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Journal of Integrated Disaster Risk Management

Original paper

Estimation of Alternative Ports for Container Transport after Large-scale Disasters - Estimation Method and Application to Port-BCPs -

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Abstract As a result of the Great East Japan Earthquake and Tsunami, the port facilities of eastern Japan on the Pacific Ocean suffered severe damage and, ports with access to the Sea of Japan or Tokyo Bay functioned as alternative ports. Similarly, after the Great Hanshin-Awaji Earthquake, Osaka port and other major ports functioned as alternatives to the damaged Kobe port. In response to these issues, each port in Japan has developed a business continuity plan (port-BCP). An important issue in port-BCPs is identifying alternative ports. In the aftermath of future large-scale disasters (LSDs) such as a Nankai Trough earthquake and tsunami, it is predicted that the three major bay ports, at which the handling of container volume in Japan is concentrated, would be severely damaged. It is therefore necessary to assume that the handling capacities of alternative ports may reach their limits after a disaster. Against this background, the purposes of this study are (1) to quantify the demands for container transport after LSDs, (2) to improve the port choice model used to identify alternative ports so that it considers the capacity constraints of those ports, and (3) to apply the estimation result to the Tohoku regional port-BCP with the aim of preventing the disruption of container transport in the region after an LSD.

Key words Container Transport; Business Continuity Plan; Port-BCP; Port Choice Model; Alternative Port.

1. INTRODUCTION

As a result of the Great East Japan Earthquake and Tsunami, the port facilities of eastern Japan on the Pacific Ocean suffered severe damage. The earthquake and tsunami destroyed breakwaters and berths, triggered soil liquefaction in cargo handling areas, and caused rubble, vehicles, and containers to sink in fairways. After the tsunami warnings and advisories had been lifted, the Tohoku/Kanto Regional Development Bureau of the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), as well as

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other groups, rushed to remove obstacles on fairways. As a result, at all damaged ports, some berths became available after about half a month. However, a much longer time was needed to restore overall port facilities. For example, full restoration of the Takasago container terminal of Sendai-Shiogama port took about a year. Before this full restoration, through emergency rehabilitation efforts, the No. 1 berth was suitable for use about 3 months after the earthquake and tsunami, and the gantry crane resumed operation about 6 months after. As a consequence of the closures, the Takasago terminal was unable to meet the demand for containerized cargo transport, and the ports with access to Tokyo Bay or the Sea of Japan, among others, were used as alternatives. This transition led to the stagnation of international container transport, disrupted the supply chains of many companies, and compounded the economic damage directly caused by the disaster.

In response to these issues, the Transport Policy Council of MLIT issued the report "Basic Policy of Anti-Earthquake/Tsunami Measures for Ports and Harbors" (June 2012). This council report indicated that the following things are important:

(1) developing business continuity plans for ports (port-BCPs) and sharing these among relevant organizations to promote effective and rapid restoration of port functions in the face of limited human and material resources; and
(2) studying and identifying alternative ports in advance of necessity.

After the Great East Japan Earthquake and Tsunami, the estimates of damage from large-scale earthquakes and tsunamis were revised upward. The Cabinet Office estimated the economic damage that would be caused by a Nankai Trough earthquake and tsunami or an inland earthquake in Tokyo at about 1.8 trillion USD and 0.8 trillion USD, respectively. Compared to the GDP of Japan, which was about 3.9 trillion USD in 2012, these estimated damages would represent an enormous impact on the Japanese economy. To mitigate this damage likely to be caused by large-scale earthquakes and tsunamis in the future, "Action for National Resilience, Disaster Prevention and Mitigation" (June 2014) was adopted at a Cabinet meeting. One of the targets among this plan is to complete port-BCP at all ports of at least "major port" class (there are 125 such ports in Japan, as shown in **Figure 1**) by the end of 2016. Therefore, many ports in Japan have been preparing a port-BCP.

2. LITERATURE REVIEW

The International Organization for Standardization (ISO) formulated a third-party certification standard for BCPs (the ISO 22301 standard) in 2012. This standard "specifies the requirements to plan, establish, implement, operate, monitor, review, maintain and continually improve a documented management system to protect against, reduce the likelihood of occurrence, prepare for, respond to, and recover from disruptive incidents when they arise" (ISO 2012). The standard requests to establish the business continuity objectives by taking account of the minimum and acceptable level of services. The objectives act as a target time and level for the resumption of operation recovery after an incident.

Since 2006, the Asia-Pacific Economic Cooperation has developed a trade recovery program (TRP) for repairing and sustaining the international economic system in the event of a disruption to the global supply chain, such as a disruption caused by a major terrorist attack, in collaboration with the World Customs Organization and International Maritime Organization (APEC 2012). In this TRP, domestic structures and processes that can resume trade quickly and effectively are to be identified by each economy.
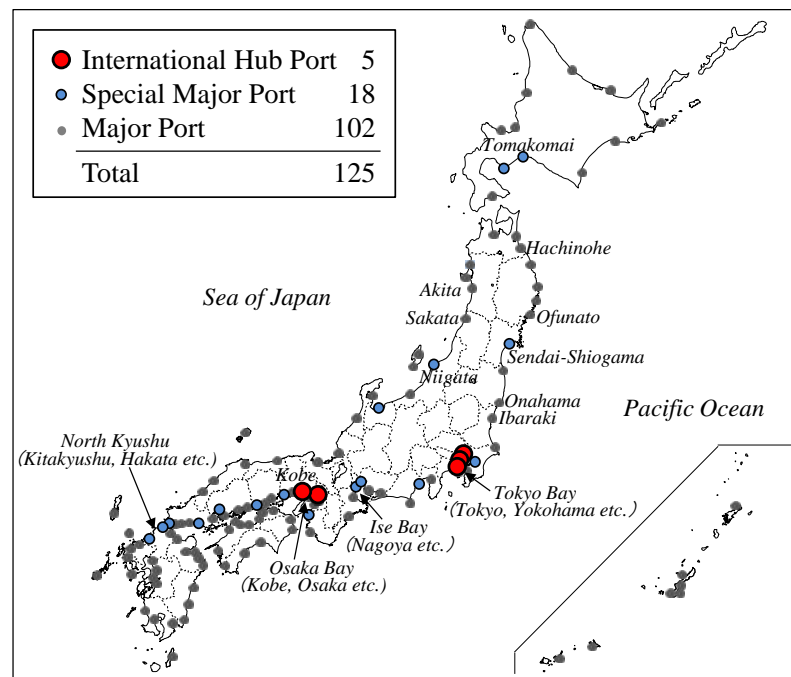
Figure 1. Ports in Japan

In the academic field, Berle *et al.* (2011) proposed a structure for assessing and reducing the disruption vulnerability for a maritime supply chain by using failure-mode assessment. Omer *et al*. (2012) proposed a framework for improving maritime transport systems on three metrics: tonnage resiliency, time resiliency and cost resiliency. Abe (2013) proposed a basic framework for the analysis of supply and demand gaps in port logistics services in case of large earthquakes. Trepte and Rice (2014) analyzed the port system in the United States and observed that there is insufficient capacity across various major ports to handle disruptions without a significant impact on economy. However, none of these papers analyzed port choice in the aftermath of a disaster with accounting for the limited capacities of alternative ports.

