISASTER VICTIM IMPACT ANALYSIS SYSTEM

This paper aims to propose a system that uses the federation strategy to create scenarios that include the impact of communication failures during floods. It is well known that communication failures occur during disasters such as floods. Communication failures during disasters include power outages, broken communication systems, and traffic congestion caused by concentrated traffic. In particular, communication failures caused by power outages and physical damage to communication systems occur frequently during floods. In recent years, 70% of floods have resulted in failures due to damage to communication systems. Such physical failures are considered to have a significant impact on the disaster victims because their recovery requires physical system relocation.

Particularly in disasters such as floods, where damage spreads gradually, the accessibility of information to disaster victims is a critical aspect before and during the disaster. Therefore, it is important to consider countermeasures including communication failures in providing and obtaining information. However, preliminary disaster assessments are based on large estimates, such as “X million network access lines will be out of service.” In preparation for network outages, there have been studies on advance deployment of systems that enable early recovery and alternative networks such as delay tolerant network [26]-[28]. On the contrary, we believe that it is essential to consider how the occurrence of such communication failures affects the access to information for disaster victims during a disaster. In the 2020 floods in Kumamoto, Japan, communication failures occurred as the rainstorms progressed, making it difficult to obtain information. Optical fibers at bridge piers were flushed away by the rising river water, and communication was damaged even in areas where no flooding had occurred.

Human behavior during disasters depends largely on what kind of information affected people have obtained. In the current society, which relies heavily on information and communication technology, we should assess what kind of situation the victims’ access to information will be in and how it will affect them by simulating the situation in advance as a strategy for disaster response. Thus, in this paper, we develop a system to create scenarios that simulate communication failures by using our federation strategy, which allows multiple simulators to be implemented in a cooperative manner. The system incorporates multiple factors such as the impact of natural disasters, human behavior, the impact of disasters on communication networks, and information services as a flood

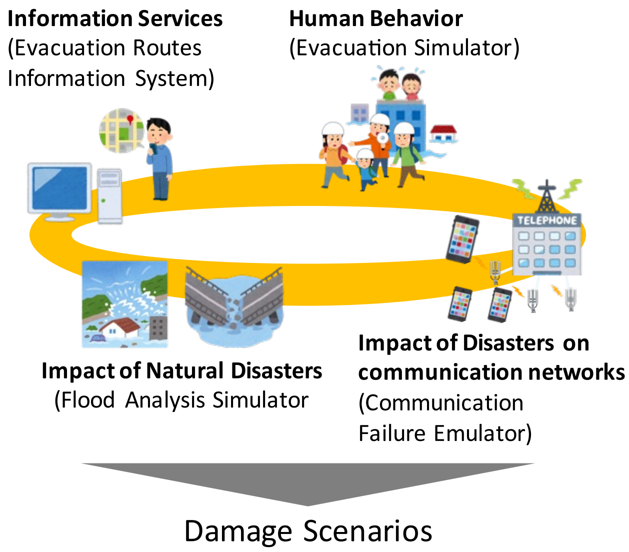

Figure 1: System Concept

analysis simulator, evacuation simulator, communication failure emulator, and evacuation routes information system, respectively, and creates scenarios of human impact by emphasizing the dependencies among these factors (Fig. 1). Using this system, we confirm that it is possible to generate multiple scenarios (optimistic scenarios and worse scenarios) related to communication failures.

4 SYSTEM CONFIGURATION

4.1 Overview

This paper simulates and analyzes human impacts from disaster phenomena simultaneously with information service technology. The incorporation of multiple factors into a simulation model requires complex and massive development efforts, although our federation strategy allows for the cooperative implementation of these multiple simulations, It can also be expected to be used as a mechanism for evaluating the accuracy and usefulness of the information service in a disaster situation.

Our system consists of multiple simulators operating in a cooperative manner. Four simulators / systems (flood analysis simulator, evacuation simulator, evacuation route service system, and communication failure emulator) exchange data with each other considering their operation timing, and progressively compute their own simulations using data from other simulators (Fig. 2).

