Journal of the Eastern Asia Society for Transportation Studies, Vol. 6, pp. 4285 - 4299, 2005

MEASUREMENT OF THE IMPACT OF LOGISTICAL DISTRIBUTION NETWORK INTERRUPTION ON REGIONAL ECONOMY

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Abstract: Transportation network interruption seriously influences not only passenger transport but freight transport as well. Further, It adversely affects regional economic activitiy. Because among the adverse effects of transportation network interruption, regression of regional economy due to freight traffic decrease is most serious, the authors aimed to develop a method for measuring the amount of economic impacts caused by transportation network interruption. We created a method to calculate the amount of economic impacts by using an inter-regional input/output table. The developed method was applied to an actual case in Hokkaido, the interruption of rail freight transportation caused by Mt. Usu eruption. As a result of the calculation, the total damages in Hokkaido area were estimated to be 78 billion yens including those resulting from the ripple effects. The damages for agriculture and food industries were more serious than those for other fields.

Key Words: Logistical Distribution Network, Network Interruption, Economic Impact, Input/Output Table, Rail Freight Transportation

1. INTRODUCTION

Interruption of a traffic network resulting from a disaster or any other cause seriously influences both passengers and logistical distribution networks. Although there have been some studies on network interruption of passenger transportation, studies on interruption of logistical distribution were few. Since logistical distribution network is linked with regional economic activities, the damage on it is as serious as that on passenger transportation. For example, the eruption of Mt. Usu in Hokkaido, Japan in March 2000 suspended the rail freight transportation between Honshu and Hokkaido, which ravaged Hokkaido economy. Both freight transportation users and the railway company suffered the damage. The transportation users' damage resulted in deterioration of the whole regional economy. Although the value of the damages incurred by the JR Freight Company by Mt. Usu eruption has been clarified, the actual value of the damages brought to regional economy has not been identified. To clarify logistical distribution network effectiveness in the area and to construct a disaster resistant network, identifying actual damages caused by rail transportation suspension to the regional economy is required.

In this study, we aimed to develop a method for calculating the amount of damages caused by freight traffic interruption. For calculating the damages, we developed a method using an inter-regional input/output table. We aimed to clarify the impacts of the freight traffic reduction as an actual amount of damage taking into consideration a number of products and commodities that had been transported by the interrupted mode before the interruption. Furthermore, the developed method was applied to an actual case, the interruption of rail freight transportation caused by Mt. Usu eruption. We tried to calculate the economic damages resulting from rail freight traffic reduction to Hokkaido prefecture.

In other papers, the economic damages brought about by disasters have been estimated. For example, Takahashi et al. estimated the economic damages of Hanshin-Awaji Great Earthquake focusing on the reduction of production or consumption activities as the damage causes. However, the damages were estimated by using questionnaire survey results. Using questionnaire results is useful to identify economic damage details. However, there are some problems that if the damages estimated by using questionnaire results would reflect the reality when the response rate is low or responses' accuracy is not dependable. Moreover, industries targeted for the economic damage estimation are apt to be limited to specific ones. There by, this method is supposed to have difficulty to estimate the economic damages of all industries. In this study, we used the inter-regional input/output table. The feature of our study is that the economic damages of all industries can be estimated by using the inter-regional input /output table.

2. INFLUECES OF INTERUPTION OF LOGISITICAL NETWORK

Logistical distribution networks can be classified to intra-regional network and inter-regional one depending on the range. In case of logistical distribution network interruption brought about by disaster, both the local and inter-regional network interruptions influence economic activities of the afflicted area. However, the inter-regional network interruption even affects areas other than the area directly hit by disaster, and such secondarily affected areas damages could be greater than those of the main disaster area. The focus of this study was how to clarify the economic damages caused by inter-regional freight traffic interruption caused by disaster.

Logistical distribution network interruption brings about various influences. When a transportation service is interrupted, freights that should have been brought through the interrupted transportation will be transported via alternative routes or alternative transportation. It would result in longer transit time and in modifications of transportation service schedule. Longer transit time will make production and sales activities quite difficult, or will give damage to freights. When the transportation is changed from the interrupted one to another one, transportation cost will be increased, or freight quality may be deteriorated. It may be difficult to use an alternative route and an alternative transportation depending on transportation status or aerial circumstances. It will result in a serious decrease in freight traffic. Freight traffic decrease also is caused when traffic capacity of an alternative route or transportation is not enough compared with the usually used transportation. When neither materials nor goods arrive, production and sales of commodities are consequently halted. Further, it will even increase transportation user's labor and mental fatigue.

