Journal of Natural Disaster Science, Volume 37，Number 1，2016，pp11-33

Inter-ward, Risk-diversified Allocation Model for Storing of Disaster Relief Goods

Tetsuro Kajihara[1], Muneta Yokomatsu[2], Hideyuki Ito[3], and Wisinee Wisetjindawat[4]

[1] Japan Railway Central,

[2] Disaster Prevention Research Institute, Kyoto University,

[3] P&I Logistics,

[4] Nagoya Institute of Technology,

(Received Apr 30, 2015 Accepted:Jun 16, 2016)

Abstract

This study focuses on the concept of an inter-ward, risk-diversified spatial allocation model for the storage of relief goods to reduce the cost of the relief goods policy. The study proposes the model, and shows the feasibility and efficiency of the suggested logistics policy by applying it to a case study of the Shonai River, Nagoya City. The simulation results show that one day's worth of stocked relief goods in each shelter is sufficient for sustaining all evacuees for three days in any disaster scenario, and reduces the total costs of the relief goods policy. The study further illustrates the applicability of the model to wide-area disasters.

Key words Disaster, Relief Goods, Humanitarian Logistics, Shelter

1. INTRODUCTION

Evacuation has been one of central issues of humanitarian disaster management in the aftermath of large disasters. Not only behaviors for escaping from hazard, but, by extending the focus to a period of several months after a disaster, improvement of quality of lives in shelters such as public schools and community centers has recently been investigated. While awareness of the necessity of various sorts of goods in shelter life, not only public provision but voluntary supplies of goods, has increased in these several decades, this sometimes even causes confusion when on-site coordinators classify and allocate those goods to evacuees in need. Matching methods of treating goods and evacuees with various needs and preferences are expected to be improved.

Focusing exclusively on a period of several days after the occurrence of disaster, the relief goods problem is characterized in a somewhat different way: we should consider disruption of transportation while the list of necessary goods is shorter because it is a period where evacuees concentrate on surviving and, for that purpose, necessary goods are in large part common and include water, foods to intake calories, blankets, and so on.

The Cabinet Office, Government of Japan, suggests that society should stock sufficient relief goods to sustain the assumed numbers of evacuees for at least three days after a disaster (Cabinet Office a). Considering the suggestion, many local governments recognize that each local government should guarantee that all evacuees can survive for three days with relief goods stocked within the jurisdiction. For example, Nagoya City is considering an alternative to stocking three days' worth of relief goods in its storehouses for the estimated number of evacuees, which amounts to four million meals, which is a huge number to manage and is associated with high costs.

Compared with other risks like traffic accidents and diseases, disaster risk is characterized as a collective risk, meaning that it brings damage simultaneously to many people in an affected area. However, some disaster risks are more localized, considering inherent geographical characteristics. For example, a dike of a river usually breaks at one point because the breakpoint releases water pressure, which results in flooding of only one side of the river basin and deep inundation in the area close to the breakpoint. If communities on the other side of the river have goods that are not used by the local people there, they can be transported for the use of evacuees in the affected area. This kind of post-disaster procurement could also be applied at the inter-city (or municipality, village, etc.) level, since no relief goods stock is touched in the unaffected area.

As a matter of fact, many relief goods are often transported from unaffected to damaged areas after a disaster. Some local governments in Japan create agreements with private companies or other local governments, although these mutual assistances are not accounted for in their planning for relief supplies in many cases, meaning that each local government does not recognize the cooperation by other organizations regarding stocked relief goods. For example, it was found in the authors' interview that, although Nagoya City has an agreement concerning disaster relief activities with the Associated General Constructors of Nagoya City, the city government itself tries to stock three days' worth of relief goods for the estimated number of evacuees. One of the reasons behind this is that the city government cannot realize the feasibility of external support in the aftermath of disaster, and thinks that it is responsible for guaranteeing three-day survival by its own stocks. Hence, our proposal of the model must be associated with a demonstration of feasibility. We deal with a case study with actual data and reveal some quantitative results.

Recently, the issue of humanitarian logistics has attracted attention, and some literature provides academic review, lists essential factors, and tries to structure them to characterize this new academic area (e.g., Kovács et al., 2011). Mathematical models such as application of linear programming and others have been developed mainly in the area of operations research with focuses such as the decision-making problem of helicopter logistics (Barbarosoğlu et al., 2002), a multi-commodity and multi-nodal framework (Haghani et al., 1996), coordination of transportation of commodities and wounded people (Yi et al., 2007), disaster-affected area grouping and relief co-distribution (Sheu, 2007), and so forth. In other areas like logistics and disaster management, quantitative studies are relatively new, and include focuses such as strategic pre-positioning of relief supplies (Balcik et al., 2008; Duran et al., 2011), optimal inventory control under uncertainty (Beamon et al., 2006), relationship between operation costs and fund-raising (Wakolbinger et al., 2011; Toyasaki et al., 2014), and so forth. A lack of inter-organizational cooperation and coordination is pointed out in various articles and practitioner reports (Thomas et al., 2007; van Wassenhove, 2006; Oloruntoba, 2010), while several methodologies are developed such as the "service provider approach" (Schulz, 2010) that is applied to the international horizontal cooperation scheme of the UN Humanitarian Response Depot (UNHDP). A multi-agent simulation model is also developed to describe the collective performance of complex humanitarian response systems in the case study of the UNHDP system (Mochizuki et al., 2015).

We share the idea of horizontal cooperation with the preceding studies above, while we point out the layered structure of the network-based stock policy: inter-ward and inter-region. Moreover, we follow a Japanese context, whereby relief goods policy is constrained by the condition that the relief goods should be provided to all evacuees for three days after disaster under any damage scenario that can occur. Furthermore, in a case study of the Shonai River, Nagoya City, we apply the results of a flood simulation of the Shonai River developed by the Shonai River Office, to identify hazard, the results of Ito et al.

(2015) who define a list of necessary goods for three days with their volumes and prices, and actual values of parameters related to shelters and transportation in Nagoya City. We explicitly deal with the cost minimization problem, where the objective function is the total cost of the relief goods policy defined as the sum of the cost of stocking relief goods and the cost of transportation. With verification with quantitative results, we aim to provide helpful knowledge for local people and those responsible for relief goods policy.

The remainder of the paper is organized as follows. Section 2 introduces basic ideas and key concepts of the study based on interview surveys. Section 3 sets up a model and identifies areas of the case study. Section 4 conducts numerical simulation and derives implications. And Section 5 concludes and suggests future research directions.

2. FOCUS AND CONDITIONS FOR RELIEF GOODS LOGISTICS

2.1 Problems Observed in Past Disasters

After the Chūetsu Earthquake that occurred in Japan in 2004, some shelters lacked relief goods, while others had a surplus (Cabinet Office a, 2007). Photo 1 was taken in a school gym, which was used as a distribution center for relief goods, seven days after the earthquake (*Mainichi Newspaper* a, 2004). As is evident, a large volume of relief goods was transported to the school gym; however, these were not well managed: the quantity of relief goods was too large, the packing styles of relief goods differed, and the delivery included unwanted relief goods. Most relief goods shown in Photo 1 were wasted and disposed of. A similar problem occurred during the Hokkaido Earthquake in 1993. Unwanted relief goods weighed more than 1,200 tons, which cost 120 million yen to dispose of. In contrast, in both earthquakes, some shelters experienced a shortage of relief goods, which could not be transported and delivered consequent to severely damaged roads.

Photo 1. Distribution Center (Source: *Mainichi Newspaper*, 2004)

In the case of the 2011 Great East Japan Earthquake, many shelters lacked relief goods following widespread fuel shortages and a badly functioning truck transportation system (Japan Trucking Association, 2012). Relief goods in short supply included powdered milk, diapers, and allergen-free foods. Diverse evacuees and types of stocked relief goods should be considered.

The "Great East Japan Earthquake report" of the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) describes relief goods as follows (MLIT, 2011):

"To transport relief goods, we tried using large-capacity ships or helicopters with high mobility.

However, we could not implement these methods, because of bad weather and the difficulty in securing trucks from a port or airport to the relief goods supply base."

