# Using Agent Simulations to Evaluate the Effect of a Regional BCP on Disaster Response

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The 2016 Kumamoto earthquake caused severe damage to economic activities and livelihood of residents by disrupting the supply chains of common resources, such as food, water, roads, and other infrastructure. This disaster has made recovery difficult for businesses in the region. The importance of addressing BCP in regional areas was made clear by the 2004 Niigataken Chuetsu earthquake and the 2007 Niigataken Chuetsu-oki earthquake. The 2011 Greate East Japan earthquake revealed that individual business continuity efforts were interrupted by disruption of common infrastructure. Therefore, a new concept of a regionwide business continuity plans (BCP) that focuses on collaboration among stakeholders, including private corporations, local government, and communities, was urgently required to enhance the resilience of the region against disasters. A new concept of Area BCP was proposed by JICA and Prefectural-scale District BCP was formulated by prefectural governments of Kyoto and Kagawa.

In order to evaluate the effect of the presence of a regional BCP on disaster response, this study focuses on one of the most important elements of a regional BCP: the disaster relief chain information-sharing factor. Based on the supply of relief goods from the distribution center in Tosu City, Saga Prefecture to the evacuation centers in Kumamoto Prefecture during the Kumamoto earthquake, the evaluation was conducted by quantitative analysis using agent simulations of relief logistics.

**Keywords:** regional BCP, emergency relief logistics, quantitative evaluation, agent simulation

## 1. Introduction

The 2016 Kumamoto earthquake caused serious damage to the economic activities and livelihood of residents in Kumamoto Prefecture. The afflicted region was faced with shortages of food, water, and other necessities. After similar experience of disasters in the past, some corporations were able to restore normal operations quickly due to effective coordination with other companies as a part of the companies' business continuity plans (BCP) [1]. However, as seen from recent disasters, a major earthquake not only disrupts the business operations but also disrupts the supply of food and water, roads, and other infrastructures. Damage to the supply of these common resources often affects the speed of business recovery. Therefore, a new concept of a region-wide BCP is urgently required.

There are many previous studies that have addressed different aspects of collaboration among relevant organizations. Minear (2002) addressed the challenges and complexities associated with collaboration in emergency relief [2]. Moore et al. (2003) studied collaboration efforts in previous disaster emergency relief operations and assessed the key factors that led to the failures or successes of these efforts [3]. In 2013, Japan International Cooperation Agency (JICA) proposed such a concept of BCP in collaboration with stakeholders, such as private corporations, local governments, and communities, in order to enhance the resilience of the region against disasters [4]. Baba et al (2015) evaluated the applied process of Area BCP/BCM and its benefits though a case study [5]. Prefecture -scale District BCP/BCM which is similar to a concept of Area BCP was developed by Kyoto Prefecture and Kagawa Prefecture respectively in 2013. Ono and Watanabe (2017) addressed that the effort of individual organization can be decomposed into the activities on a specific area, such as "supporting public infrastructure" and "supporting community and residents" and activities focused on an organization's business strategy, such as "requirement form customer," "CSR point of view," and "competitiveness" and that the efforts of organizations to become resilient can be measured by considering the expenses and investments in activities aimed at both the purposes [6].

There are also other studies that elaborately describe the actual state of emergency relief logistics after the 2016 Kumamoto earthquake, and those studies also summarize the effective methods for role-sharing and resource utilization according to the characteristics of various private business operators/organizations [6, 7]. However, the previous approaches lacked quantitative analyses and evalua-



Fig. 1. General state of relief logistics during Kumamoto earthquake.

tion of the information-sharing factor in emergency reliefchain collaborations.

Therefore, using quantitative analysis of the agent simulation of relief logistics, this paper focuses on the effect of a regional BCP on disaster response. Using AnyLogic software package, this study adopts Geographic Information System (GIS) networks and agent simulation method. A model of an emergency relief supply chain is built to predict the performance of a relief logistics system under various conditions and according to the actual state of relief logistics in the 2016 Kumamoto earthquake. In this paper, the results of various simulations are compared with each other based on the conditions in emergency relief chain. The difference in the delivery time and compliance of supplies prove that the information-sharing factor in emergency relief chain collaboration is an indispensable and important part of relief operations.