Akakura *et al.* (2013b, 2014) have previously written about quantifying the demands for containerized cargo transport after large-scale disasters (LSDs) and have developed a port choice model for identifying alternative ports. Extending these results, this paper proposes an improvement for the port choice model by considering the capacity constraints of alternative ports. The proposed model is then applied to port-BCPs for preventing the disruption of container transport after LSDs.

3. CONTAINER TRANSPORT DEMAND AFTER LSDS

3.1 Supply-Demand Relation in Port-BCPs

Port logistics encompasses many functions, such as containerized cargo transport, dry bulk cargo transport, liquid bulk cargo transport, ferry services, and roll-on/roll-off transport. Just after an LSD, the transport of humanitarian relief goods will be of critical importance. Among these various shipments, dry/liquid bulk cargo transports are originated from or destined to the sea-side area of a small number of companies. Therefore, the bulk cargo demands after LSDs are dependent on the situation of the main companies. Here, the focus is on international containerized cargo because it is more difficult to quantify the volume of demand resulting from the large number and wide range of involved companies.

Figure 2 shows a typical relation between supply and demand for containerized cargo transport after an LSD. After an LSD, containerized cargo demand recovers at a pace related to the recovery of manufacturing and other industries. Container handling capacity is restored by removing obstacles in fairways and restoring the berths, gantry cranes, and other port facilities. The port-BCPs are intended to allow maintaining this handling capacity at an acceptable level immediately after an LSD and to accelerate the restoration of its capacity. However, even when the restoration of container handling capacity can be accelerated by the preparation of a port-BCP, it is considered difficult, based on the lessons learnt from the case of Takasago container terminal restoration in Sendai-Shiogama port after the Great East Japan Earthquake and Tsunami, to fully eliminate the supply-demand gap. Actually it took six months for restoring a first gantry crane of the port. Great Hanshin-Awaji Earthquake also required two years for the full recovery of container terminals in Kobe port. Therefore, it is crucially important to pre-emptively include alternative ports into each port-BCP.
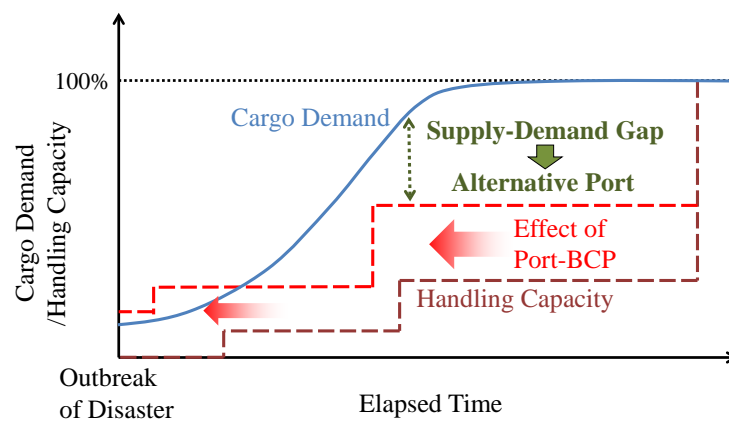
Figure 2. Supply-Demand of Containerized Cargo Transport

## 3.2 Recovery Curve of Containerized Cargo Transport

In Akakura *et al.* (2014), the recovery curve for international containerized cargo transport was quantified from the results of survey questionnaires distributed to companies in the manufacturing sector. The Tohoku and Kinki Regional Development Bureaus of MLIT administered these questionnaire surveys in 2011 and 2012. The questionnaires inquired as to the level of operation capacity after the Great East Japan Earthquake and Tsunami.

The recovery rates depend on the elapsed time and the degree of the damage, which is correlated with the strength of the hazard. **Table 1** shows the levels for the strength of hazard. First, the strength is distinguished by the occurrence of tsunami inundation because damages from tsunamis were far more severe than those from earthquakes in the case of the Great East Japan Earthquake and Tsunami. Note that, there were no available data regarding of factories that suffered a tremor with a Japan Meteorological Agency (JMA) seismic intensity of 7 in our questionnaire. Second, JMA seismic intensity is used as the index for earthquake damage. In Japan, JMA seismic intensity is typically used to express the strength of ground motion and has a very strong correlation with spectrum intensity (SI), as shown in **Figure 3** (JMA and FDMA 2009).

Table 1. Settings for Strength of Hazard

Tsunami Inundation	Inundation Depth	JMA Seismic Intensity
Exist	≥ 2.0m	All
	< 2.0m	
None	None	7
		6+
		6-
		5+
		5-
		4
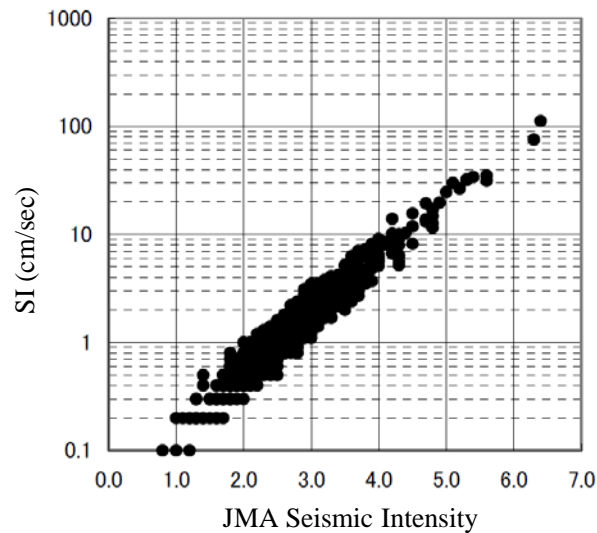
Figure 3. JMA Seismic Intensity vs. SI (JMA and FDMA 2009)

Figure 4 shows the estimated recovery curves for the various hazard strengths. A Gompertz curve with a ceiling of 100%, shown in formula (1), was adopted as the fitting curve.