In this study, we considered the freight traffic decrease as the most serious problem caused by transportation interruption. The freight traffic decrease means that there exist freights which cannot be transported. This means that the original purpose of the logistical distribution network has not been achieved, which most seriously influences the regional economic activities. On the other hand, damages caused by delay in freight delivery due to lagging transportation service schedule need to be differentiated from those resulting from no-delivery of freights. That is because in case of the delay in freight delivery, the transported materials or goods will finally arrive at their destinations. Freight traffic decrease due to non-arrival of freights will make regional economic activities difficult so as to bring serious damages to regional economy. Therefore, we aimed to identify the economic damages caused by freight traffic decrease.

3. MEASUREMENT OF THE ECONOMIC IMPACTS OF TRANSPORTATION INTERRUPTION BY USING AN INTER- REGIONAL INPUT/OUTPUT TABLE

3.1 An Approach for Measurement of Economic Impacts of Transportation Interruption

We focused on the influence of freight traffic reduction due to network suspension, which adversely affects economic production and sales of local industries. Figure 1 shows the flow for the economic damages measurement. And we applied the inter-regional input/output table, and built the economic damages measurement approach. Even if a network is suspended due to a disaster, all transportation modes do not stop service. Even if a transportation mode which is influenced by the network suspension, there exist transportation modes which are not be influenced by the network interruption. To quantify the freight traffic reduction due to transportation interruption, we defined a rate of freight traffic change.

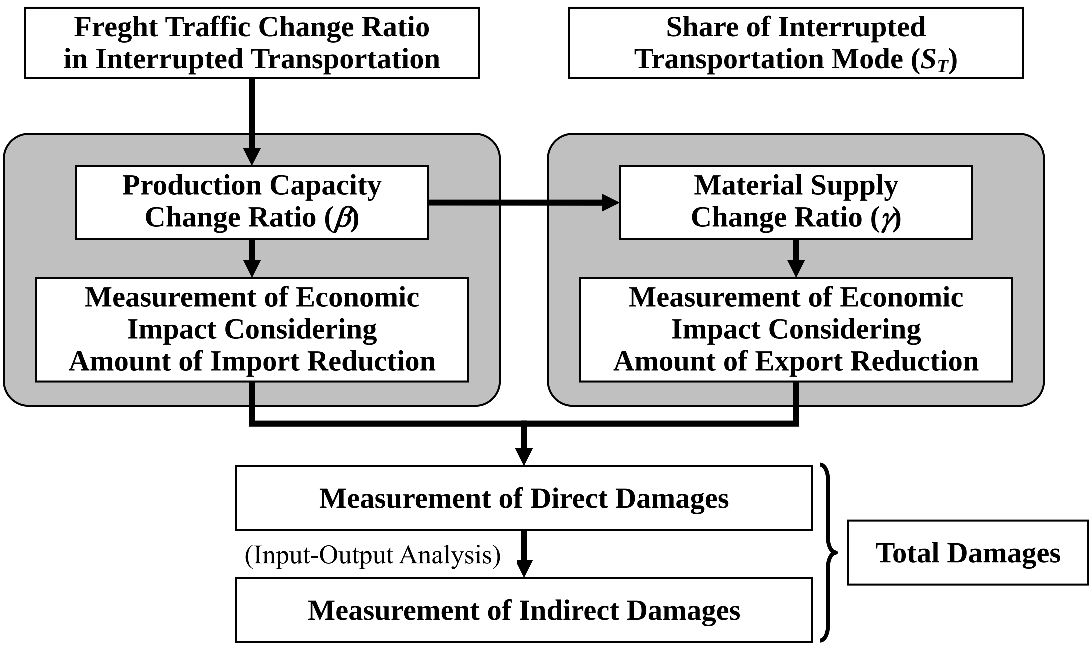

Figure 1. Measurement of Economic Damages in this Study

A rate of production change (β) and a rate of raw-material supply change (γ) are derived from the interrupted transportation' freight share and a rate of freight traffic change. The rate of raw-material supply derives the damages caused by production stoppage, and the rate of production change enables to measure the amount of damage resulting from goods sales difficulty. We defined the total amount of these damages as the damages directly induced by disaster. Thereby, we define the amount of damages directly caused by disaster is that of production activities and sales activities, which was caused by freight traffic reduction. Moreover, we performed inter-regional input-output analysis, which assumes the amount of damage as the negative final demand to seek the extended damages. We defined the damages of businesses customers of the businesses directly suffered from the production reduction and sales reduction as the indirect damages. The indirect damages are not supposed to influence reduction of inter-regional freight traffic.