# 2. Supply of Relife Goods in 2016 Kumamoto Earthquake

# 2.1. General State of Relief Logistics in Kumamoto Earthquake

After the first strike of the killer earthquake, primary deliveries of relief supplies to the Tosu distribution center were discharged from municipalities and manufacturers throughout Japan. Secondary deliveries were made from the Tosu distribution center to the evacuation centers located in Kumamoto Prefecture, as shown in Fig. 1. For the municipalities in the affected areas, the procurement and transportation of relief supplies, such as water, food, and blankets, were the primary tasks. Such special tasks including primary deliveries and secondary deliveries are performed only during emergencies. Since the number of facilities (such as warehouses and forklifts) for effectively procuring and transporting goods and the number of specialists in emergency relief logistics are insufficient, it is extremely difficult for an affected municipality to implement these tasks without any help.

# 2.2. Problems in Relief Logistics During the Earthquake

Because all three of the Kumamoto prefecture's logistics bases for relief supplies were damaged by the Kumamoto earthquake, Nippon Express and Yamato Transport, which are experts in logistics, replaced Kumamoto Prefecture as a distribution center, and push-type distribution of relief supplies was conducted. The function as a logistics base is not satisfied unless space for loading, forklift, pallet storage, cargo handling worker, transportation truck are all available. In that sense, it can be said that the supply of relief goods was made successful by the specialist in logistics hit this mission. Also, although the government temporarily instructed the Self Defense Force to replace Nippon Express, the role was returned to Nippon Express because it could not satisfy the function mentioned above.

According to the interview conducted by the authors at Tosu branch of Nippon Express, the outline of secondary delivery is as follows. 80 thousand rice balls entered each day. Because most of supplies arrived on solid stack on a truck, workers handed down them from the truck, put them on a pallet, and loaded them to another truck with a forklift. Nippon Express had 30 cargo handling workers in the sorting. Each truck picked relief supplies up in the morning and came back in the evening. Nippon Express received mobile phone numbers of evacuation officials in each municipality from the Cabinet Office and contacted the officials every morning to grasp the necessary supplies. While the places to deliver relief supplies were not clear, they tried to deliver relief supplies to places that need supplies and brought the rest back. As a result, they had to dispose two containers of supplies every day.

They needed road information in order to enter the relief supplies bases, evacuation centers, but they could not know where they could pass. It is necessary to investigate in advance whether 4t trucks will enter or not. When traveling on Kyushu Expressway, Police guided Nippon Express cargos from Hirokawa Interchange to Mashiki Interchange. From there the Kumamoto Prefectural Police guided them, so the Nippon Express vehicles were able to arrive at the site in about 3 hours. On the other hand, the Self Defense Force took seven hours.

Even in the disaster, it is important to consider supply of relief supplies as part of logistics and carry the necessary quantity to the necessary place where necessary. However, in the Kumamoto earthquake, the primary and secondary delivery flowed relatively well, but the last one mile from the municipal relief supplies base to each evacuation center became a bottleneck. In the local logistics companies in Kumamoto, there were cases in which the driver's home and family were affected, and the delivery service became impossible, even though trucks did not suffer.

Yamamoto (2017) summarized the issues to be considered in logistics of relief supplies as follows. First of all, it is important to eliminate anxiety in afflicted areas at the initial stage. Therefore, even if there is no information and it is not possible to grasp the situation in afflicted area, regardless of whether there is a request from the affected area, we must secure a transportation route and supply



Fig. 2. Form of provision of relief goods (after the flow chart from Udagawa [8] was corrected by the authors).

goods for life support. In the next stage, it is important to focus all their know-how, such as aggregating all information and participating in distribution business operators, and do their best. When emergency where emphasis is placed on efficiency such as storage and sorting beyond normal times, it is desirable to divide roles for each group called professionals [7].

Since the Great East Japan Earthquake, large efforts and plans to improve the delivery of relief supplies have been made at the national level; however, at the prefecture level, there is still a great need for a more concrete clarification of how a logistics system of transporting goods from terminal distribution to evacuation centers could serve a disaster area. In addition, the participating agencies are mainly logistics-related private enterprises and organizations, such as warehouses and truck associations, as well as home delivery, manufacturing, and distribution companies. There is still an insufficient effort for cooperation to create a more effective logistics system [4].