4.2 Federation Strategy

We describe a federation strategy for four different simulators / systems: a flood analysis simulator, an evacuation simulator, an evacuation route service system, and a communication failure emulator. To achieve this cooperative operation, this system needs to be addressed, including physical data exchange between simulators and systems, processing timing control. We aim to achieve this goal through a federation strategy that develops a larger framework incorporating

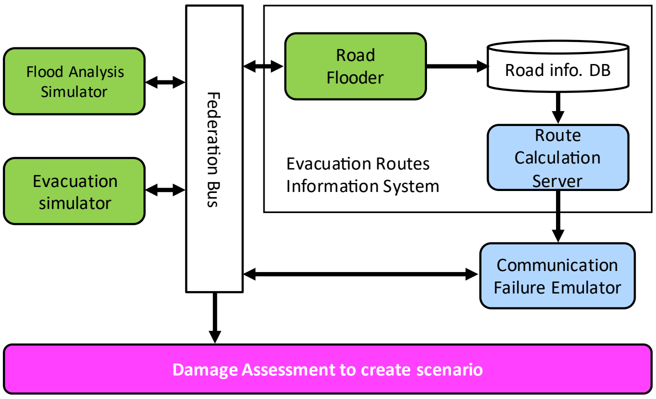

Figure 2: System Configuration

these simulations and systems as a single feature. We aim to achieve this goal through a federation strategy that develops a larger framework integrating these simulations and systems as functions. The process to achieve the federation strategy involves several phases, all of which are provided on a single platform. We have addressed the design and implementation of simple data exchange and processing timing control [25] for pre-verification, and a real-time data exchange and processing timing control [29] for practical service. As a feasibility study on static scenario, this paper uses the simple data exchange and processing timing control shown in [25] to cooperate with simulations and systems. This paper aims to propose a system that uses the federation strategy to create scenarios that include the impact of communication failures during floods.

4.3 Federation Bus

In our federation strategy, the federation bus is responsible for their data exchange and timing control. The federation bus consists of an MQTT broker for Publish-Subscribe message exchange and a federation manager for time synchronized progress management. As the name suggests, the data exchange function is responsible for exchanging data between simulators and systems. The data exchange function is composed of an MQTT broker. Each simulators / systems outputs the calculation results for each step as MQTT messages. Other simulators and systems subscribe to others' MQTT messages based on pre-defined information and use the messages as input data for their respective calculations. Although each of the simulators takes a different amount of time to compute, we achieved the cooperation of multiple simulators/systems by using this timing control manner.

The processing timing control function is a server that manages processing timing. The processing timing control function manages the operation of four simulators / systems as a coordination manager responsible for time synchronized progress management. When starting the overall simulation, this function sends a simulation start order to all simulators / systems. When the first step of each calculation is completed, the simulators / systems publish the MQTT message that the first step of the calculation is completed, as well as the calculation results. Upon receiving messages from all simulators/systems, the processing timing control function determines that the first step calculation is complete. It then sends an order to all simulators / systems to start the second step of the calculation. By repeating this process, the calculation proceeds with multiple simulators/systems working cooperatively. Then, our system creates scenarios by changing the alert timing, and analyzing the behavior of disaster victims and their access to information as calculated by the evacuation simulator.

4.4 Flood Analysis Simulator

Our federation strategy can allow us to use a conventional flood analysis simulator. However, in this paper, we use data from API[1], which performs flood calculations, due to the difficulty of obtaining the input data for the flood calculations. For the scenario area, Hitoyoshi City, Kumamoto Prefecture, we regard the flood data as calculated at specific time intervals and connect it to a federation bus.

Road Flooder progressively calculates the impassable roads, according to the flooded value from the flood data. The calculation result is transmitted to the road management DB through the federation platform, and the road information is updated. Road information management DB stores the road information and the shelter information, which are used for the evacuation route calculation in the target area.

The flood analysis simulator receives MQTT messages for timing control from the federation bus. Upon receiving this MQTT message, it publishes the flood values for each grid for one step.

4.5 Evacuation Simulator

Our evacuation simulator is developed using a multi-agent simulator. At the beginning of simulation, evacuation simulator generates the evacuee agents, according to the population distribution which is set in the map. Determination of each behavior can be set the parameters for each agent as evacuation characteristics. In other words, we can set the evacuation behavioral characteristics of each agent according to age, disaster experience, and ability to access information. Besides, the shelter where to which each agent evacuates is set as the initial value for each agent. The total number of evacuee agents can be set on the evacuation simulator.