$$f(x) = a \cdot b^{\exp(-cx)} \tag{1}$$

Here a, b, and c are regression parameters obtained through estimation. Since there are no significant difference among the reproducibility of estimated recovery curves by area, authors considered the proposed recovery curves for containerized cargo port handling demand can be employed for evaluating those from the possible affected areas by future earthquakes and tsunamis. It is, however, necessary to pay enough attention to the amplified negative impact of LSDs such as a Nankai Trough earthquake and tsunami and an inland earthquake in Tokyo due to the damaged lifeline, transportation facility and related businesses. Note that, the parameters for containerized cargo port handling demand curve with JMA seismic intensity 7 were estimated separately by using the data of Nakano *et al.* (2013).
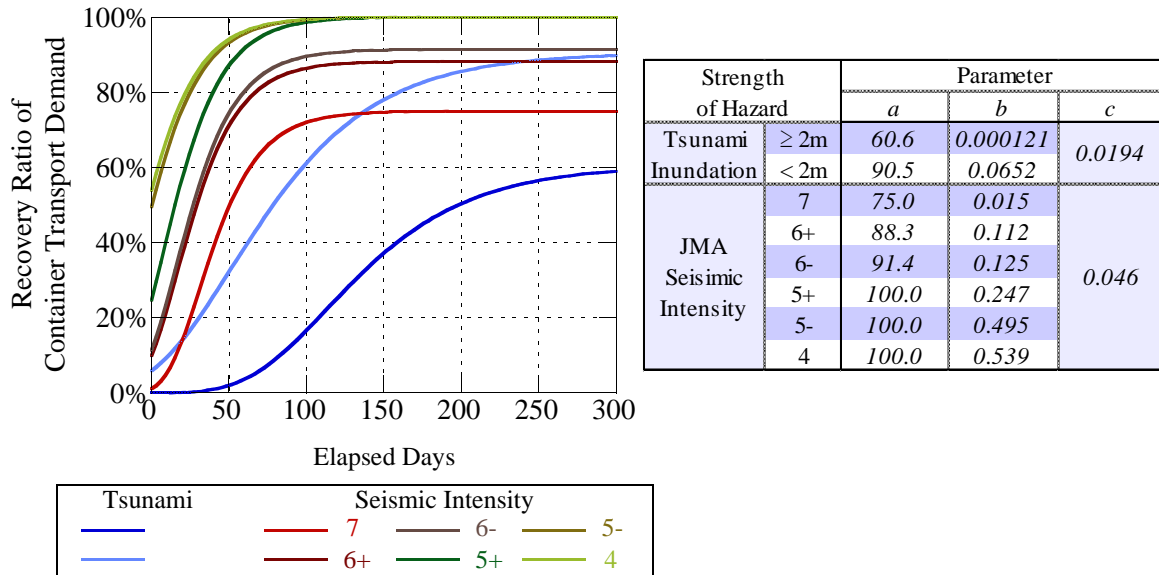
Strength of Hazard		Parameter		
		a	*b*	*c*
Tsunami Inundation	≥ 2m	60.6	0.000121	0.0194
	< 2m	90.5	0.0652	
JMA Seisimic Intensity	7	75.0	0.015	0.046
	6+	88.3	0.112	
	6-	91.4	0.125	
	5+	100.0	0.247	
	5-	100.0	0.495	
	4	100.0	0.539	

Figure 4. Estimated Recovery Curves for Containerized Cargo Transport Demand

3.3 Estimation of Supply-Demand Gap after the Great East Japan Earthquake and Tsunami

The supply-demand gap for containerized cargo transport after the Great East Japan Earthquake and Tsunami were estimated to be as shown in **Figure 5** by using the recovery curves. The lines in **Figure 5** are based on the following definitions.

✓ Potential: Containerized cargo volume estimated without the disaster

= Volume of each month in 2010 × Average of year-on-year increase during January and February from 2010 to 2011

✓ Demand after Disaster: Containerized cargo demand at each port after the disaster, as estimated by mobilizing recovery curves of **Figure 4** in the following way:

(1) identifying geographical position of the municipality basis origin and destination (O/D) of the containerized cargo based on data from the nationwide export and import container transportation survey in 2008 undertaken by MLIT; and

(2) applying the recovery curve for every containerized cargo O/D by considering tsunami inundation depth and JMA seismic intensity of the respective municipalities.

✓ Actual: Actual containerized cargo volume handled at each port in 2011 which was deemed to reflect constraints of port and shipping sub-sections, and local land transportation network

The gap between "Potential" and "Demand after Disaster" in **Figure 5** indicates the recovery rate of containerized cargo demand at each port. The gap between "Demand after Disaster" and "Actual" is the supply-demand gap of each port. For example, at Hachinohe port, the supply exceeded the demand in September, but at Sendai-Shiogama port there was a capacity shortfall even at the end of 2011. The containerized cargos that would have not been handled at damaged ports by these supply-demand gaps were handled at alternative ports. The primary aim of this paper is to estimate these alternative ports.
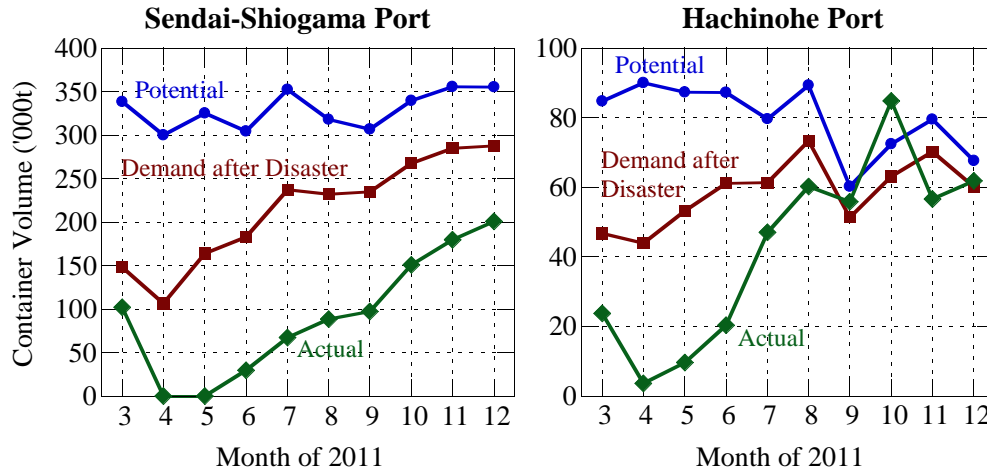
Figure 5. Estimated Containerized Cargo Demand after the Disaster

4.   ESTIMATION OF HANDLING CAPACITIES OF ALTERNATIVE PORTS

4.1 Importance of Estimation

As previously mentioned, the occurrence of an LSD due to a Nankai Trough earthquake and tsunami or an inland earthquake in Tokyo is a source of concern in Japan. In comparison with the Great East Japan Earthquake and Tsunami, a larger capacity of container ports—including international hub ports—would be damaged by these disasters. **Table 2** shows the containerized cargo volumes of the ports most likely to be damaged by these disasters, and the proportion of affected volume in nationwide volume. The proportion of containerized cargo volume handled at the ports damaged by the Great East Japan Earthquake and Tsunami was only about 1% of the national volume, but projections for Nankai Trough and Tokyo inland disasters indicate that the affected ports will account for about 20% to 40% of national volume. Because of this, the identification of alternative ports should include an estimation of the container-handling capacity of each port after disasters.