## 2.3. Actual States of Relief Goods and Delivery Routes

## 2.3.1. The Features of Relief Goods

Relief supplies provided by municipalities to victims during disasters include diverse items, such as water, meals, daily materials (e.g. blankets and diapers), and other expendable items commonly used at evacuation centers. Relief supplies can be roughly divided into two categories: "daily delivered food," such as lunch boxes and rice balls; these items do not have long shelf lives; and "general merchandise" that have long shelf lives considering the expiration dates and the commercial flow. In the logistics of daily delivered goods, temperature control is indispensable to a distribution center, and prompt delivery is required for logistics organizations.

### 2.3.2. Forms of Procurement and Provision of Relief Supplies

As shown in **Fig. 2**, from the perspective of afflicted local governments, there are four main ways of providing relief goods to the affected citizens [4]. The first method is the provision of already available stockpiled goods from the warehouses; this provision is usually done by the afflicted municipality.

The second form is "push-type support," which may be given shortly after the occurrence of a disaster. Regionalwide administration, such as the central government, provides necessary relief supplies to the afflicted area before receiving any requests for aid from the afflicted municipality. Push-type support has the following advantages: First, since governments usually take a long time to organize and process the needs of the residents of an afflicted area, the implementation of push-type support would save much time; secondly, the supply of goods by the below mentioned pull-type support may be insufficient, but push-type support could ensure the sufficient provision of necessary materials to the residents immediately after a disaster.

The third form of provision is called "pull-type support." As time elapses after a disaster, procurement based on orders becomes restored to a certain extent. With time, this kind of support will become more frequent than the other kinds of support. There are many types of relief supplies, such as daily necessities, food, and water. These supplies are produced and delivered by manufacturing and distribution companies. Logistics bases are necessary for the storage and management of large quantities and for multiple types of goods. Since the goods required by the affected people change as time passes, the temporal matching of supply and demand enabled by pull-type support is an advantage that is not available in the push-type support. Therefore, information functions, such as the information about needs and management of inventory, become crucial.

The fourth form is the spontaneous donation of goods by volunteers, such as individuals and private enterprises. The other three forms of support provide necessary information about the availability of relief goods; however, when the donated goods are delivered directly to the affected municipalities without prior communication, information about the goods remains unknown, potentially causing much trouble for the disposal of these donated goods.

## 2.4. Relief Headquarters in Cooperation with Private Business Operators and Organizations

In the headquarters of a disaster relief department, the information processing functions for relief supplies are divided into five types [8]:

• Information on procurement, such as availability and

quantities of relief goods.

- Information on transportation, such as the number of vehicles required.
- Information processing functions related to warehouse management.
- A need for information function related to collecting and processing requests for relief goods.
- Overall adjustments of distribution and delivery of relief goods.

In any of these types, affected municipalities, private sectors and organizations involved in logistics must share information at both prefecture level and municipality level and operate efficiently. In order to realize this information linkage, it is necessary for private sectors and organizations to participate in disaster countermeasure headquarters of affected prefectures and municipalities. In particular, the comprehensive and overall coordination on relief supplies in the prefecture's disaster countermeasures headquarters is important, and the construction of a system for delivering goods directly from the secondary delivery base to evacuation centers is effective. Also, as suggested by Suzuki (2012, 2016), it is clear that an information system that all stakeholders can share various disaster information including relief supplies from evacuation centers through logistics bases is necessary [9, 10]. Thus, disaster relief chain information-sharing is the major factor governing relief operations.

# **3. Regional BCP and Conditions of Simula**tions

# 3.1. Definition of Regional BCP

BCP refers to any effort that aims to achieve business continuity by doing whatever is necessary to protect a company's production, information, equipment, and employees [1]. However, from the recent disasters, we have learned that there would be a disruption of energy supplies, roads, and other infrastructure when a major earthquake occurs. Damage to the supply of these common resources often affects the speed of business recovery. Therefore, the efforts of private sectors, even with a wellprepared BCPs, is far from sufficient to restore normal levels of business operations. Therefore, a new concept of region-wide BCP is urgently required. In 2013, JICA has proposed a new concept of regional BCP. The regional BCP designates a direction and outline of collaboration to mitigate the damages, and it also ensures in providing continuous necessary strategy to the stakeholders who are united in the region for effective business recovery [4].