The evacuation simulator calculates the behavior of the evacuee agents, depending on the flooded value calculated from the flood analysis simulator. The evacuee agents determine their behaviors on the basis of their own location, walking speed, or information. Evacuee agents have their own smartphones. When local agency sends the evacuation information, evacuee agents move in accordance with their own evacuation behavioral characteristics. For example, an agent who has better evacuation behavior characteristics starts to evacuate to the shelter immediately after receiving information. We configure several types of the evacuation behavioral characteristics; the agent who start the evacuation several minutes after receiving the information, or who start if their surrounding agents start to move.

Evacuee agent consults the evacuation routes information system to determine the safe evacuation route after their deci-

[1] https://suiboumap.gsi.go.jp/

sion, then starts to move to the shelter. During their evacuation, they confirm the flooded value of the surrounding grids at each simulation step. If flood has not occurred around the agent, they move to the next grid on their route. If the flooded value exceeds the threshold, their evacuation routes are flooded; in consequence, they re-ask the other safe route to information system. This threshold is used to set the flooded value as impassable for a given road for each agent.

Evacuee agents search for safe evacuation routes when flooding above a threshold occurs around them at the start of evacuation or during evacuation. After each search, the route calculation server calculates the evacuation route and sends it to each agent's smartphone. If there is a communication failure at the current location of the evacuee agent, the evacuee agent will not be able to receive flood information and cannot access further route searches. In case of search at the start of evacuation, the evacuee agent does not start evacuation. In the case of search during evacuation, the evacuee agent does not update the evacuation route and stops at the location where it cannot move due to flood. The evacuation simulator calculates the amount of damage and data access status in a progressive manner using data from evacuation agents.

The evacuation simulator receives MQTT messages for timing control from the federation bus. Upon receiving this MQTT message, it receives the flood values for each grid calculated by the flood analysis simulator and determines if the evacuee agent can move based on these values. In addition, it receives MQTT messages from the communication failure emulator with the location of each base station, its communication range, and its status. Each evacuee agent calculates its communication accessibility based on its current location. If communication is available, it publishes an MQTT message with its current location and destination.

4.6 Evacuation Routes Information System

Before the evacuation, each evacuee agent searches the safest evacuation route to the shelter using their smartphone. Evacuation routes information system search and provide the evacuation route. The system consists of road flooder, road information management DB, and route calculation server.

When the evacuee agents search for an evacuation route, the route calculation server excludes impassable roads calculated by the road flooder and computes them according to the current location of the agent and of the nearest shelter. By inputting the location of the evacuee agents and the destination node ID, the route calculation server determines a route by weighted Dijkstra method in consideration of distance and cost, and it returns a list of nodes on the route. In the evacuation simulation, the location of the evacuee agents and the ID of the destination node are transmitted by MQTT via the federation bus. Upon receiving the data, the smartphone emulator receives a list of nodes from the route calculation server using the REST API and transmits the list to the evacuation simulator using MQTT.

The route calculation server generates a weighted undirected graph $G_N = (\mathbb{N}, \mathbb{N}_{next})$ with the distance between nodes as the weight. Simultaneously, a set node $\mathbb{N}_{next}$ is selected from a table of links connecting to the set of nodes $\mathbb{N}$. The initial value of the cost of the graph G_N is configured to the distance between the nodes; however the ID of the nodes and links that have become impassable due to the flood expansion can be updated to the graph G_N via the road information management DB. After the river floods, if the grid on a agents' route becomes impassable, the node ID and link ID included in the grid are transmitted to the road management DB, and the cost of the corresponding nodes and links of the graph G_N is updated. After the cost is updated, when the agent inquires of the evacuation route via their smartphone, the route calculation server returns the detour route.

The evacuation routes information system receives MQTT messages for timing control from the federation bus. Upon receiving this MQTT message, the evacuation routes are calculated based on the flood values received from the flood analysis simulator. It also receives MQTT messages from the evacuation simulator about the current location and destination of each evacuee agent, calculates the safety evacuation routes based on this data, and then publishes the evacuation routes for each evacuee agent.

4.7 Communication Failure Emulator

Our communication failure emulator is an emulator that simulates communication failures related to smartphones in floods. The emulator consists of a mobile base station, a mobile relay station, a wired communication line between the mobile base station and the relay station, and a power supply to the mobile base station and the relay station. The mobile base station transmits radio waves within a defined range and is used for information access by evacuee agents within the range. If the flood water level rises in the flood analysis simulator and the mobile base station itself or the power supply function of the mobile base station is flooded, the mobile base station loses its communication function. The wired communication lines between the mobile base station and the relay stations are connected by the shortest path. When there is damage to the communication line due to flood flow, the mobile base station to which it is connected loses its communication function. The mobile base stations and the relay stations are supplied with electric power, and when a power outage occurs due to flood, the power supply is stopped and the communication function is disconnected at the same time. Channels and alternative means of power supply to the mobile base station are not considered in this paper.