Table 2. Container Throughput of Damaged Port

Disaster (Earthquake/Tsunami)	Damaged Port	2010 Conteiner Volume ('000TEU & %)	
the Great East Japan	Hachinohe ~Kashima	*258.5*	*1.3%*
Tokyo Inland	Tokyo Bay	*7,691.0*	*37.6%*
Nankai Trough	Shimizu ~Aburatsu	*3,570.1 ~9,211.1*	*17.5% ~45.0%*

  * TEU: Twenty-foot Equivalent Unit

4.2 Challenges of Municipal-Level Community Well-being Approaches

Common situations of alternative ports were summarized by questionnaire surveys after the Great East Japan Earthquake and Tsunami and a survey of literature about the Great Hanshin-Awaji Earthquake, which occurred in 1995 and caused devastating damage to the port facilities of Kobe port. The following conclusions can be drawn from the available data.

- ✓ The volumes of containerized cargo at alternative ports increased drastically after the disasters. These containerized cargos had been handled at a damaged port before the disasters. As a result of the use of alternate routes for cargo, container handling capacities at the alternative ports reached (or closely approached) critical limits.

- ✓ At the alternative ports, extended hours of operation for stevedoring and gate controls were needed for the container terminals. Temporary container storage yards were prepared.

- ✓ The average time that a container was stored was extended because of the insufficiency of container drayage capacities, delays in return of empty containers, extended stays of imported containers, and other such effects.

- ✓ Extra stevedores from the damaged ports supported the alternative ports, and handling machines such as chassis for container drayage were also supported.

4.3 Estimation of Handling Capacity

The number of containers that can be handled at a terminal depends on the minimum capacity among the following: (1) accommodating capacity of berths, (2) handling capacity of gantry cranes, (3) storage capacity of yards, and (4) throughput capacity of gates. In Japan, the storage capacity of yards is the dominant factor at most ports because the others have some margin of excess. The utilization rate for accommodating capacity of berths is typically 30% to 40%. As previously mentioned, after the Great East Japan Earthquake and Tsunami and the Great Hanshin-Awaji Earthquake, the working hours of gantry cranes and gate controls were extended; however, even then these were not 24 hours a day. At one of the alternative ports, stevedoring work by gantry cranes was extended to 9 pm; however, it would be possible in theory to expand crane and gate capacities by extending the hours of operation.

Because the storage capacity of the container yard is the limiting factor in terminal capacity, the handling capacity is formulated by V (in TEU/year) as a function of the storage capacity of the container yard, N (in TEU), as shown in formula (2) (Takahashi 2003).

$$V = N \cdot \frac{g \cdot e}{f} \tag{2}$$

Here, g is an effectiveness factor; e is annual rotation frequency; and f is a peak coefficient. **Table 3** shows the additional capacity ratios of alternative ports after the opening of temporary storage yards following the Great East Japan Earthquake and Tsunami and the Great Hanshin-Awaji Earthquake. Although there were differences by ports, the average capacities of temporary storage yards corresponded to between about 20% to 50% of the ordinary storage yards. The increase in storage capacity yields an increase in handling capacity, as implied by formula (2).

In formula (2), the rotation frequency e is found by dividing the annual number of working days by the average number of days of storage per container. The average container storage days at alternative ports extended after the Great East Japan Earthquake and Tsunami and the Great Hanshin-Awaji Earthquake. For example, at the Niigata port it is estimated that the average storage days was extended from 7.8 days to 10.9 days by the disaster. The extension in average storage days reduces handling capacity.

Table 3. Relative Additional Capacity from Temporary Storage Areas at Alternative Ports

Disaster	Alternative Port	Additional Storage Capacity
Great East Japan	Akita	22%
	Sakata	53%
	Niigata	89%
Great Hanshin-Awaji	Nagoya	42%
	Osaka	39%
	Kitakyushu	28%
	Hakata	26%

After the Great East Japan Earthquake, neither Akita port nor Sakata port exceeded the critical limits of storage capacity. However, as reported in the questionnaire survey, stevedoring companies' capacities at these ports reached (or closely approached) the critical limits as a result of insufficient staff and equipment such as chassis. The stevedoring companies' capacities cannot increase rapidly after disasters but can increase to some extent by drawing on support from the stevedoring companies at damaged ports. It is estimated that the stevedoring companies' capacity at Akita port increased by approximately 30% after the disaster, and the increase at Sakata port was approximately 80%.

Given the situations described above, it is assumed from here that the handling capacities of alternative ports after a disaster will depend on the following two factors:

(1) the handling capacities of the storage yard, increased by temporary storage yards and decreased by the extension of storage days; and

(2) the handling capacities of stevedoring companies, supported by companies at damaged ports.

5. ALTERNATIVE PORT CHOICE

5.1 Sacrifice Model

As the port choice model, this study adopts a sacrifice model proposed by Iyama *et al.* (2012). In the sacrifice model, each containerized cargo is transported by the route that minimizes the total amount of sacrifices, quantified as *S* (generalized cost) by formula (3).

$$S = C + T \cdot \alpha \tag{3}$$

Here, *C* is transport cost, *T* is transport time and α is the value of time. By this model, containerized cargos with the same intended origin/destination select different ports according to the value of time. Time values are assumed to follow lognormal distributions, which were estimated by using data from the nationwide export and import container transportation survey in 2008 undertaken by MLIT. **Table 4** shows the estimation results for time values by Iyama *et al.* (2012). In this model, the port of origin (resp., destination) and the port of loading (resp., discharge) were calculated as transportation routes (for exports the route is from the place of production in Japan to the port of origin to the port of loading to the overseas port of destination to the consumption location; in direct shipping, the port of origin and port of loading are the same).