# 3.2. Necessity of Regional BCP

At the time of disaster, enterprises in a region are affected along with the communities. However, each enterprise is one of the members constituting the local com-



Fig. 3. Definition of regional BCP.

munity, and they benefit from external resources, such as social infrastructure and environment.

In the context of regional BCP, the term "external resources" includes energy (electricity, gas, etc.), water (supply, sanitary, and sewerage), transportation (roads and railways, ports, harbors, airports, etc.), food, medical supplies, logistic services, and accommodation.

The purpose of vital external resources management is to ensure the availability of the resources and share them effectively among the stakeholders when a disaster strikes. Unlike internal resources, such as buildings, facilities, and equipment, external resources are usually controlled by public organizations and are not managed by private sectors. The distribution of these external resources is not only for the purpose of restoring and maintaining business operations but also for ensuring the continuity of basic operations of local communities and the livelihoods of residents. Therefore, when an emergency imposes limited allocation of these resources, collaborative efforts are required among the private sector, public sector, and local community to maintain the supply of critical external resources, as shown in **Fig. 3**.

Under various scenarios of disaster and changing situations, region-wide management can flexibly enlarge the scale of management. Thus, collaboration between the private and public sectors is the essential framework of a region-wide disaster management system.

# **3.3. Relationship Between Actual States and Conditions of Simulations**

As one of the most critical procedures of regional BCP, emergency relief chains include local governments, relief organizations, military forces, and private companies. When a major disaster strikes, no single organization has sufficient resources to deliver relief by itself. During the Kumamoto earthquake, supplies were provided from all over the country to the afflicted areas but were difficult to deliver to the evacuation centers. It has been pointed out that the main cause was not the shortage of the number of goods but the problem of transporting them from distribution centers in the Saga Prefecture to the evacuation centers in the Kumamoto Prefecture. There is a huge necessity for strengthening among logistics compa-



Fig. 4. Actual state and condition of simulation of relief supply chain during the Kumamoto earthquake.

nies, and its reason and remedies are presented herein. At the prefecture level, it can be said that there is a high need for more concrete clarification of how a logistics system can transport supplies from terminal distribution centers to evacuation centers.

In this study, "pull-type support" form of providing relief goods is taken into account for examination. The disaster-afflicted municipalities of Mashiki Town and Nishihara Village in Kumamoto Prefecture request necessary supplies from the distribution center in Tosu City, Saga Prefecture. As time passes, more and more procurement is based on orders, and pull-type support becomes more frequent. Relief supplies provided by manufacturing and distribution companies range from food to other daily necessities. The types of food delivered by pulltype support are more diverse than those by push-type. The direction of effort is toward meeting the demands of the residents. Therefore, information functions, such as information about the afflicted communities' needs, and inventory management become important.

Relief supplies provided to victims in the event of a disaster include a diversity of items, such as water and meals. "Daily delivered foods," such as lunch boxes and rice balls, do not have long shelf lives and should be processed quickly. Likewise, prompt transportation and de-livery are critical. Therefore, transportation information on road conditions, such as road closures and traffic jams, becomes vital.

Considering the information processing functions of the departments responsible for relief supplies, in the disaster management headquarters of relevant organizations, the following conditions should be taken into consideration for the simulation: (1) The presence or absence of information-sharing about needs and processing requests for relief goods; (2) The presence or absence of the sharing of traffic information, such as closed roads and traffic jams; (3) Proper overall adjustment among relevant organizations. **Fig. 4** demonstrates the simulation of actual states and conditions of the relief supply chain during the Kumamoto earthquake.

## 4. Simulation Using Anylogic

### 4.1. Agent-Based Simulations

Agent-based simulations are an effective way of simulating the various phenomena in complicated systems. Among the many tools for building agent simulations, AnyLogic was adopted in this study for the following purpose: Using the AnyLogic Process Modeling Library objects, we can model real-world systems in terms of agents (distributors, orders, trucks, etc.), processes (such as sequences of operations typically involving queues, delays, and resource utilization), and resources. The processes are specified in the form of flowcharts, which are widely adopted graphical representations used in various fields, such as manufacturing and logistics. AnyLogic flowcharts are hierarchical, scalable, extensible, and object-oriented, enabling the user to model large complex systems to any level of detail. Another important feature of the Process Modeling Library is its ability to create very sophisticated animations of process models [11].