"In this disaster, most relief goods were transported by truck. However, it is necessary to establish a plan that enables us to choose a wide variety of transportation, regardless of the disaster that occurs."

These descriptions imply that unplanned incidences can occur after a disaster. Specifically, Sendai Airport, a relief goods supply base, was severely damaged in the Great East Japan Earthquake. This rendered air transportation impossible, and goods had to be transported by truck. Relief goods should be dispatched immediately; thus, it is necessary to secure a base that cannot be damaged in any disaster. Furthermore, resilient modes of transportation are essential.

On the other hand, the authors visited two places in Tohoku that were used as shelters, Iwate Prefectural Ofunato High School and Ishinomaki Senshu University, and conducted interviews with persons in charge of the shelters at the time. Points of their statements are itemized in the appendix. The following is a summary of their findings on relief goods management.

Iwate Prefectural Ofunato High School:

"Fortunately, the shelter was equipped with some bedclothes, such as blankets. However, they were not enough. Students first distributed these commodities among elderly people, women, and children. The students did not complain about the lack of commodities, as they knew each other before the disaster. Problems might have occurred if they had been strangers."

"The water supply was stopped and evacuees were forced to use residual water in the water tank. Consequently, a lack of water became a concern. Furthermore, they did not know when the water supply would be restored. From two days after the disaster, they left the shelters to search for water, and transported spring water back to the shelter on a cart in plastic bottles. They then used these bottles of water for the toilets. Clearly, the shelters were faced with many problems; however, evacuees managed to utilize the limited goods stocked in the shelter through trial and error."

"There was a surplus of relief goods at the shelter from the second day after the disaster. For example, too many rice balls were transported from other regions, and the evacuees could not eat them all."

IIshinomaki Senshu University:

"Evacuees housed in the shelter ran short of water and made a request to Ishinomaki City to supply it. The next day, too much water was delivered. In addition, a volunteer unexpectedly sent more water to the shelter."

"From three to four days after the disaster, there was enough food and water thanks to volunteers and NPOs. However, baby goods, sanitary goods, pet goods, and cigarettes were in short supply."

"The toilets did not function, and the evacuees had to use portable toilets."

"Relief goods were transported through long-distance transportation within two days of the disaster. The evacuees were able to feel safer and more secure, because they felt connected to other regions. They were surprised at how quickly transportation companies and road networks were restored."

It was pointed out that evacuees could not help to allocate and share goods that they found at the shelters for survival until relief goods were transported from unaffected areas. On the other hand, after the relief goods started to arrive at the shelters, the amounts of some kinds of goods were way beyond those needed.

Considering the above findings, this study proposes a model where basic relief goods that are critically important for surviving for one day are stocked at each shelter and the logistics for redistribution of the goods after the second day are controlled for quantity with a guarantee of mobility. CI model and *ba* are not provided here. This study first describes the networking process as a spiral phenomenon, in which new knowledge is generated by transactions both within a volunteer group and between different organizations. Then, the words of network members and the observed facts are evaluated through the SECI process.

2.2 Classification of Relief Goods and Estimation of Volume

Description of our model of relief goods management starts with identification of necessary goods. Figure 1 identifies three types of relief goods needed during three stages that follow a disaster.

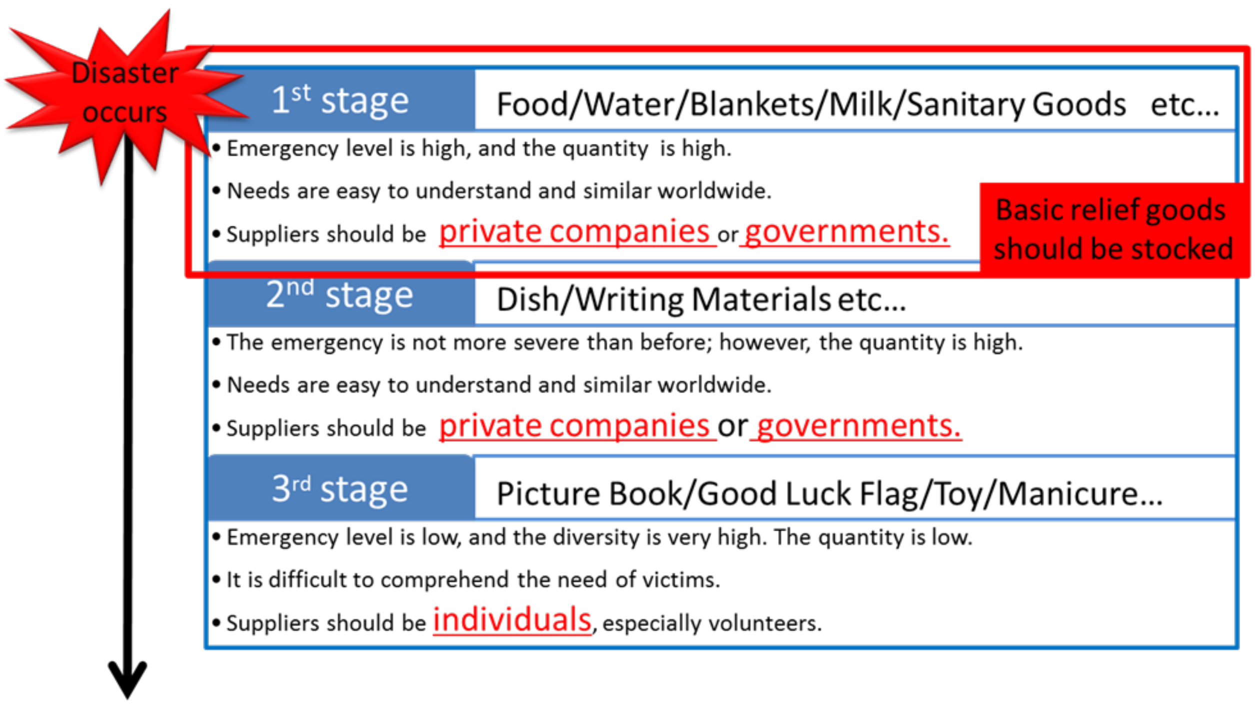

Figure 1. Classification of Relief Goods

The relief goods needed during the first stage can be termed “basic relief goods.” Municipalities have different viewpoints regarding what types of goods should be stocked as basic relief goods, although they do stock similar types. For example, Table 1 summarizes the inventory of relief goods by municipalities in Aichi Prefecture, Japan, which includes Nagoya City (Aichi Prefecture). According to Table 1, biscuits, instant noodles, rice, canned foods, bottles of drinking water, powdered milk, and other foods are stocked. These commodities are classified as basic relief goods. Furthermore, equipment needed to guard the privacy of evacuees, such as toiletries and room partitions, should also be stocked. These relief goods are necessary in terms of protecting the dignity of evacuees. In addition, they are helpful in preventing the spread of diseases in shelters.

Table 1. Inventory of Stocked Relief Goods in Aichi Prefecture, Japan

	Commodity・Equipment															
					Tent			Toilet (item)								
	Baby's Bottle (item)	Candle (item)	Flashlight (item)	Blanket (item)	(item)	(people)	Stretcher (item)		Portable Toilet (item)	Temporary Toilet (item)	Water Cleaner (item)	Clothes (item)	Under Clothes (item)	Baby's Diaper (item)	Adult's Diaper (item)
Nagoya	3,000	1,350	0	71,000	0	0	22	351,257	350,000	1,257	16	40,360	0	25,320	15,040

Commodity・Equipment								
Sanitary Goods (set)	Blue Sheeting (item)	Towel (item)	Toilet Roll (roll)	Portable gas stove (item)	Generator (item)	Light (item)	Body Bag (item)	Coffin (item)
0	0	0	0	0	0	0	0	0

	Food・Water																
	Staple Food (Meal)	Sort of Hardtack (Meal)	Hardtack (Meal)	Biscuit (Meal)	Instant Noodle (Meal)	Rice (Meal)	Polished Rice (Meal)	Dried Rice (Meal)	Can (Meal)	Dried Food (Meal)	Bread (Meal)	Others (Meal)	Others (Meal)	Drinking Water (L)	Supplementary Food (Meal)	Powdered Milk (g)
Nagoy	392,666	273,885	273,885	0	0	118,781	0	118,781	0	0	0	0	0	0	0	797,200

Tables 1 and 2 show a sample list of basic relief goods. Ito et al. (2015) provides a detailed discussion on a variety of needs based on a variety of attributes such as gender, age group, allergies, and so on. These special needs must differ among communities both in their variety and quantity depending on the composition of the people. Therefore, community members in each community should discuss and determine a list of special types of basic relief goods in terms of quality and quantity.