Table 4. Estimated Time Values (Iyama *et al.* 2012)

Route	Export		Import	
	Average	St. Dev.	Average	St. Dev.
Europe and North America	*2,146*	*6.4*	*1,963*	*9.9*
Intra-Asia	*1,590*	*6.8*	*1,233*	*6.8*

* Unit: JPY/hour/TEU

5.2 Improvement from Previous Model

The previously proposed model (Iyama *et al.* 2012) had sufficient reproducibility for practical use: the coefficient of determination between the actual and estimated container volumes was 0.96; however, the reproducibility at small ports was not so good. To improve overall reproducibility, although the same survey data were used, the authors divided the origin and destination areas in Japan from 47 prefectures into the 207 community areas for increasing the number of data and improving the homogeneity of area data. **Figure 6** shows the reproducibility of the improved model. The coefficients of determination between the actual and estimated container volumes exceed 0.99 for all ports.
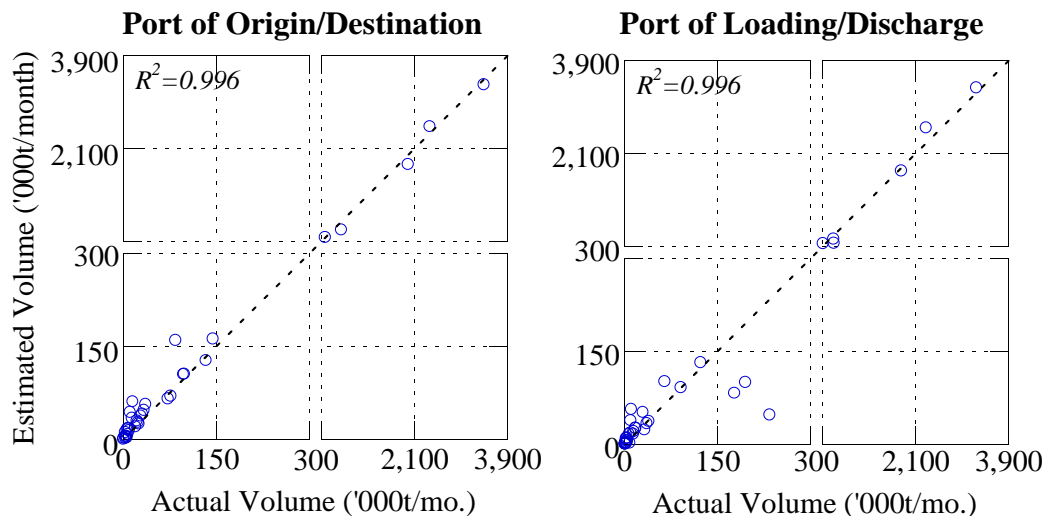

Figure 6. Reproducibility of Improved Model

In a previous study undertaken by Akakura *et al.* (2013b), the alternative ports one month after the Great East Japan Earthquake and Tsunami were estimated by using the previous model developed by Iyama *et al.* (2012). In that estimation, the container volumes to/from damaged areas were reduced by the procedure described in Section 3.2, and the service conditions of damaged ports and alternative ports were given. The resulting estimated container volume of each port almost reproduced the situation after the disaster as a whole; however, the estimation volume of one port on the Sea of Japan exceeded the handling capacity of the port by a wide margin. Because the previous model (Iyama *et al.* 2012) was designed for port choice during ordinary operations, the handling capacity of each port was not considered in the model calculation. However, the consideration of the capacity constraints of alternative ports is needed for estimation models intended to consider the port choice after disasters.

5.3 A Method for Considering the Handling Capacity

During estimation, overflows can occur when considering the capacity constraints of alternative ports. To resolve the overflows, iterative calculation is needed, which can be done as shown in **Figure 7**. The first estimation using the sacrifice model does not need to consider the capacity constraints of each port. However, after the initial calculation, the estimated container volume for each port is compared with the handling capacity for that port. When the estimated volume exceeds the handling capacity, the ports of origin/destination for the overflow volume are recalculated, with the volumes at overflowed ports constrained to capacity.
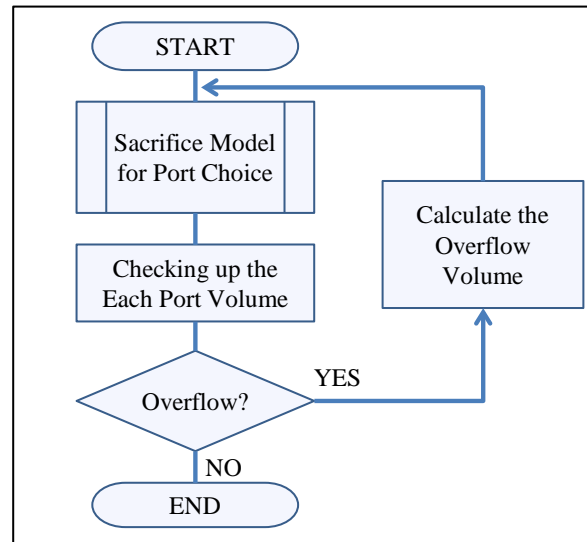
Figure 7. Estimation Flow for Considering Overflow

By using this iterative procedure and setting the handling capacities of alternative ports by the procedure described in Section 4.3, the containerized cargo volume one month after the Great East Japan Earthquake and Tsunami is reproduced. **Figure 8** shows the results of estimated changes in container volume from ordinary operation, both with and without capacity constraints. Since the ports at Sendai-Shiogama, Ibaraki, Hachinohe, Ofunato, and Onahama port were closed due to damage, the volumes at these ports are decreased by 100%. At the Akita and Sakata ports, the estimated volumes reached critical limits, and the changes in volume from ordinary time are decreased by considering the ports' capacities. The impact of this result is that the estimated volume at Niigata port increased and approached the critical limit. The estimated volume changes at three major bay ports (Tokyo, Ise, and Osaka) and the estimated volume at Tomakomai port is also slightly changed.
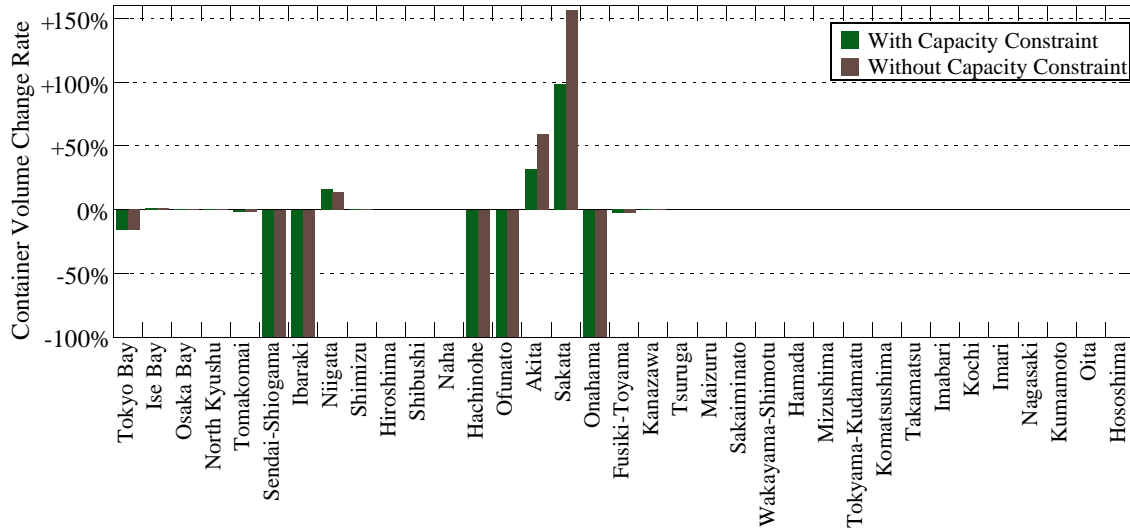
Figure 8. Estimated Container Volume Change Rate with and without Capacity Constraints