The communication failure emulator sends the availability status of the mobile base station via MQTT over the federation bus. Depending on the location of the evacuee agent, it determines which base station to use and transmits the availability status of that base station back to the evacuation simulator. If the mobile base station is active, evacuee agents in the evacuee simulator will have access to routes to the shelter and alerts. If the base station is not available, the evacuee agents will not be able to access information. With the above steps, the communication failure emulator simulates information access in the event of a flood.

The communication failure emulator receives MQTT messages for timing control from the Federation bus. Upon receiving this MQTT message, it calculates the communication status and power supply status of base stations, fiber, and relay stations based on the flood values received from the flood analysis simulator. According to the calculation results, it publishes MQTT messages for the location, communication range and status of each base station.

5 PERFORMANCE STUDY

5.1 Overview

The previous section describes a system that uses a federation strategy to simulate and analyze human impacts from disaster phenomena simultaneously with information service technology. We use this system to generate scenarios of communication failures during floods. The flood analysis simulator uses data of the Kuma River flooding that occurred on July 4, 2020 in Hitoyoshi City, Kumamoto Prefecture, Japan. In this flood, the water level exceeded the flood hazard level at six water level observation stations, and overflows from the river occurred at 34 locations along the main Kuma River. Regarding telecommunications, 88, 70, and 111 mobile base stations were out of service in Kumamoto Prefecture by NTTdocomo, KDDI, and Softbank, respectively. We create scenarios in this system by changing alerts timing as trigger the start of evacuation and the time of the simulation. Using the scenarios, we analyze the possibility of creating multiple scenarios and the effects of communication failures from the viewpoint of disaster victims.

5.2 Setup

To set up the flood analysis simulator, the API selects one of the breakpoints as the point where the levee broke in a past flood event, and uses the flooding time series data from the largest assumed flood disaster. The evacuation simulator generates evacuee agents according to the population distribution in Hitoyoshi City and sets them to move to the nearest evacuation center. For the communication failure emulator, we visually survey the actual mobile base station locations within Hitoyoshi City and set them up in the emulator in the same arrangement as the actual base and relay stations. The setting values are the location information of a total of 31 antennas installed on top of buildings, telephone poles, and steel towers, the communication coverage areas of the base stations are set to radiuses of 1,000 meters, 200 meters, and 1,500 meters, respectively. Note that we have not set a distinction between telecommunications carriers. When the mobile base stations in the communication failure emulator are in operation, our evacuation routes information system presents the shortest route to the shelter, excluding flooded roads, in response to access by the evacuee agent in the evacuation simulator. Each simulator runs on a virtual machine placed in the same network and exchanges data via MQTT.

For performance study, we experimented and discussed two assessment points. The first study creates a scenario that includes the impact of communication failures. This study aims to investigate the feasibility of developing a system that creates scenarios to reflect the impact of a communication failure during a flood event, using a federation strategy that is integrated with a communication failure emulator. The second study is to confirm that it is possible to create multiple scenarios of communication failures, and then to discuss the impact of the communication failures from the viewpoint of the victims in each scenario. For the performance study, we prepared three scenarios, Scenario A)-C).

5.3 Damage Scenario

Scenario A) Scenario A) assumes that evacuation information is published before 60 minutes of the flood, and evacuee agents in the evacuation simulator start moving to the nearest shelter. The evacuee agent obtains the information every 10 minutes with a probability of one-half. This assumes that information is updated every 10 minutes. Since the frequency of information access is expected to depend on each evacuee, this scenario is set to a probability of one-half. to obtain the information. When the evacuee agent arrives at the evacuation shelter, the system counts the completed evacuation. For the performance study of the communication failure emulator, the evacuee agent is set to start evacuating as soon as the information is published. If a road is flooded to a depth that prevents passage, the evacuee agent searches for another evacuation route using their smartphone. The base station of the communication failure emulator stops working when it is flooded more than 1 meter depth, and the evacuee agents within its communication area cannot connect their smartphone to the station. We assume this setting because power supply facilities installed at base stations are often located at the similar heights. Under the above conditions, the purpose of Scenario A) is to investigate the differences between this system with and without the communication failure emulator under conditions where there is a relatively long time remaining before the flooding starts.