One of the greatest advantages of AnyLogic is its ability to combine different modeling styles to capture the complexity and heterogeneity of real-world systems. The Process Modeling Library is an open framework that enables us to combine our process models with system dynamic or agent-based models [11]. Taking into account parameters such as delivery time and compliance of supply content, this simulation model combines the Any-Logic GIS network and a discrete-event model to predict the performance of an emergency relief logistics system. The AnyLogic GIS space function allows us to place agents into a geospatial environment defined by an online GIS map. GIS space support has abilities to set and remove the current locations of agents; these abilities help us make the agents move at specified speeds from one place to another, execute actions upon the arrivals of the agents, animate the moving or static agents at their locations, and establish links based on the layout of the agents.



Fig. 5. Framework of simulation model.

## 4.2. Conception of Simulation Model

## 4.2.1. Basic Simulation Model Design

This study builds a model of an emergency relief supply chain to predict the performance of a relief logistics system under various conditions based on the actual state of relief logistics during the Kumamoto earthquake. The supply chain model includes one distributor agent located in Tosu City, Saga Prefecture, two retailer agents located in Mashiki Town and Nishihara Village, Kumamoto Prefecture, and a fleet of truck agents delivering goods from a distributor to retailers and order agents in charge of necessary relief supplies. Retailer agents are able to generate order agents and send demands to the distributor agent through the order agents. The order agents possess necessary information on relief goods. The distributor agent receives, processes, and passes on the orders to truck agents, who move on the real roads between the origin and the destinations of the supply chain, as shown on a map. Here, a truck agent stands for a combination of a truck and a driver. Fig. 5 illustrates the framework of the simulation model.

In this study, the relief logistics system simulation model was built using Process Modeling Library objects in terms of agents, process, and resources. The processes of simulating the logistics system are specified in the form of flowcharts, and they can be extended to any depth with custom functionality, as shown in Fig. 6. The flowcharts define the order processing on the distributor side, including the process of receiving orders, sending orders to trucks, and defining truck deliveries. Additionally, the ability of AnyLogic to combine different modeling styles to capture the complexity and heterogeneity of the realworld systems can be used to our advantage. This simulation requires objects with specific functionalities that are different from those of the Process Modeling Library objects, therefore, other agent types, such as order or truck agents can be created, and by using Enter objects on its interface, then such component will be able to be inserted in the process flow chart of Process Modeling Library objects. For example, for truck agents, statecharts can be used to map the movements of trucks, as shown in Fig. 7.



Fig. 6. Distributors and connections to trucks.



Fig. 7. Flowchart for truck movements.

#### 4.2.2. Description of Simulation Processes

**Figure 8** illustrate traffic situations in simulation model. For the first group of simulations, an evacuation center in Mashiki Town was selected as a destination. Mashiki Village sends a request for 5,000 bottles of water and 6,500 pieces of confectionary bread at 08:00 hr. to the distributor in Tosu. These numbers of supplies were heard from Nippon Express as an amount that can be loaded in 4 ton trucks. The simulations assume the presence of traffic jams and closed roads. Lines A–B, E–F, and E–G represent the road in a normal state, as shown in **Fig. 8**. Truck speed is set as the speed limit for each actual road type, as shown in **Table 1** and **Fig. 9**.

In **Fig. 8**, Line C–D shows a road with a light traffic jam, and truck speed got reduced to slightly lower than the speed limit. Line B–C represents a road with heavy traffic jam, and truck speed got greatly reduced. Both breakpoints D and F represent the points where road blockages have occurred due to the earthquake. These situations of traffic jam more or less reflect the road situation in the case of the Kumamoto earthquake.