Figure 9 shows the same results as volume change (in t), where the left (resp., right) figure is with (resp., without) considering the capacity constraints of alternative ports. Overall, the coefficient of determination between actual and estimated volumes is unchanged by considering capacities; however, focusing on the surrounding ports of the damaged ports (Tomakomai, Niigata, Akita, and Sakata ports), the coefficient of determination is increased by considering capacities. The ports in the Tokyo Bay area, which functioned as alternative ports after the Great East Japan Earthquake and Tsunami, were skipped by container vessels due to rumors of harm from radioactivity (MLIT 2011). This decrease in vessel calls was also considered as a condition for the container detour estimation and the decrease in volume at the ports in the Tokyo Bay area was almost reproduced accordingly.
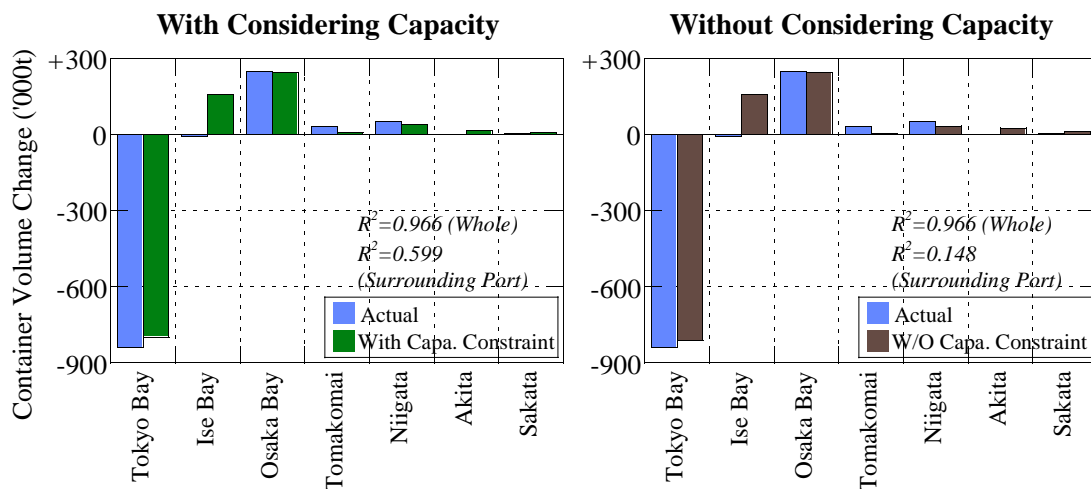

Figure 9. Container Volume Change with and without Capacity Constraints

Figure 10 shows the estimated alternative ports for Sendai-Shiogama port. By considering handling capacities, the proportions of cargo using Sakata and Niigata ports slightly decrease, and the proportions using Tokyo Bay and Niigata ports slightly increase.
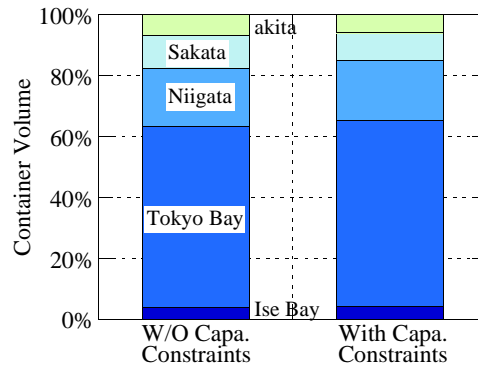
Figure 10. Estimated Alternative Ports for Sendai-Shiogama Port

6. APPLICATION TO TOHOKU REGIONAL PORT-BCP

6.1 Outline of Tohoku Regional Port-BCP

In the Tohoku region, the preparation of port-BCPs has proceeded by incorporating the lessons learned from the Great East Japan Earthquake and Tsunami. In November 2011, the "Basic Policy for Rehabilitation and Reconstruction of Ports in Tohoku Region" was completed. This policy indicates that the port-BCP is important and should be prepared as soon as possible. In March 2013, the Regional Council of Tohoku Port-BCP was established and a local port council was also established at each port to prepare port-BCPs. In June 2013, guidelines for port-BCPs in the Tohoku region were approved by the regional council. As of 9 December 2014, 6 of the 14 ports in the Tohoku region (13 major ports and 1 special major port) have finished a port-BCP, and 6 ports are expected to finish within the 2014 fiscal year.