Scenario B) In Scenario B), we set the evacuation information to be published as soon as the flooding starts, and the evacuee agents in the evacuation simulator start moving to the nearest evacuation shelter. The information access rate of the evacuation agents, the time to evacuation, and the communication failure settings are the same as in Scenario A). The purpose of Scenario B) is to investigate the difference between this system with and without the communication failure emulator in a condition where communication failure is more likely to occur.

Scenario C) Then, in Scenario C), approximately 60 minutes after the flood, evacuation information is published and the evacuee agents in the evacuation simulator begin evacuating to the nearest shelter. The information access rate of the evacuation agents, the time to evacuation, and the communication failure settings are the same as in Scenario A). In an actual flood situation, it is unlikely that evacuation information would be published 60 minutes after the flood. However, we will investigate the impact of the communication failure in the setting of Scenario C) to find out how large the impact of the communication failure would appear, if the evacuation behavior occurred after the communication failure.

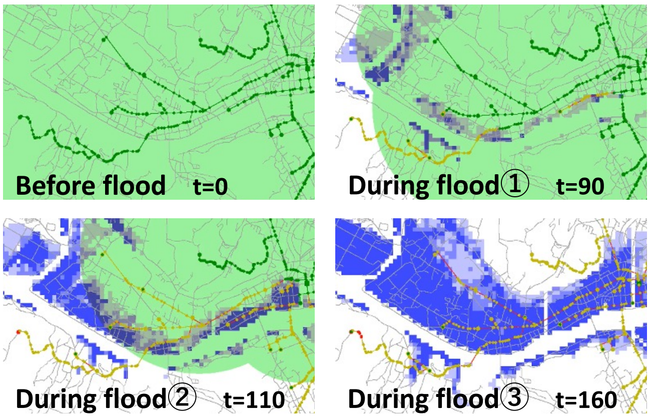

Figure 3: Communication failure

5.4 Result and Discussion

Scenario A) Figure 3 shows the communication failure when we operated a system that uses the federation strategy. The green areas indicate communication available areas. Green dots and lines indicate active base stations and fibers, yellow indicates fibers with downstream base stations that have stopped function, and red dots and lines indicate base stations and fibers that have stopped their function. As the floodwaters spread, the power supply facilities of the base stations are flooded and stop working as well as the area where communication is not possible is expanding.

The 31 base stations became inoperable as the flooding expanded, and the area where communication was not possible gradually expanded. The time series change in the number of evacuee agents that have completed evacuation is shown in Fig. 4. When there is no communication failure emulator, many agents are able to complete the evacuation. Without the communication failure emulator, evacuee agents can obtain evacuation information at any time. Also, their behavior is not affected by the information availability necessary for their movement, such as the evacuation route. On the other hand, with a communication failure emulator, the number of agents who have completed evacuation is reduced by half. The availability of evacuee agents to obtain evacuation information is affected by whether they are in a communication-enabled area, and the probability of obtaining such information decreases after the flood expansion. In addition, if roads on the evacuation route are flooded, alternative route information is not accessible.

In the scenarios with and without the communication failure emulator, shown in Fig. 4, we confirmed that our system would have different numbers of evacuation completed. Since there are many settings that differ from the actual situation, such as flooding phenomena, population distribution at the time of flooding, and communication fiber paths, it seems unlikely that the system was able to reproduce the actual situation of communication failure during a flood, but at least by operating the system including the communication failure emulator, a scenario was created considering the effects of communication failure.