Table 2. Sample List of Basic Relief Goods

Relief Goods	Blanket	Blanket (baby)	Water	Water (baby)	Food (biscuit)	Powdered Milk	Baby's Bottle	Sanitary Goods	Diaper (baby)	Diaper (adult)	Defecation Bag	Toilet Roll	Bag for Toilet	Simple Toilet Seat	Partition Wall
Supply Unit per 1 evacuee	2.00	1.00	3.00	3.00	3.00	130g	1.00	6.00	7.00	7.00	6.80	0.20	equipment	equipment	equipment

We estimate the quantity of basic relief goods to be stocked like Table 3 below. It is important to estimate the volume because space for storage is not limitless.

Table 3. Calculation of Basic Relief Goods for 1,000 Evacuees per Day

	per 1 day			per 1 package			Total amounts of relief goods stocked in each shelter for 1st day				Total amounts of relief goods transported from other region for 2nd day			
Relief Goods	Percentage	Supply Unit per 1 evacuee	The number of evacuees	The number of relief goods	Size(cm)	Volume(m^3)	The number of relief goods	The number of packages	Volume(m^3)	Percentage	The number of relief goods	The number of packages	Volume(m^3)	Percentage
Blanket	0.99	2.00	990.00	10.00	54*74*33	0.13	1980.00	198.00	26.12	0.73	0.00	0.00	0.00	0.00
Blanket (baby)	0.01	1.00	10.00				10.00	1.00	0.13	0.00	0.00	0.00	0.00	0.00
Water	0.99	3.00	990.00	24.00	24*36*16	0.01	2970.00	123.75	1.71	0.05	2970.00	123.75	1.71	0.34
Water (baby)	0.01	3.00	10.00				30.00				30.00		0.00	0.00
Food (biscuit)	0.99	3.00	990.00	150.00	25*50*38	0.05	2970.00	19.80	0.94	0.03	2970.00	20.00	0.94	0.19
Powdered Milk	0.01	130g	10.00	12.00	32*43*12)/12	0.00	1625g	2缶	0.00	0.00	1625g	2缶	0.00	0.00
Baby's Bottle	0.01	1.00	10.00	40.00	58*60*44	0.15	10.00	0.25	0.04	0.00	0.00	0.00	0.00	0.00
Sanitary Goods	0.06	6.00	60.00	50.00	57*60*43	0.15	360.00	7.20	1.06	0.03	360.00	7.20	1.06	0.21
Diaper (baby)	0.01	7.00	10.00	336.00	60*78*36	0.17	70.00	0.21	0.21	0.01	70.00	0.21	0.21	0.04
Diaper (adult)	0.02	7.00	18.00	104.00	60*78*36	0.17	126.00	1.20	0.20	0.01	126.00	1.20	0.20	0.04
Defecation Bag	0.97		972.00	100.00	11.1*31.7*26.0	0.01	6804.00	69.00	0.63	0.02	6804.00	69.00	0.63	0.13
Toilet Roll	0.97		972.00	12.00	20*20*34.2	0.01	204.00	17.00	0.23	0.01	204.00	17.00	0.23	0.05
Bag for Toilet	1.00		1000.00	2.00	88.5*62*0.25	0.00	61.00	31.00	0.04	0.00	61.00	31.00	0.04	0.01
Simple Toilet Seat			8.00	1.00	38*50*23	0.04	8.00	8.00	0.35	0.01	0.00	0.00	0.00	0.00
Partition Wall				1.00	1.1*1.33*0.09	0.14	28.00	28.00	3.84	0.11	0.00	0.00	0.00	0.00
								Sum	**35.50**	1.00		**Sum**	**5.03**	1.00

Table 3 shows that the volume needed for relief goods for 1,000 evacuees per day is estimated to be approximately 35 m^3. Given that the height of the shelter is 2 m, 17.4 m^2 is needed. Nagoya City assumes about 2 m^2 to be the standard space in a shelter per person, and the space for 1,000 evacuees is 2,000 m^2. Therefore, the space needed to stock relief goods occupies only 17.4 m^2 of 2,000 m^2 in the shelter. The volume of relief goods supplied from the second day after the disaster can be reduced from 35.5 m^3 to 5.03 m^3, since blankets, baby bottles, and room partitions are only distributed on the first day. It should be emphasized that the volume of blankets occupies 73% of the entire volume of all basic relief goods. It follows that replacing this blanket with a lighter one increases the space available to store other important goods. The same idea can be applied to other relief goods. For example, candy is high in calories and low in volume; therefore, as long as safety for small children is ensured, it may be efficient in terms of calories per volume.

2.3 Transportation of Relief Goods

We now consider how to transport relief goods after a disaster occurs. The logistics of damaged areas and unaffected areas differ greatly because of damaged infrastructure. We must also prepare a distribution center that efficiently connects logistics in damaged areas to those in unaffected areas. Figure 2 outlines the logistics regarding relief goods. The figure depicts the “Distribution center,” “Logistics in damaged areas,” and “Logistics in unaffected areas.”

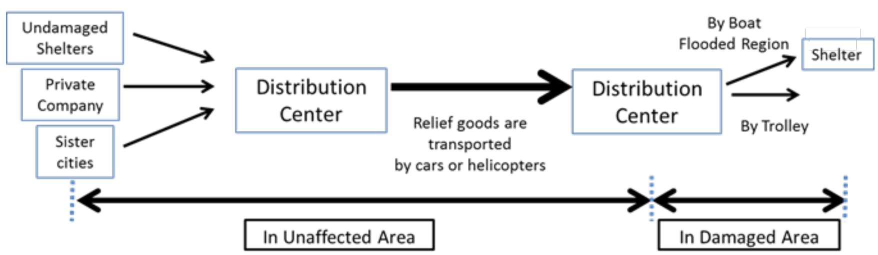

Figure 2. Logistics for Relief Goods after a Disaster

Logistics in unaffected areas remain as they are under regular conditions. Relief goods are transported from unaffected areas to a distribution center soon after a disaster has occurred. If a distribution center is appropriately located, transporting relief goods should not be difficult.

At the distribution center, logistics ensure that relief goods are suitably repackaged for efficient transportation to damaged areas. Goods are transported to appropriate shelters in terms of quantity and quality. These processes should be conducted quickly. In previous disasters, relief goods could not be transported because facilities did not function effectively. In the early stages following a disaster, basic relief goods should be transported especially quickly to ensure the survival of evacuees. This facility must begin working just after a disaster occurs and for 24 hours without interruption.

In damaged areas, infrastructure also gets damaged, rendering it impossible to transport relief goods under normal conditions. Transportation methods appropriate for different types of disasters should be prepared for damaged areas. If we cannot use trucks in a damaged area, we must use bicycles or trolleys. If roads are flooded, we must use boats for transportation. Photo 2 shows an emergency drill in Chiba Prefecture (Chiba City). Trolleys were used to transport goods. Photo 3 shows Nagoya City after the Tokai Heavy Rain. Here, boats were used to transport evacuees and relief goods (*Mainichi Newspaper* b).

Considering the urgency of supplying basic relief goods, helicopters are an effective transportation method. Although helicopters have relatively small capacity, they can quickly transport relief goods to isolated shelters. Thus, we must improve the operation of helicopters and use them efficiently. For example, we should consider ways to reduce loading time and the number of takeoffs and landings and improve methods of supplying relief goods to shelters by helicopter.