These port-BCPs will accelerate the restoration of port handling capacity after an LSD; however, it is difficult to eliminate the supply-demand gap, as previously indicated in Section **3.1**. As a measure to mitigate expected damage, the Tohoku Regional Development Bureau of MLIT is preparing a regional based port-BCP, the "Tohoku Regional Port-BCP". The targets of this regional port-BCP are (1) coordinating the alternative port use of container transport, (2) facilitating the provision of machines and equipment between ports for emergency rehabilitation of port facilities or for restarting of cargo handling, and (3) identifying the role of relevant organizations and the needed emergency contact system. A regional coordination procedure for mobilizing alternative ports for container transport is shown in **Figure 11**. The estimated volumes at alternative ports after the earthquakes and tsunamis of the disaster scenarios are indicated by the Tohoku Regional Port-BCP. Each alternative port is requested to develop a backup system to handle a certain amount of containers transferred from damaged ports. This development is planned in the port-BCP of the alternative port. Of course, these alternative ports along with the possible cargo redeployment are to be included in the port-BCP of the damaged port, as described in Section 3.1.
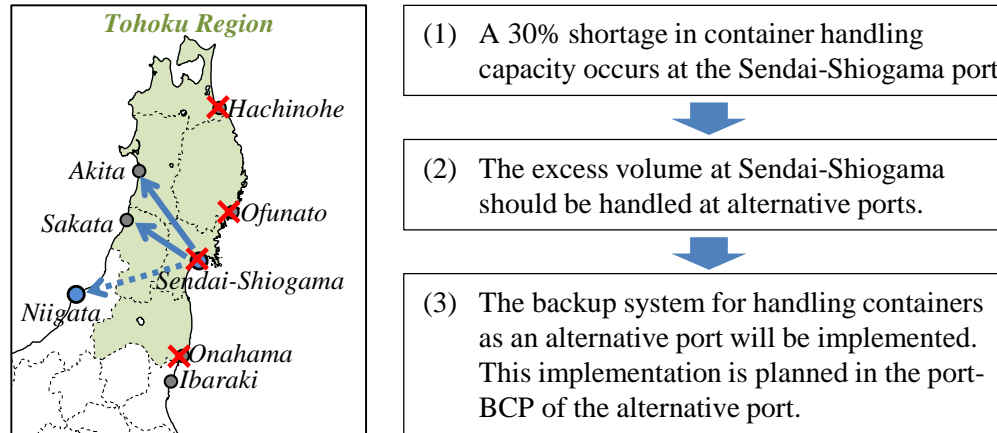
Figure 11. Coordination Procedure for Mobilizing Alternative Container Ports

6.2 Estimation Scenario and Procedure

Alternative port estimation for the Tohoku Regional Port-BCP is done by using the port choice model of this study. Two scenarios are developed for the estimation: (1) a recurrence of the Great East Japan Earthquake and Tsunami; and (2) a major earthquake and tsunami in the Sea of Japan that causes damage to ports in Akita, Sakata, and Niigata. The time point for estimations is 3 months after the earthquake and tsunami, with this time point chosen because the Takasago Container Terminal at Sendai-Shiogama port resumed service 3 months after the Great East Japan Earthquake and Tsunami. It is assumed that as a worst case, damaged ports stop all port functions.

The container volumes are set by the 2013 average monthly throughput, and the impact of the scenario earthquake and tsunami are estimated based on the recovery curve described in Section **3.2**. For the import level, it is assumed that the container volume for rehabilitation activity is equivalent to 25% of the ordinary volume at damaged ports (Akakura *et al.* 2013a). The handling capacity of each alternative port in the Tohoku region is set by choosing the smallest among the capacities of storage yard and stevedoring company operation, as described in Section 4.3. The additional capacity of temporary storage yards is assumed to be up to 40%, except for at Sendai-Shiogama port, which has no space to mobilize a temporary yard; also, the additional stevedoring capacity that can be obtained from companies at the damaged ports is assumed to be up to 50%. The calculation of the sacrifice model is done by the method described in Section 5.3.

At alternative ports, the increases in container volume will lead to increases in the number of calling container ships. After the Great East Japan Earthquake and Tsunami, increases in the number of calling container ships was directly proportional to the container volume, as shown in **Figure 12**. For this scenario, the number of calling ships at alternative ports is increased at same rate as the container volumes, except in cases where the increase is less than 15%.
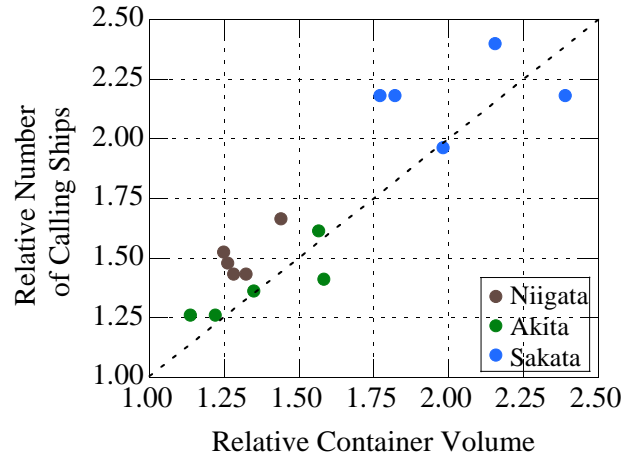
Figure 12. Increases in Container Volume and Number of Calling Container Ships

6.3 Estimation Result and Application to port-BCP

Figure 13 shows the estimation results for the scenario with damage on the Pacific side of the Tohoku region. The table of container volumes at alternative ports (right side of figure) shows that the volume of Sakata port is excessively increased if capacity constraints are not considered, and that the volume is decreased from the high estimate by considering capacity constraints. In the lower-right panel, the volume ratio of alternative transport containers at Sakata port also decreases by considering capacity constraints. This result indicates that the alternative transport containers, which would ordinarily be handled at the damaged ports, will gather at Sakata port; however, the handling capacity at Sakata port will not be sufficient. As the result, over half of the alternative transport containers will be handled by ports in the Tokyo Bay area.
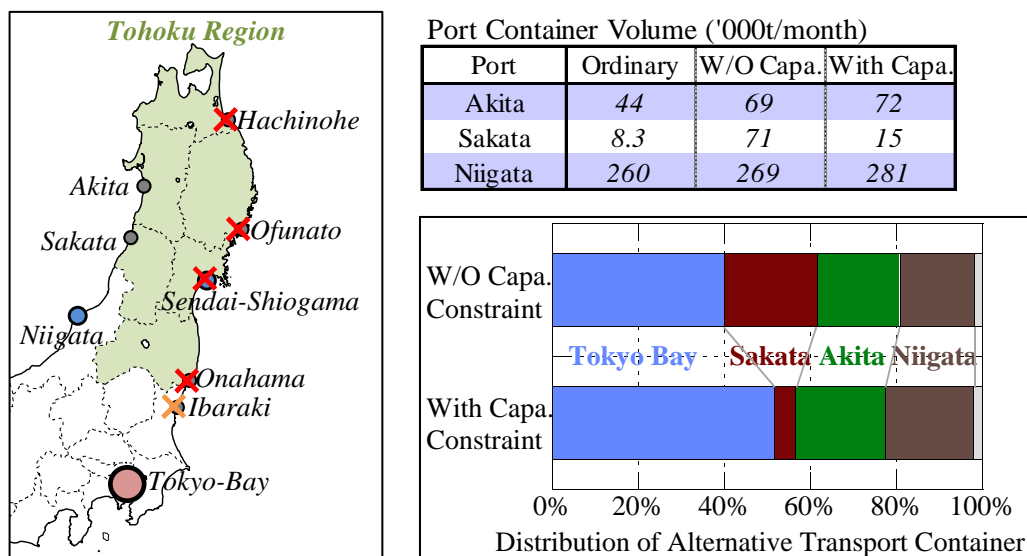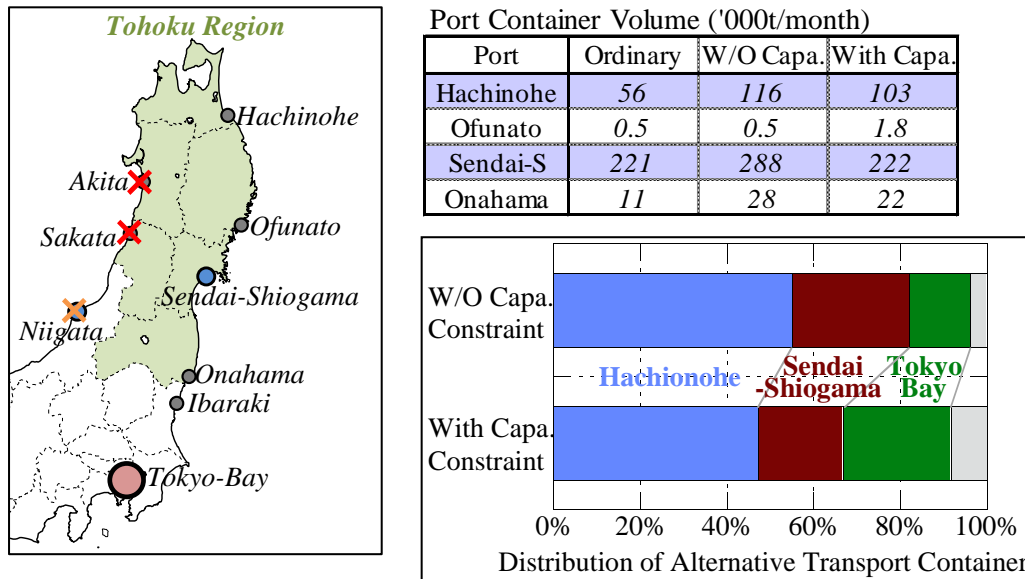