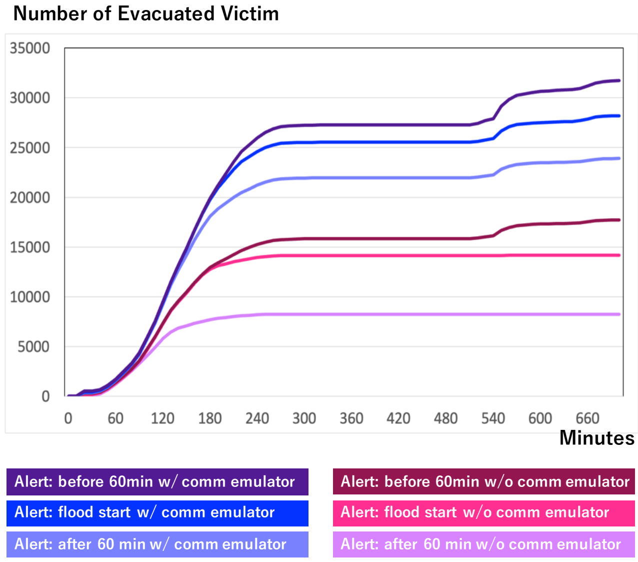

Figure 4: Performance study results

Scenario B) Figure 4 shows the results of the scenario when the evacuation information was published at the same time as the flooding started. Without the communication failure emulator, many agents completed the evacuation. The number of agents who completed the evacuation with the communication failure emulator was lower than that without the emulator, as in Scenario A). The number of agents who completed the evacuation with and without the communication failure emulator was lower than in Scenario A), which changed the announce timing of the evacuation information. We confirmed that different scenarios can be created by changing the setting values in Scenario A) and Scenario B).

In Scenario B) situation, many agents will not be able to receive the evacuation information because communication failures have already occurred when the evacuation information is published. Furthermore, the probability that moving agents will encounter flooding will be higher than in Scenario A). There is also a higher probability that there will be no passable roads left due to flooding at the time of rerouting. Therefore, it is likely that fewer agents in Scenario B) will be able to complete the evacuation than in Scenario A). The above effects could be considered as the impact of communication failure on the victims.

Scenario C) The results of Scenario C), assuming that the evacuation information was published 60 minutes after the flood, are shown in Fig. 4. Without the communication failure emulator, the number of agents who were able to move, among those who received the evacuation information, was the lowest in Scenario C). However, more agents still completed the evacuation than in the case without the communication failure emulator in Scenario A). With the communication failure emulator, in this scenario, a flood spread throughout the city at evacuation information announcements, and communication failures occurred in various locations. As a result, few agents were able to obtain information after the evacuation information was published, and many agents faced difficulties in moving relatively early in the process. This is indicated in the other scenarios, where the number of agents completing the evacuation is constant between 180 and 240 minutes, but in this scenario, it becomes constant at about 120 minutes, with almost no increase in the number of those who complete the evacuation. It would seem that after this time, even if the information was accessible, it would not have led to the evacuation completed because they would not have been able to continue to move. In reality, it is unlikely that evacuation information would be published this late. However, when evacuation information access is delayed for some reason, as in the case of disaster victims' access to information, and they are unable to move, the impact of communication failures will be greater. This suggests that the more the water damage proceeds, the greater the impact of communication failure will be on the victims.

Discussion We investigated two assessment points in this performance study. The first one is to examine whether this system can create scenarios that consider the impact of communication failures. The second is to investigate whether the system can create multiple scenarios, and in each scenario, what impact the communication failure has on the victims. For the first assessment point, through scenario A)-C), we examined the case with and without the communication failure emulator and found a clear difference in the number of agents who completed evacuation in all scenarios. This difference can be considered to result from the accessibility of information and the behaviors based on this information access with and without the communication failure emulator. Information access affects the triggers for behaviors such as starting an evacuation, as well as the choice of behaviors based on the situation, such as rerouting. We think that the federation strategy allowed us to reproduce such information situations in our system. Although this performance study uses a number of assumptions in its setup, which may differ from the actual number of victims who can complete the evacuation, we believe that we were able to show some differences in the impact of the system with and without communication failures.

Regarding the second assessment point, the three scenarios with different timing of information announcements resulted in different numbers of agents who completed the evacuation. We suppose that this can be described as several different scenarios with different settings. This means that we were able to develop a system that could create multiple scenarios, which we had aimed to achieve. Obviously, in this study, we modified just one setting value and created relatively simple scenario.