The logistical difficulties in damaged areas on March 16, 2011 were reported (*Asahi Newspaper*). A large volume of relief goods was transported to areas surrounding the destination; however, damaged roads made it impossible to transport them to the destination itself.

Photo 2. Utilization of Trollies
(Source: Chiba City Homepage)

Photo 3. Utilization of Boats
(Source: *Mainichi Newspaper*)

2.4 Two Viewpoints regarding Relief Goods Logistics

In the following section, two viewpoints are applied: “non-uniform distribution of disaster damage” and “inter-ward network for storage of relief goods,” based on which we formulate a model to analyze the efficiency of the network stocking policy that we propose.

In Nagoya City, each shelter stocks the same quantity of relief goods. This tactic may be reasonable from an equality viewpoint. However, disaster strikes locally, and the distribution of disaster damage is non-uniform. For example, a tsunami damages low-elevation areas, not elevated areas. Thus, an efficient tactic seems to be stocking varied quantities of relief goods in each shelter depending on the non-uniform distribution of disaster damage.

Some shelters are often short of relief goods after a disaster occurs. In this situation, relief goods are transported from unaffected to damaged areas. Suppliers are various organizations such as volunteers, private companies, or local governments. Moreover, the networks formed by these organizations can help compensate for shortages of relief goods. However, this type of cooperation is seldom considered before a disaster occurs. Here, an efficient tactic is that local governments in certain areas stockpile goods and compensate each other’s shortages when needed.

3. A MODEL SETTING AND PARAMETERS FOR A CASE STUDY

3.1 Nagoya City and the Shonai River

We formulate a model based on the concepts that are proposed in the previous section, and apply it to areas of the Shonai River basin, Nagoya City, Japan. Nagoya City is the capital of Aichi Prefecture and the largest city in Japan’s Chubu region that is located in the center of the Pacific coast of the main island of Japan. As of 2014, the population of the Chukyo metropolitan area totaled 8.74 million people, and that of Nagoya City, 2.27 million. The area of Nagoya City measures 326.43 km^2 (Nagoya City a). The Shonai

River is a Class-1 river flowing through Gifu Prefecture and Aichi Prefecture in Japan's Chubu region. In this case study, the target areas are five wards around the Shonai River: Nakagawa Ward, Nakamura Ward, Nishi Ward, Kita Ward, and Minato Ward. These target areas face a flood risk from the Shonai River.

Figure 3 depicts the eight areas assumed in this case study to be at risk of a dike break along the Shonai River. Furthermore, in this case study, Komaki Airport is assumed to be a relief goods supply base.

Figure 3. Map Depicting Eight Cases and the Supply Relief Goods Ba

We conducted an interview survey in June, 2014, with officers of departments that are in charge of management of disaster relief goods in Nagoya City, who told us that, currently, following the above-mentioned government policy (Cabinet Office c), the Nagoya City government was planning to increase the quantity of meals stocked in its storehouses. It currently assumed that the quantity of meals should be the amount that equals "the assumed number of evacuees" multiplied by "three-day meals per one evacuee." For example, if 400 thousand evacuees stay in a shelter and take meals three times a day for three days, the quantity of meals stored in all shelters will be 3.6 million in total. However, this policy raises various problems. For example, many goods have a shelf life and the space for storage of the relief goods is limited, resulting in an increase in associated costs.

We numerically test our hypothesis that Nagoya City does not need to stock a large amount of relief goods but that local governments transporting relief goods from unaffected to damaged areas seems to be more effective. In this case study, from a cost perspective, we compare two policies: 1) the "Planned Policy," that is, Nagoya City's currently proposed policy; and 2) our proposed "Network Policy."

3.2 Policy on Stocking Relief Goods

If a disaster occurs, evacuees at isolated shelters will have to survive on stocked relief goods until new goods can be transported from other areas. In this case study, based on a flood simulation calculated by the MLIT, we assume that it takes 24 hours for relief goods to be transported from other areas.

The quantity of stocked relief goods at each shelter should exceed the number of assumed evacuees at each shelter. If each shelter stocks this quantity of relief goods, every evacuee can survive for at least the first day, even in the case of flooding. The quantity of relief goods is provided in Table 3.

In severely damaged areas, evacuees may have to stay at the shelter for more than two days after the disaster. Here, relief goods will be transported from an unaffected to the damaged shelter.

3.3 Target Shelters and Number of Evacuees

The number of target shelters is 301 in five wards. These shelters are depicted on Nagoya City's hazard map (Nagoya City b). In Table 4, the second column provides the names of shelters, while the third column gives the capacity of the shelter in Flood Scenario 1. In this case study, we define the capacity of shelters as the assumed number of evacuees for the sake of brevity.

Table 4. Assumed Number of Evacuees, Shelter Type, and Flood Depth in Flood Scenario 1 (Abstract)

Shelter Number	Shelters (anonymous)	Assumed Number of Evacuees	Shelter Type	Flood Depth			
				Peak	6h later	24h later	48h later
1	H elementary school	360	E	0	0	0	0
2	H junior high school	460	D	～0.5m	0	0	0
3	M high school	630	E	0	0	0	0
4	H community center	70	D	～0.5m	0	0	0
5	S elementary school	220	C	～0.5m	～0.5m	0	0
6	N high school	520	C	～0.5m	～0.5m	0	0
7	S community center	70	E	0	0	0	0
8	IB elementary school	320	C	1.0m～2.0m	1.0m～2.0m	0	0
9	I elementary school	350	B	1.0m～2.0m	1.0m～2.0m	～0.5m	0
10	I community center	39	C	1.0m～2.0m	1.0m～2.0m	0	0
11	H junior high school	640	B	2.0m～5.0m	1.0m～2.0m	～0.5m	0
12	D school	1,040	B	1.0m～2.0m	1.0m～2.0m	～0.5m	0
13	N elementary school	240	C	0.5m～1.0m	～0.5m	0	0
14	N community center	60	C	1.0m～2.0m	1.0m～2.0m	0	0
15	N sports center	810	C	0.5m～1.0m	～0.5m	0	0
16	N bicycle racetrack	270	C	0.5m～1.0m	～0.5m	0	0
17	T elementary school	280	C	0.5m～1.0m	0.5m～1.0m	0	0
18	T community center	60	C	0.5m～1.0m	～0.5m	0	0
19	N learning center	470	C	0.5m～1.0m	0.5m～1.0m	0	0
20	Former H elementary school	310	C	0.5m～1.0m	～0.5m	0	0

3.4 Dike Break Point and Flood Depth of Each Shelter

In this case study, four areas are assumed to be dike break points. Furthermore, since each has a left and a right side, eight points are assumed in total. We show them in Figure 3.

We calculate the flood depth of the target areas by using the flood simulation software developed by the MLIT. The software can calculate the flood depth of target areas at 15-minute intervals after the dike breaks. The probability of this type of heavy rain is once every 200 years. A dike break point can be selected from every 1.0 km from the break point along the Shonai River. The size of meshes for calculation is 50 m x 50 m. These calculation results have already been applied to Nagoya City's hazard map.

In this case study, we calculated the flood depth for eight flood scenarios, and used the flood depth for each shelter at four points in time, namely the peak hour, six hours, 24 hours, and 48 hours after the dike breaks. Figure 4 illustrates an example of simulation results for Flood Scenario 5, which shows the flood depth at the sixth hour after the dike break. In Table 4, the fifth to eighth columns show the flood depth of Shelters 11 to 20 in Flood Scenario 1.