In the measurement proceedings, clarifying interrelations between the freight items and individual industries is necessary. Therefore, we paid our attention to the non-competing inter-regional input/output table. This local catch crop business linkage table was created based on the Japan's national statistics table showing industry production. This table divides the whole country into nine areas and summarizes and charts inter-industries dealings within a local area as well as among different. In this study, we measured the economic damages due to transportation interruption focusing on a region. For simplifying the explanation, we regarded regions other than the target region as one region, and developed the inter-regional input/output table between the assumed two regions. To measure the economic damages using the inter-regional input/output table, one industry was supposed to produce only one product.

Table 1. Concept of the Integrated Inter-regional Input/Output Table

		Middle Demand								Final Demand		Export	Import	Total Production
		Region r				Region s				Region r	Region s			
		Industry 1	Industry 2	⋯	Industry j	Industry 1	Industry 2	⋯	Industry j					
Region r	Industry 1	x_{11}^{rr}	x_{12}^{rr}	⋯	x_{11}^{rr}	x_{11}^{rs}	x_{12}^{rs}	⋯	x_{11}^{rs}	F_1^{rr}	F_1^{rs}	E_1^r	M_1^r	X_1^r
	Industry 2	x_{21}^{rr}	x_{22}^{rr}	⋯	x_{21}^{rr}	x_{21}^{rs}	x_{22}^{rs}	⋯	x_{21}^{rs}	F_2^{rr}	F_2^{rs}	E_2^r	M_2^r	X_2^r
	⋮	⋮	⋮		⋮	⋮	⋮		⋮	⋮	⋮	⋮	⋮	⋮
	Industry j	x_{j1}^{rr}	x_{j2}^{rr}	⋯	x_{jj}^{rr}	x_{j1}^{ss}	x_{j2}^{ss}	⋯	x_{jj}^{ss}	F_j^{rr}	F_j^{rs}	E_j^r	M_j^r	X_j^r
Region s	Industry 1	x_{11}^{sr}	x_{12}^{sr}	⋯	x_{11}^{sr}	x_{11}^{ss}	x_{12}^{ss}	⋯	x_{11}^{ss}	F_1^{sr}	F_1^{ss}	E_1^s	M_1^s	X_1^s
	Industry 2	x_{21}^{sr}	x_{22}^{sr}	⋯	x_{21}^{sr}	x_{21}^{ss}	x_{22}^{ss}	⋯	x_{21}^{ss}	F_2^{sr}	F_2^{ss}	E_2^s	M_2^s	X_2^s
	⋮	⋮	⋮		⋮	⋮	⋮		⋮	⋮	⋮	⋮	⋮	⋮
	Industry j	x_{j1}^{sr}	x_{j2}^{sr}	⋯	x_{jj}^{sr}	x_{j1}^{ss}	x_{j2}^{ss}	⋯	x_{jj}^{ss}	F_j^{sr}	F_j^{ss}	E_j^s	M_j^s	X_j^s
Added Value		V_1^r	V_2^r	⋯	V_j^r	V_1^s	V_2^s	⋯	V_j^s					V
Total Investment		X_1^r	X_2^r	⋯	X_j^r	X_1^s	X_2^s	⋯	X_j^s	F^r	F^s	E	M	

3.2 Variables Used in This Study

A rate of freight traffic change, a rate of production volume change and the rate of raw-material supply change were used in this study. We expressed the amount of freight traffic reduction by transportation interruption with the freight traffic change ratio. A freight traffic change ratio is expressed as α in the formula (1). We calculated the freight traffic change ratio in a certain fiscal year. When transportation service is halted by disaster, it is assumed that there exist items whose transportation is stopped. In that case, the untransportable items at the time of the interruption are supposed to be shipped after the transportation restoration. As we calculated traffic rate change per fiscal year, industries that did not ship products until transportation restoration and items which handled by them were excluded from the measurement.