For order requests, two scenarios were set up. In one scenario, the distributor receives orders from a retailer and loads the right goods onto a truck; the truck departs at the right time. In the other scenario, the distributor does not receive any requests from the retailer, so until an actual order is received, the distributor loads the wrong relief goods onto a truck, which departs at the wrong time because foods have to be delivered before their expiration date. Finally, a distributor loads a truck, which departs



Fig. 8. Traffic situations in simulation model.



Fig. 9. Speed limits of road types.

late but with the right goods.

According to the interview to Nippon Express, Drivers basically pass the shortest route. In terms of traffic conditions, the truck departs from Tosu in Saga Prefecture to the affected area. Traffic jams usually occurred along the route for a while after the earthquake. Even if the truck arrives in the affected area, the road blockages are occurred in some places due to the earthquake. Thus, the priorities for route selection by the driver are as follows:

1<sup>st</sup> priority: Select the shortest route.

2<sup>nd</sup> priority: Select a route that has no traffic jam.

3<sup>rd</sup> priority: Select a route that is not closed.

The conditions of the presence and absence of traffic information in the relief supply chain simulation are classified into four types and are organized according to the type of truck, as shown in **Table 2**.

Table 1. Speed limits of road types.

<b>Route Section</b>	Road Type	Speed Limit (km/h)		
J-K (left)	Expression	100		
K-L	Expressway			
I-J		60.80		
J-K (right)	National highway			
K-M	National ingliway	00-80		
K-N				
H-I	Drafactural road	30-40		
N-G	Fletectular Ioau			

Table 2. Priorities for route selection.

Truck	1	2	3	
А	0	0	0	
В	0	0	×	
С	0	×	0	
D	0	×	×	
Necessary traffic information	Shortest route	Traffic jam	Closed road	

For the second group of simulations, another town that (Nishihara Village) requested supplies was added. This group only considers the order request conditions and assumes that the truck driver already knows about the current traffic situation.

## 4.2.3. Simulation Results

Considering the information processing functions of the department responsible for relief supplies sent by the disaster headquarters, ten cases of simulations were conducted. Cases 1 to 8 in the first group of simulations were set up for collecting and arranging requests of relief goods and were also set up based on the presence or absence of sharing traffic information, such as traffic jam information and closed roads information.

Cases 9 and 10 in the second group were set up on the proper overall adjustment among the relevant organizations. All cases and results are summarized in Tables 3 and 4. Table 3 shows extremely large time differences among the first eight cases. For example, in Case 4, the truck arrives at the destination with the right goods in just 2 hours and 20 minutes. On the contrary, in Case 8, the truck departs late by 3 hours from the scheduled time and takes 11 hours and 29 minutes to reach its destination. In cases 5 through 8 where the request of relief supplies was not received, it was assumed that the request arrived 2 hours after the scheduled departure time, relief goods were loaded over 1 hour, and finally the truck departed 3 behind the schedule. Since the time difference between these two cases is more than 12 hours, considering the expiration date of the relief goods, prompt transportation and delivery are found to be critical.

Cases 9 and 10 in **Table 4** were set up under the premise that the truck drivers possess the traffic information. In

Case	Supply Request Received? (Y/N)	Traffic Jam Situation known? (Y/N)	Closed Road Situation known? (Y/N)	Compliance of Supplies	Departure Time	Time to Destination
1	Y	Ν	Ν	Right	09:06	11 h 29 min
2	Y	Ν	Y	Right	09:06	7 h 50 min
3	Y	Y	Ν	Right	09:06	2 h 30 min
4	Y	Y	Y	Right	09:06	2 h 21min
5	N	Y	Y	Right	12:06	2 h 21 min
6	N	Y	Ν	Right	12:06	2 h 30 min
7	N	N	Y	Right	12:06	7 h 50 min
8	Ν	Ν	Ν	Right	12:06	11 h 29 min

 Table 3. Results of Case Group 1.