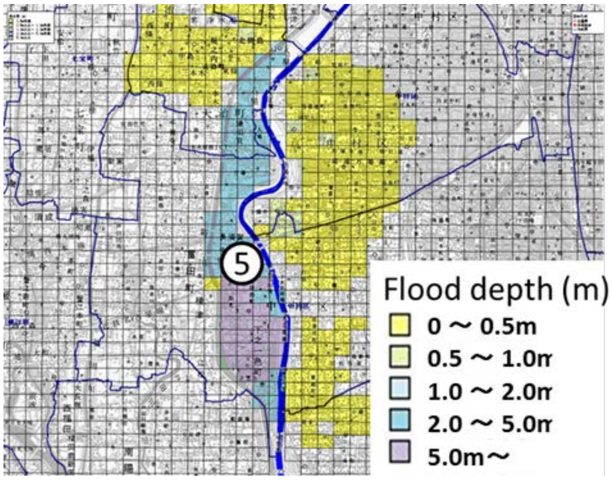

Figure 4. Example of Flood Simulation

3.5 Classification of Shelters According to Flood Depth

Based on the simulation results, we classify the five types of flood impacts as in Figure 5. The severity ranges from Type A (high) to Type E (low). Type-E shelters are not flooded, while Type-A shelters are still flooded 24 hours after the dike breaks. As such, Type-A shelters are the most severely damaged. Also, flood depth will determine whether or not the relief goods stocked in one shelter are to be distributed to evacuees in that shelter.

In Type-E shelters, the stock of relief goods will not be distributed to evacuees, because the surrounding areas are not damaged and citizens do not need to evacuate to a shelter. Thus, Type-E shelters will have surplus stock, and as such, become a relief goods donor.

In Type-C and Type-D shelters, the stock of relief goods at a shelter are to be used itself. Here, citizens will evacuate and stay at a shelter for less than 24 hours after the dike breaks.

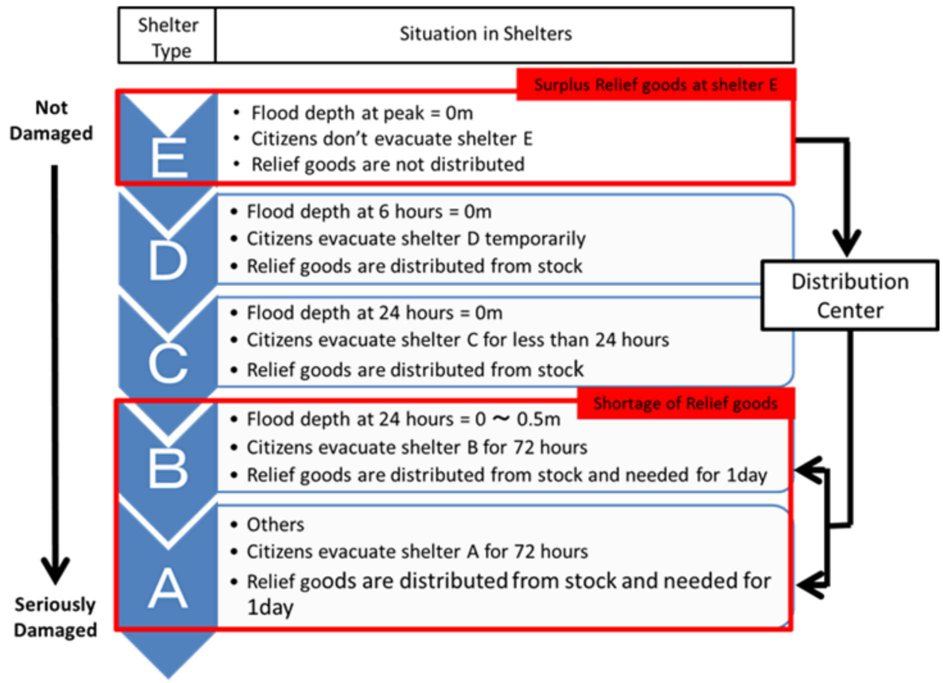

Figure 5. Classification of Shelters

In Type-A and Type-B shelters, the stock (which is prepared for one day) will be used. Furthermore, it is assumed that citizens will evacuate for 72 hours after the dike breaks (Japan Automobile Federation). Consequently, they will need relief goods for two more days (the second and third days after the dike breaks). To compensate for the shortage, goods stored in Type-E shelters can be transported to Type-A and Type-B shelters via a hub. Flooded roads reduce the possibility of reaching Type-A shelters by truck. Therefore, transportation to Type-A shelters should be conducted by helicopter. It is still possible to reach Type-B shelters by truck and, hence, small two-ton-trucks are to be used in order to guarantee accessibility to narrow roads. The type of helicopter is assumed to be the "Bell 204B." In Table 4 above, the fourth column shows the classification of Shelters 11 to 20 in Flood Scenario 1. Notably, the classification was conducted for each of the eight flood scenarios; therefore, one shelter is classified into a different type for each scenario.

4. OPTIMIZATION PROBLEM

4.1 Objective Function

For planning of disaster relief goods, plural possible scenarios of dike breaks in terms of geographical break point should be equally taken into account. In other words, it is not appropriate to determine the policy for storage and transportation by considering only one disaster scenario. We should determine many scenarios as a bundle so that all evacuees can survive in any scenario.

The objective is to minimize total cost, C (unit: yen), which is composed of several types of costs as is illustrated in Figure 6, and represented by the sum of the storage cost of relief goods, CS, and the expected transport cost, CT:

$$C = CS + CT. \tag{1}$$

There are two sorts of control variables in this cost minimization problem: the quantity of stocks of relief goods in all the shelters, and the quantity of relief goods transported from one shelter to another after the inundation heights of all areas are known. Namely, the former is determined before occurrence of a flood, and the latter, after occurrence of each flood event. Concretely, the quantity of relief goods stocked in Shelter *i* is represented by M_i where the subscript *i* is the index of shelter; the quantity of relief goods transported from Shelter *i* to the distribution center by truck in Scenario *s* is represented by $T1C_{iks}$ where the subscript *k* represents the distribution center; the quantity of relief goods transported from the distribution center to Shelter *i* by truck in Scenario *s* is represented by $T1C_{iks}$; the quantity of relief goods transported from the distribution center to Shelter *i* by helicopter in Scenario *s* is represented by $T1H_{iks}$.

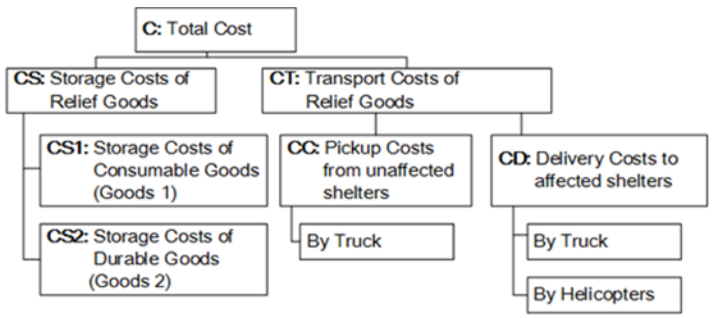

Figure 6. Outline of Total Cost

$$\min\ C_s = CS_s + CT_S. \tag{2}$$

The problem is solved backward. First, the planner can obtain the optimized policy for Scenario *s* by solving the following cost minimization problem:

The stock of relief goods is classified into consumable goods (called Goods 1), and durable goods (called Goods 2). The total storage cost of relief goods is the sum of the storage cost of Goods 1, $CS1_s$, and that of Goods 2, $CS2_s$:

$$CS_s = CS1_s + CS2_s, \tag{3}$$

$$CS1_s = AS1 \times \sum_{i=1}^{301} M1_{is}, \tag{4}$$

$$CS2_s = AS2 \times \sum_{i=1}^{301} M2_{is}, \tag{5}$$

where *AS1* and *AS2* represent the unit storage cost of one set of the necessary amounts of the bundle of Goods 1 for Scenario *s* and that of Goods 2, respectively, and $M1_{is}$ and $M2_{is}$, the quantity of Goods 1 stored in Shelter *i* for Scenario *s* and that of Goods 2, respectively. The total number of shelters is 301.

On the other hand, the transport cost of relief goods, CT_s, is defined as the sum of the cost of picking up relief goods, CC_s, and the delivery cost, CD_s.

$$CT_s = CC_s + CD_s. \tag{6}$$

The cost of picking up relief goods in Scenario *s* is defined as the cost of transporting relief goods from a Type-E shelter to the distribution center by truck as follows:

$$CC_s = \sum_{i=1}^{301} (B1C \times DC_{ik} \times T1C_{iks}), \tag{7}$$

where *B1C* represents the unit transport cost of one set of Goods 1 by two-ton-truck per km (unit: yen/(set×km)). DC_{ik} is the distance from Shelter *i* to Distribution Center *k* by truck (unit: km). $T1C_{iks}$ is the quantity of Goods 1 transported from Shelter *i* to the center.