Port Container Volume ('000t/month)

Port	Ordinary	W/O Capa.	With Capa.
Akita	44	69	72
Sakata	8.3	71	15
Niigata	260	269	281

Figure 13. Estimation Result (Damage at the Pacific Side)

Figure 14 shows the estimation results for a scenario of damage to the west coast ports facing the Sea of Japan. The table in the upper right of the figure shows the estimated port container volumes at Hachinohe, Ofunato, Sendai-Shiogama, and Onahama ports. These results suggest that the container volume is somewhat higher without capacity constraints than with capacity constraints, except for at Ofunato port. From the graph in the right panel, the relative volumes for alternative transport containers at Hachinohe, and Sendai -Shiogama ports also decreased by considering capacity constraints. In this scenario, the handling capacities of Hachinohe, Sendai-Shiogama, and Onahama ports will not be sufficient to meet container cargo handling demand after the disaster.

Port Container Volume ('000t/month)

Port	Ordinary	W/O Capa.	With Capa.
Hachinohe	56	116	103
Ofunato	0.5	0.5	1.8
Sendai-S	221	288	222
Onahama	11	28	22

Figure 14. Estimation Result (Damage at the Sea of Japan Side)

As described in Section 6.1, one of the aims of the Tohoku Regional port-BCP is to coordinate alternative port use for container transport. From the estimation results, the handling capacity of alternative ports in the Tohoku region will not be sufficient for some scenarios. Therefore, each port is requested to prepare for mobilization as an alternative container port after an LSD and strengthen its handling capacity for that role as necessary in the port-BCP. This will become the second step in making the port-BCP for each port. Concretely, the first step for each port is to prepare the recovery of port services as soon as possible; the second step is to prepare to serve as an alternative port that supplies service to another port. As preparation for strengthening of handling capacity, cooperation among stevedoring companies at different ports is a key factor because stevedoring companies at each port maintain handling capacities sufficient only to their busiest time. They cannot afford to support idle machines and unnecessary staff; therefore, the support of stevedoring companies from the damaged ports will be quite important for increasing handling capacity at the alternative ports. In addition, sharing information between the damaged port and alternative port is a crucial factor because without accurate information shippers cannot smoothly select an appropriate alternative port. From this viewpoint, cooperation between port managers and between agencies should be established in advance. The stagnation of port logistics functions across the whole Tohoku region after an LSD can be avoided if smooth cooperation is ensured.

7.   CONCLUSIONS

In Japan, the possibility of a Nankai Trough earthquake and tsunami or an inland earthquake in Tokyo is a serious concern. The damage from the LSDs that would occur will have a destructive impact on the national economy. One of the measures that could mitigate possible future damage is to strengthen the resiliency of the supply-chain of industries. Preparing port-BCPs is one of the most important countermeasures against LSDs.

The aim of port-BCPs is to keep port users even after LSDs by maintaining the port functions at an acceptable level immediately after LSDs and accelerating the restoration to the required capacity. However, it is difficult to eliminate the supply-demand gap. Therefore, the preparation for container cargo handling at alternative ports in the port-BCPs is also very important.

This paper showed a method for identifying alternative ports while considering the handling capacities of those ports. Those capacities depend on the storage capacities and the capacity of the stevedoring companies. The previously developed sacrifice model was adopted for the port choice model and has been improved here to provide additional accuracy. To consider handling capacity, an iterative calculation method was proposed. The ability of the model to reproduce the effects of the Great East Japan Earthquake and Tsunami was improved by adopting the proposed calculation method. This method can be a powerful tool to strengthen the resiliency of maritime containerized transport.

In the Tohoku region, each port has been preparing a port-BCP, and, as further countermeasure against LSDs, a regional port-BCP is now being prepared by the Tohoku Regional Development Bureau of MLIT with the cooperation of the Regional Council of Tohoku Port-BCP. In this regional port-BCP, estimation of alternative ports in two scenarios for earthquakes and tsunamis was carried out by using the proposed port choice model. From the estimation results, the handling capacities of alternative ports in Tohoku region were not sufficient against both scenarios. Therefore, each port is requested to strengthen its capacity to act as an alternative port in the port-BCP by mutual cooperation. This process will strengthen the resiliency of port functions in the Tohoku region.

The authors will continue to research ways to contribute to the progress of developing port-BCPs for each port, each region, and the whole country to mitigate the future damage by LSDs such as a Nankai Trough earthquake and tsunami or an inland earthquake in Tokyo. A resilient logistics network is indispensable to the future of the Japanese economy.

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