In addition, examining the specific behaviors of agents' information access in scenarios A)-C), there were several aspects of information access that were important. The first issue is the access to evacuation information. Communication environments are required if they rely only on smartphones for evacuation information. While information can be accessible while the floodwaters are not expanding, this is not possible in the case a communication failure occurs. If victims search for information by themselves before the floodwaters spread, they can access information, whereas if they are familiar with providing information, this will have a significant impact. As a matter of course, in reality, smartphones are not the only means of accessing information. There are a variety of other means available, such as television, radio, and emergency broadcast system. However, each of these has its own disadvantages, such as the need for a power supply for television and the difficulty of hearing the emergency broadcast system during heavy rain. We consider it necessary to improve our system so that the federation strategy can reproduce the actual information access environment in the future. The second issue is information access for rerouting. In our setting, when flooding occurs, the agents use their smartphones to search for a passable route. If the search fails, the agent stops moving. But realistically, as residents, they already know of other routes (except if the road is flooded or not.). Therefore, they do not need to have a communications environment in order to continue moving. On the other hand, it is considered that other routes could be flooded and that non-resident victims may not have knowledge of the routes. This setup is not exactly realistic, but there are victims for whom this setup is applicable. The system would be able to simulate the likely effects of real-world access to information by changing the setting values in addition to the information announcements.

Finally, our system uses a federation strategy to simultaneously operate a flood analysis simulator, an evacuation simulator, a communication failure emulator, and an information service. This enables us to consider factors that have not been previously incorporated into the simulation, such as communication failures. Meanwhile, we concern that there are difficulties due to the increase in the number of factors. All simulators and emulators require configuration settings, although it is difficult to reproduce flood flows, the population distribution during a disaster, the communication environment, and information systems in a precise manner. While some accuracy is necessary, we believe that a perfect setup and reproduction of reality is difficult to achieve. Therefore, we would like to use this system not to perfectly reproduce the real disaster situation, but to output the likely impact on victims and infrastructure, and to derive countermeasures to address the situation. This performance study does not reproduce past disasters, using the data available as setting values. However, the impacts on victims' information access identified in this study could well occur in the real situation. We believe that our next challenge is to improve our system in order to simulate these potential impacts.

6 CONCLUSION

This paper proposed a system that uses the federation strategy to create scenarios that include the impact of communication failures during floods. Communication failures caused by power outages and physical damage to communication systems occur frequently during floods. Physical failures are considered to have a significant impact on the disaster victims because their recovery requires physical system relocation. Particularly in disasters such as floods, where damage spreads gradually, it is relevant to the accessibility of information to the disaster victims before and during the disaster. Therefore, it is important to consider strategies including communication failures in providing and obtaining information.

This paper focused how the occurrence of such communication failures affects the access to information for disaster victims during a disaster. We develop a system to create scenarios that simulate communication failures by using our federation strategy, which allows multiple simulators to be implemented in a cooperative manner. Using this system, we confirmed that it is possible to generate multiple scenarios (optimistic scenarios and worse scenarios) related to communication failures.

Our system can simulate and analyze human impacts from disaster phenomena simultaneously with information service technology. It consists of multiple simulators operating in a cooperative manner. Four simulators / systems (flood analysis simulator, evacuation simulator, evacuation route service system, and communication failure emulator) exchange data with each other considering their operation timing, and progressively compute their own simulations using data from other simulators. The incorporation of multiple factors into a simulation model requires complex and massive development efforts, although our federation strategy allows for the cooperative implementation of these multiple simulations. It can also be expected to be used as a mechanism for evaluating the accuracy and usefulness of the information service in a disaster situation.

After we developed four simulators / systems, we generate scenarios of communication failures during floods. Creating scenarios, we used data of the Kuma River flooding that occurred on July 4, 2020 in Hitoyoshi City, Kumamoto Prefecture, Japan. We set actual mobile base station locations within Hitoyoshi City up in our communication failure emulator. Four simulators/systems were simultaneously operated to simulate flood water value by the flood analysis simulator and to simulate the accessibility of information by the evacuee agents generated by the evacuation simulator. Using the scenarios, we confirmed the possibility of creating multiple scenarios and analyzed the effects of communication failures from the viewpoint of disaster victims.

This paper confirms that our system is capable of creating multiple scenarios. Our goal in the future will be to analyze in more detail the relationship between communication and behavior of disaster victims. Especially key to this analysis will be the extraction of worse cases that have occurred in previous disasters, as well as cases that have not occurred so far but could occur. We plan to develop a method for extracting these cases, and to develop more practical means of access to information for evacuees so that their behavior can be simulated more closely to actual situations.

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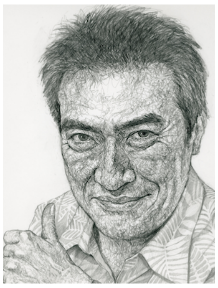

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