The delivery cost of relief goods in Scenario *s* is defined as the sum of the cost of transporting relief goods from the distribution center to a Type-B shelter by truck and to a Type-A shelter by helicopter as follows:

$$CD_s = \sum_{i=1}^{301} (B1C \times DC_{ki} \times T1C_{kis} + B1H \times DH_{ki} \times T1H_{kis}), \tag{8}$$

where *B1H* is the unit transport cost of one set of Goods 1 by helicopter per km. DC_{ki} and DH_{ki} are the distance from Distribution Center *k* to Shelter *i* by truck and that by helicopter, respectively. $T1C_{kis}$ and $T1H_{kis}$ are the quantity of Goods 1 transported from Distribution Center *k* to Shelter *i* by truck and that by helicopter, respectively.

Secondly, the planner considers the optimal quantity of relief goods stocked in each shelter so that it ensures that all evacuees can survive in any scenario among the eight scenarios. Therefore, the quantity of Goods *x* (=1,2) (unit: set/($\text{day} \times \text{person}$)) that should be stocked in Shelter *i*, Mx_i, is represented as follows:

$$Mx_i = \max_s Mx_{is}, \tag{9}$$

where Mx_{is} represents quantity of Goods *x* in Shelter i that is necessary in Scenario *s*. Correspondingly, the cost of stocking relief goods, CS (unit: yen), is given by

$$\mathrm{CS} = \max_s CS_s, \tag{10}$$

where CS_s is the cost of stocking relief goods that are necessary in Scenario *s*.

On the other hand, we assume that the transportation cost in the objective function of the cost minimization problem is represented by the expected transportation cost:

$$CT = E[CT_s], \tag{11}$$

where *E*[ ] represents the expectation operator and we assume that the probabilities of all the scenarios are uniform. Hence, the objective function of the optimization problem that is given by Eq.(1) is rewritten as follows:

$$\mathrm{C} = \max_s(\mathrm{CS}_s) + E[CT_s]. \tag{12}$$

Finally, the optimization problem is represented as follows:

$$\min_{M,T} C, \tag{13}$$

where *M* and *T* represent the bundle of stocks of relief goods and the bundle of transported goods, respectively.

4.2 Constraints

We have three main constraint conditions. Firstly, in all cases, the total quantity of relief goods stocked in all shelters should be greater than or equal to the total demand for relief goods.

$$\sum_{i=1}^{301} M1_{is} \geq \sum_{i=1}^{301} DE1_{is}\ ,\quad \sum_{i=1}^{301} M2_{is} \geq \sum_{i=1}^{301} DE2_{is} \quad \text{for all } s, \tag{14}$$

where $DE1_{is}$ and $DE2_{is}$ are the quantity of demand for Goods 1 and Goods 2, respectively, at Shelter *i* in Scenario *s*, and given by

$$DE1_{is} = Ni \times Day_{is}, \quad DE2_{is} = Ni, \tag{15}$$

where Ni is the estimated number of evacuees (unit: person), and Day_{is} is the number of days that evacuees stay at Shelter *i* in Scenario *s* (unit: day).

Secondly, we identify the upper and lower bounds for the quantity of relief goods stocked at each shelter. It is assumed that evacuees manage to survive with the stock of relief goods at each shelter after a disaster until other relief goods are delivered to their shelter in the damaged area. Thus, the quantity of relief goods stocked at each shelter is set as a certain threshold to ensure that evacuees manage to survive:

$$M1_{is} \geq Ni \times DayR\ , \quad M2_{is} \geq Ni \quad \text{for all } i \text{ and } s, \tag{16}$$

where $DayR$ is the number of days that it takes to deliver relief goods to a shelter after a disaster. On the other hand, with consideration given to the storage space of each shelter, the maximum quantity of relief goods stocked at each shelter is given:

$$M1_{is} \leq M1_i\text{max}, \quad M2_{is} \leq M2_i\text{max} \quad \text{for all } i \text{ and } s. \tag{17}$$

Finally, we set constraint conditions of transported relief goods. The sum of the stocked relief goods and the transported relief goods in Shelter *i* must be greater than the quantity of relief goods demanded in Shelter *i* for all cases as follows:

$$M1_{is} + T1C_{kis} + T1H_{kis} \geq DE1_{is} \quad \text{for all } i \text{ and } s. \tag{18}$$

The constraint conditions are summarized as follows:

$$\sum_{i=1}^{301} Ni \times Day_{is} \leq \sum_{i=1}^{301} M1_{is} \quad \text{for all } s, \tag{19}$$

$$\sum_{i=1}^{301} Ni \leq \sum_{i=1}^{301} M2_{is} \quad \text{for all } s, \tag{20}$$

$$Ni \times DayR \leq M1_{is} \leq M1_i\text{max} \quad \text{for all } i \text{ and } s, \tag{21}$$

$$Ni \leq M2_{is} \leq M2_i\text{max} \quad \text{for all i and s}, \tag{22}$$

$$M1_{is} + T1C_{kis} + T1H_{kis} \geq Ni \times Day_{is} \quad \text{for all } i \text{ and } s. \tag{23}$$

4.3 Parameters

The values of $AS1$ and $AS2$ are identified by using the price of each relief good sold by private companies. $B1C$ is set by using the representative price suggested by the Kanto District Bureau (Tokyo Route Truck

Conference Association). $B1H$ is set by using the cost of helicopter transportation services provided by a private company (ARK EFI ALL). DC_{ik}, DC_{ki}, DH_{ik}, and DH_{ki} are set by using the data supplied by ZENRIN DataCom. Day_{is} is set by using the classification of shelters based on the flood depth at each shelter, as in Table 4. Evacuees are assumed to stay in a Type-A or Type-B shelter for a maximum of three days after a disaster. Ni is set by using the capacity of each shelter as provided by Nagoya City. Furthermore, based on the flood data calculated by the flood simulation developed by the MLIT, we identified *DayR* to be unity for all *i* and *s*, namely $DayR$=1. We finally assume the limitation of space for storage in each shelter by $M1_i \max = M2_i \max = Ni \times 2$.

4.4 Simulation Results

We call the simulation results in this section the "Network Policy." The results are compared with those of Nagoya City's policy, which is named the "'Planned Policy." Table 5 presents an excerpt of the entire simulation results where the numbers of stocked and transported relief goods of seven shelters that are Shelter $i = 1, \cdots, 7$, under three scenarios, Scenarios 1, 2, and 3, among the eight scenarios are selectively shown due to limitation of space.

Table 6 summarizes the results of the costs in each scenario under the "Network Policy" as well as the costs of the "Planned Policy." Finally, Table 7 shows a comparison between the Planned and the Network Policies. Note that, in this case study, the Planned Policy is that "in each shelter, Goods 1 should be stored in an amount of 'the estimated number of evacuees' x 'three days', and Goods 2 should be stored for the estimated number of evacuees".

Now, the results of the Network Policy show that if all the shelters stock a one-day supply of Goods 1 and Goods 2, evacuees in Types-A and -B impacted shelters can survive for three days in the shelters, thanks to elastic transfer of goods within the inter-ward network. Moreover, owing to the reduction in stocks of Goods 1 by 67%, the total cost of the Network Policy is lower than that of the Planned Policy by 25%, which is equivalent to 396,572 thousand yen. This is because the unit cost of stocking relief goods is significantly higher than the unit cost of transporting relief goods.

Another potential benefit of the Network Policy will be estimated when we consider the expiration dates of the disaster relief goods. As a matter of fact, at least some relief goods that are not consumed because areas are not damaged must be thrown away although some of them are used in evacuation drills. Now, the Network Policy can decrease the amount of those goods that would be disposed of under the Planned Policy because the Network Policy increases the probability that each good is used in some shelter. The numerical estimation of this benefit is left for future study.