**Table 4.** Results of Case Group 2.

Case	Mashiki Town Supply Request Received? (Y/N)	Nishihara Village Supply Request Received? (Y/N)	Traffic Jam Closed Road Known? (Y/N)	Compliance of Supplies to Mashiki Town	Compliance of Supplies to Nishihara Village	Mashiki Town Departure Time (Time Required)	Nishihara Village Departure Time (Time Required)
9	Y	Ν	Y	Right	Wrong	09:06 (2 h 21 min)	unloading (4 h 34 min)
10	Y	Y	Y	Right	Right	09:06 (2 h 21 min)	9:06 (2 h 47 min)

Case 9, the distributor only possesses information about the needs in Mashiki Town, while in Case 10, the distributor possesses this information about both Mashiki Town and Nishihara Village. In Case 9, the correct goods are loaded onto the trucks going to Mashiki Town, while the wrong goods are loaded onto those going to Nishihara Village. In Case 9, the truck arrives and unloads the goods at Mashiki Town, and then, leaves for Nishihara Village with the wrong goods. In contrast, in Case 10, two trucks depart separately. One truck travels directly to Mashiki Town, while the other travels to Nishihara Village without stopping and unloading at Mashiki Town. As a result, in Case 10, the latter truck takes almost 2 hours more than it does for in Case 9 to complete the same task. Furthermore, in Case 9, the wrong goods (i.e., unrequested goods) are delivered to Nishihara Village. Table 3 reveals that it is extremely important that the overall adjustment be accomplished by smooth informationsharing among the relevant organizations in charge of the relief supply.

# 5. Concluding Remarks

This paper focuses on one of the most important elements of a regional BCP – the information-sharing factor in disaster relief goods supply chains – in order to evaluate the effect of the regional BCP on disaster response; this effect of the regional BCP on disaster response was evaluated by conducting a quantitative analysis that uses an agent simulation of relief logistics from the distribution center in Tosu City, Saga Prefecture to the evacuation centers in Kumamoto Prefecture based on the actual states of relief goods supplied during the Kumamoto earthquake. The conclusions obtained are summarized as follows:

- (1) The relief logistics system based on its actual state during the 2016 Kumamoto earthquake can be modeled using AnyLogic Process Modeling Library objects, such as agents, processes, and resources. The feature of AnyLogic to combine different modeling styles to capture the complexity and heterogeneity of real-world systems proved useful in constructing the simulation model for this study.
- (2) The time difference with and without informationsharing among the relevant organizations in charge of relief supply is more than 12 hours. Since the relief goods had short expiry time, prompt transportation and delivery are found to be critical.
- (3) Overall adjustment carried out by smooth information-sharing among the relevant organizations in charge of relief supply is extremely important.
- (4) The presence of a regional BCP enhances smooth information-sharing and proves to be critical in relief supply chains as countermeasures against large disasters.

Logistics is playing an extremely important role in emergency response in the event of a disaster. In this study, we focused on only onshore truck transport, but as railroad, aircraft, helicopter, ship etc. are added, different supervisory ministries and various industries are involved in relief logistics operations. In addition, prefectures and municipalities are unfamiliar with unusual crisis management. Thus, the larger the scale of the disaster, the more surely the problem will be exposed in the relief supplies logistics.

As a case where the overall adjustment function was demonstrated, in this study, logistics was carried out by experts, sharing of traffic restriction & jam information, information of relief supplies required in evacuation centers, and distribution of relief supplies was conducted directly to the evacuation center from the prefectural distribution center. In order to realize this situation, it is essential that each stakeholder resides in the head office as a member of the prefecture's disaster countermeasure headquarters, and information sharing of various stakeholders through the information system is carried out.

In order to enhance Public-Private Partnership [12] in the disaster, it is necessary for Public-Private Partnership in ordinary business to be carried out. As a result, it is desirable that private sectors are widely recognized from society not only from the viewpoint of CSR but also the role serving as designated public bodies supporting prefectures and municipalities.

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#### **Selected Publications:**

• T. Suzuki and X. Hao, "Verification of the Effect of On-Site Damage Report using Smartphones on the Efficiency in Disaster Response Operations," Procs. of the Society of Social Safety Science, No.16-1, pp. 85-93, 2018 (in Japanese).

• T. Suzuki, T. Miyamoto, and Y. Hada, "Application of the BECAUSE Model to Establishment of a Collaboration System with Relevant Administrative Agencies for Regional Evacuation due to Large River Flooding," Procs. of Disaster Information Studies, No.14, pp. 105-115, 2016 (in Japanese).

#### Academic Societies & Scientific Organizations:

- Japan Society for Disaster Information Studies (JSDIS)
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