In summary, by guaranteeing that relief goods are transported from shelters in unaffected areas to those in damaged areas to compensate for possible shortages, evacuees' demands will be met in all cases under the Network Policy and its cost is lower than that of the Planned Policy because the cost of transportation is significantly lower than the storage cost of relief goods.

Table 5. Excerpt of Results of the Estimated Quantities of Stocked Relief Goods (M) and Transported Relief Goods (T) for the "Network Policy" for Three Sample Scenarios

unit : set / day · person

i	Scenario1					Scenario2					Scenario3				
	Stock		Transportation			Stock		Transportation			Stock		Transportation		
	M1_i	M2_i	T1C_ik	T1C_ki	T1H_ki	M1_i	M2_i	T1C_ik	T1C_ki	T1H_ki	M1_i	M2_i	T1C_ik	T1C_ki	T1H_ki
sum	**99,325**	**99,325**	**33,788**	**14,188**	**19,600**	**99,325**	**99,325**	**38,630**	**17,416**	**21,214**	**99,782**	**99,325**	**39,063**	**20,806**	**18,257**
1	360	360	238	0	0	360	360	0	0	0	360	360	316	0	0
2	460	460	0	0	0	460	460	0	0	0	460	460	0	0	0
3	630	630	335	0	0	630	630	0	0	0	630	630	365	0	0
4	70	70	0	0	0	70	70	0	0	0	70	70	0	0	0
5	220	220	0	0	0	220	220	0	0	0	220	220	0	0	0
6	520	520	0	0	0	520	520	0	0	0	520	520	344	0	0
7	70	70	120	0	0	70	70	0	0	0	70	70	217	0	0

Table 6. Results of the Estimated Cost of the "Network Policy" for Each Scenario and the "Planned Policy"

unit : thousand yen

Cost \ S	Scenario1	Scenario2	Scenario3	Scenario4	Scenario5	Scenario6	Scenario7	Scenario8	All Scenarios	Planned Policy
C(Total)	1192912	1193071	1193782	1195504	1192245	1192646	1192232	1192192	1196218	1589200
CS(Stocking)	1191900	1191900	1192814	1194580	1191900	1191900	1191900	1191900	1195494	1589200
CS1(Goods1)	198650	198650	199564	201330	198650	198650	198650	198650	202244	595950
CS2(Goods2)	993250	993250	993250	993250	993250	993250	993250	993250	993250	993250
CT(Transporting)	1012	1171	968	924	345	746	332	292	724	0
CC(Collection)	85	99	101	97	23	46	25	27	63	0
CD(Distribution)	927	1072	867	826	321	700	307	265	661	0

Table 7. Comparison between the "Planned Policy" and the "Network Policy"

unit : thousand yen

Cost	Planned Policy	Network Policy	Network —Planned	
C(Total)	1,589,200	1,192,628	-396,572	-25%
CS(Storage)	1,589,200	1,191,900	-397,300	-25%
CS1(Goods1)	595,950	198,650	-397,300	-67%
CS2(Goods2)	993,250	993,250	0	0%
CT(Transport)	0	728	728	--
CC(Collection)	0	55	55	--
CD(Distribution)	0	673	673	--

unit : set / day · person

Goods	Planned Policy	Network Policy	Network —Planned	
M1 (Goods1)	297,975	99,325	-198,650	-67%
M2 (Goods2)	99,325	99,325	0	0%
T1C_ik (Collection)	0	27,473	27,473	--
T1C_ki (Distribution)	0	12,409	12,409	--
T1H_ik (Distribution)	0	15,012	15,012	--

4.5 Wide-area Disaster

So far, flooding of the Shonai River has been assumed to be the target disaster. In fact, Nagoya City also has the potential to undergo a wide-area disaster such as the Nankai Trough Quake. This model can be expanded to deal with a larger disaster such as the Nankai Trough Quake. In the above case study, we focused on the non-uniform distribution of damage among five wards of Nagoya City; however, if the Nankai Trough Quake occurs, these five wards will be damaged uniformly because earthquakes comprise a wide area. Thus, it is necessary to construct an "Inter-regional Network for the Storage of Relief Goods." One of the constraints of this policy is that areas must not be damaged uniformly when a disaster occurs. Furthermore, the number of assumed evacuees in each of these areas must be similar because the quantity of relief goods in each area is theoretically the same. For example, we show the possibility of developing a network for the storage of relief goods for the Nankai Trough Quake. Nagoya City could suffer from this earthquake and the resulting tsunami because it is located near the trough plate and the Pacific Ocean. On the other hand, cities located on the other side of the main island of Japan are assumed not to suffer serious damage because they are located far from the seismic center of the earthquake and a tsunami would not hit. Consequently, Nagoya City should develop its network with other cities on that side; we hypothetically identify two cities that we call K City and F City, respectively.

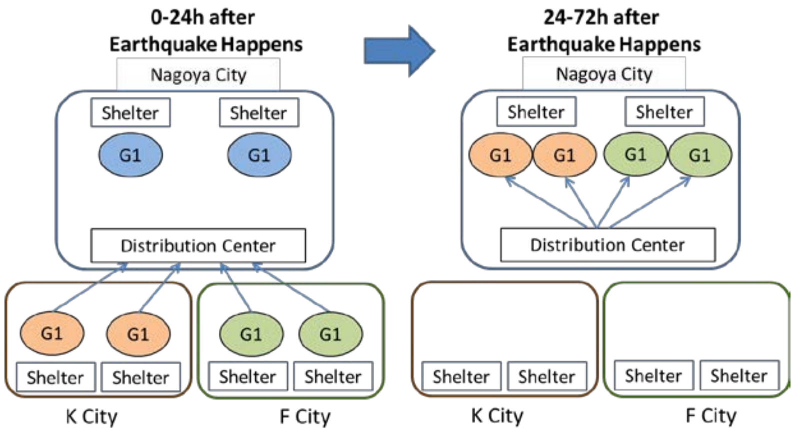

Figure 7. Inter-regional Network for the Storage of Relief Goods (G1 represents Goods 1.)

We now simulate a scenario after the Nankai Trough Quake occurs as follows: suppose an inter-regional network among the three cities is developed. Each city stocks relief goods at each shelter for the assumed number of evacuees for one day. We assume that these three cities are not damaged by the same disaster. They reach the following agreement with each other: “If one city is damaged by a disaster, the other cities have to deliver relief goods to the distribution center of the damaged city.” Given that Nagoya City would be seriously damaged by the Nankai Trough Quake, this agreement means that the evacuees in all shelters in Nagoya City would be forced to stay there for 72 hours after the earthquake occurs. They can survive with the relief goods stored in each shelter for the first 24 hours after the earthquake occurs.

On the other hand, since K City and F City are not damaged by the earthquake, they will deliver relief goods to the distribution center of Nagoya City within 24 hours without any logistical problems. Then, on the second day, the goods are delivered from the distribution center to each shelter in Nagoya City by truck and helicopter. Hence, relief goods are not in shortage in any shelter in Nagoya City as shown in Figure 7. From the fourth day after the earthquake, we expect that relief goods will be delivered constantly, thanks to the disaster recovery effort and the elimination of road obstacles.

On the other hand, in practice, it will be difficult to identify the names of what we call “K City” and “F City” above, since there is no city on the Sea of Japan side whose population is as large as that of Nagoya City. Hence, “K City” or “F City” can be a consociation of several cities, towns, or villages. Although making of a consociation is one of the important challenges in the area of politics whose possibility should be analyzed both practically and theoretically, as described above, this model may be extended to deal with a larger disaster, such as earthquakes or tsunamis, to avoid a shortage of supply of relief goods.

5. CONCLUSION

This study described the present problems of relief goods policies based on interview surveys, formulated an optimization problem of relief goods policy, and examined its effects. We developed a model focusing on the non-uniform distribution of damage and an inter-ward storage network for relief goods, with real data on the necessary amount of goods and transportation conditions, and applied it to a case study of the Shonai River, Nagoya City, Japan to determine the quantity of stocked and transported relief goods and the associated costs. The results showed that it is possible to guarantee three days’ worth of supplies for the expected number of evacuees by storing one day’s worth of relief goods. It is, therefore, possible to reduce the costs of the relief goods policy with this model. This study contributes knowledge helpful to those responsible for enacting an efficient relief goods policy that guarantees the lives of evacuees.

A foreseeable extension of this research would be to include the following points: we need to take into account the probability that roads are damaged so that it takes greater time and cost to transport goods in the aftermath of a disaster. It is also important to consider the scenario whereby a distribution center is damaged. The Great East Japan Earthquake damaged the public office in Rikuzen Takata City. Therefore, it is possible that an important hub intended to function during disaster recovery activities could be damaged. This study assumes Komaki Airport to be the only distribution center. However, it is necessary to consider a scenario such as actually occurred in Rikuzen Takata City.

The second point is to consider the disaster relief goods' expiration dates. As is pointed out in Subsection 4.4, Network Policy must be further advantageous over Planned Policy if expiration dates are taken into account. This merit should also be numerically estimated by extending the model, where a transfer strategy includes a criterion whereby goods with the shorter expiration date should be provided to the damaged shelter.

The third point is to determine what kind of management system is needed to guarantee an efficient relief goods network policy. For example, who should manage the collection of relief goods in each shelter? How can community members reach agreement on a list of goods that reflects the special circumstances of their community? From the viewpoint of community disaster prevention, each shelter should be managed by each community. Since it is an issue of implementability of community-based activity of disaster prevention, further discussion on risk perception, risk communication, leadership, solidarity, and activity planning is necessary.

Acknowledgements
We would like to express our gratitude to related departments of the City of Nagoya, and Mr. Hidemitsu Yukawa, city council member of Nagoya City, for providing information on relief goods of Nagoya City. We are also grateful to the Shonai River Management Office for giving us the calculation result of flood depth of the Shonai River. We further wish to express our sincere thanks to Professor Takashi Sakata, president of Ishinomaki Senshu University, and Mr. Yoshihiro Yamamoto, a teacher at Ofunato Prefectural High School.

APPENDIX Interview Survey in the Tohoku Area
As described in Chapter 2, the authors visited two places in the Tohoku region of Japan that were severely damaged by the earthquake and resulting tsunami in the Great East Japan Earthquake of 2011, in order to obtain knowledge and lessons learned regarding relief goods. The following is a summary of interview surveys with persons in charge of a shelter at the time.

1) Iwate Prefectural Ofunato High School
Iwate Prefectural Ofunato High School is located in Ikawacho, Ofunato City, Iwate Prefecture. This high school was used as a shelter in the aftermath of the Great East Japan Earthquake in 2011. The authors conducted an interview survey with a male teacher aged 29. He was at the high school when the earthquake occurred. He also managed the shelter for a week until all evacuees returned to their homes. Points of his statements are itemized as follows.

- ✓ A 60-square-meter room, usually used for club activity training camps, served as a sleeping space.
  Most high schools in Iwate Prefecture have a similar type of room. The room is usually used during everyday situations; thus, students can use this room efficiently in an emergency.
- ✓ A shelter can be well managed with the cooperation of evacuees.
  Fortunately, the shelter was equipped with bedclothes, such as blankets. However, there were not enough of these commodities. Students first distributed these commodities among elderly people, women, and children. The students did not complain about the lack of commodities, as they knew each other before the disaster. Problems might have occurred if they had been strangers. In that case, they may have had to consider rationing relief goods per person. For example, if water supply per person is two-thirds of a bottle, distribution would have been difficult, and there may have been complaints. Riots may have occurred if people were starving. Without cooperation, managing the evacuation shelter would have been difficult.
- ✓ Light gave evacuees a sense of security.

A kerosene oil stove played an important role as a source of both heating and light. Because electricity was cut, the light helped many evacuees feel safe, especially at night. Considering that a kerosene oil stove provided mental support to evacuees, it is more effective than electrical heating apparatus, which would not have been able to work during the power outage.

- ✓ In an emergency, cooperating with private organizations is effective.

  Soon after the disaster occurred, an electronics store located near the high school provided them with relief goods, such as heating apparatus. This proved helpful to evacuees.

- ✓ Evacuees survived with goods stocked in shelters through trial and error.

  For example, the water supply had been stopped and evacuees were forced to use residual water in the water tank. Consequently, a lack of water became a concern. Furthermore, they did not know when the water supply would be restored. From two days after the disaster, they left the shelter to search for water, and transported spring water back to the shelter on a cart in plastic bottles. They then used these bottles of water for the toilets. Clearly, the shelters were faced with many problems; however, evacuees managed to utilize the limited goods stocked in the shelter through trial and error.

- ✓ The ability of the local government to function effectively as a base for disaster recovery greatly impacts disaster recovery.

  There was a surplus of relief goods at the shelter from the second day after the disaster. For example, too many rice balls were transported from other regions, and the evacuees could not eat them all. Large volumes of relief goods were transported to the shelter, as Ofunato City Office was a well-functioning disaster recovery base. On the other hand, the Rikuzentakata City Office was severely damaged by the tsunami, and could not function as a disaster recovery base (Rikuzen Takata City). Consequently, relief goods could not always be supplied to those shelters lacking food.

2) Ishinomaki Senshu University

Ishinomaki Senshu University is a private university located in Ishinomaki City, Miyagi Prefecture, Japan. The university was used as a shelter and base of the volunteer center, Red Cross, Japan’s Self-Defense Forces camp, and heliport after the 2011 Great East Japan Earthquake (Ishinomaki Senshu University). The authors conducted an interview with the president of the university. When the earthquake occurred, he was charged with managing and making all decisions regarding the shelter. Points of his statements are itemized as follows:

- ✓ The situation in the evacuation shelter changed from moment to moment, making it difficult to understand evacuees’ needs.

  For example, the evacuees housed in the shelter lacked water and requested that Ishinomaki City supply it. The next day, too much water was supplied. In addition, a volunteer unexpectedly sent more water to the shelter.

- ✓ There was enough food and water, but other goods were in short supply.

  From three to four days after the disaster, there was enough food and water thanks to volunteers and NPOs. However, baby goods, sanitary goods, pet goods, and cigarettes were in short supply.

- ✓ The president experienced many difficulties in making decisions as a private university.

  The private university is not a public facility. As such, the president did not know what to do in his capacity as the president of a private university. Despite this, he was forced to make decisions in various scenarios. For example, although the university was not designated as a shelter, many evacuees arrived there. He accepted evacuees by his own decision, as they were unable to evacuate to other shelters.

- ✓ The sewerage treatment facility did not function, and the evacuees had to use portable toilets.

  Initially, evacuees used the regular toilets. However, they began using portable toilets after noticing that the sewerage treatment facility was not functioning. We have to consider how evacuees can use toilet facilities comfortably. Problems regarding toilet facilities are important, as they are related to security and health problems.

- ✓ Long-distance transportation was restored within two days of the disaster.

  Relief goods were transported through long-distance transportation within two days of the disaster. The evacuees were able to feel safer and more secure, because they felt connected to other regions. They were surprised at how quickly transportation companies and road networks were restored.
- ✓ A supplement with a quality energy vitamin per volume was effective.

  Evacuees could not obtain natural vitamins from food, such as fruits and vegetables. Consequently, they suffered from malnutrition and stomatitis. In these cases, supplements were beneficial to those who were ill.
- ✓ Managing warehouse stock was a lifeline for shelters.

  Fortunately, one volunteer was skilled in logistics. With his help, the type and quantity of relief goods needed could be calculated, which helped in managing the shelter. It would be useful to create a system whereby people skilled in logistics are dispatched to each shelter. In medical facilities, D-MAT is organized similarly to the system I recommend here (D-MAT Office).
- ✓ In evacuation shelters, both volunteers with specialized skills and regular volunteers are needed.

  Regular volunteers are helpful, but volunteers with specialized skills are invaluable. The university president felt that volunteers with specialized knowledge in public relations, logistics, distribution, and medicine for example would be helpful during disaster recovery.

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