$$\alpha_i^{rs} = \frac{Q_{Ti}^{rs} + Q_{T'i}^{rs}}{Q_i^{rs}} \tag{1}$$

α_i^{rs}: the freight traffic change ratio from Region *r* to *s* for Industry *i* ($0<\alpha<1$)
Q_{iT}^{rs}: freight traffic volume from Region *r* to Region *s* for Industry *i* in the case of using interrupted transportation *T*
$Q_{iT'}^{rs}$: freight traffic volume from Region *r* to Region *s* for Industry *i* in the case of using non-interrupted Transportation *T'*
Q_i^{rs}: total freight traffic when transportation does not stop service

We defined the production capacity change ratio as β and material supply change ratio as γ by using the interrupted mode's share S_T and freight traffic change ratio α. These variables are derived by transactions dealings from the Industry I to industry *j* in the input/output table between the areas. Here, we assume that the inter-industry transaction value is determined by the freight traffic volume between the industries. The inter-industry transaction value is divided into that by certain transportation and that by the other transportation as the formula (2).

$$x_{ij}^{rs} = S_{Ti}^{rs} x_{ij}^{rs} + (1 - S_{Ti}^{rs}) x_{ij}^{rs} \tag{2}$$

x_{ij}^{rs}: the transaction value from an Industry *i* to *j*
S_{Ti}^{rs}: the share of transportation mode *T* from Region *r* to Region *s*

When a certain transportation mode stops service, it is thought that the transactions using the transportation would decrease according to freight traffic change ratio α. The transaction value in that case is shown in the formula (3). We defined variable β as the production capacity change ratio. The production capacity change ratio means the reduction rate of traffic amount between Industry *i* and Industry *j*, which is from Region *r* to Region *s* when transportation service is interrupted. Thereby, the production change of Industry *i* is derived by multiplying the transaction value of Industry *i* by production change ratio β.

$$\begin{aligned} x_{S\,ij}^{rs} &= \alpha_i^{rs} S_{Ti}^{rs} x_{ij}^{rs} + (1 - S_{Ti}^{rs}) x_{ij}^{rs} \\ &= \{1 - (1 - \alpha_i^{rs}) S_{Ti}^{rs}\} x_{ij}^{rs} \\ &= \beta_i^{rs} \cdot x_{ij}^{rs} \end{aligned} \tag{3}$$

x_{Sij}^{rs}: the transaction value from Industry *i* to Industry *j* when Transportation *T* is interrupted
β_i^{rs}: the production capacity change ratio for Industry *i* from Region *r* to Region*s*

Next, the influence of decrease of the freight imported from the outside of a region on production within the region was identified by using the concept of the expense composition in the inter-regional input/output table. The expense composition that is divided into that for commodity purchase within a region, and that for the purchase outside the region is shown by the formula (4). Moreover, when certain transportation stops service, the freight import amount by the transportation is supposed to decrease at a rate expressed as β. Therefore, the import transaction value of a certain industry as a whole is shown by the formula (5).

From the formula (4) and (5), the ratio between the import amount when the transportation is not interrupted and that when transportation is interrupted is derived. We defined this variable γ as the material supply change ratio. The material supply change ratio means a ratio between the amount of certain product's raw material which can be supplied when a mode of transportation is interrupted and its amount when the transportation is not interrupted. And the values differ by every product used as raw material.

$$x_{ij}^{s} = x_{ij}^{ss} + x_{ij}^{rs} \tag{4}$$

$$x_{Sij}^{s} = x_{ij}^{ss} + \beta_{i}^{rs} \cdot x_{ij}^{rs} \tag{5}$$

x_{ij}^{s}: the whole expense composition when transportation does not stop service
x_{ij}^{ss}: the expense composition for Region *s* (ex. within the region)
x_{ij}^{rs}: the expense composition for Region *r* (ex. outside the region)
x_{Sij}^{s}: the whole expense composition when a certain transportation stops service

$$\gamma_{ij}^{s} = \frac{x_{ij}^{ss} + \beta_{i}^{rs} \cdot x_{ij}^{rs}}{x_{ij}^{s}} \tag{6}$$

γ_{ij}^{s}: the material supply change ratio from Industry *i* to Industry *j* for Region *s*

4. MEASUREMENT OF ECONOMIC DAMAGES TAKING INTO CONSIDERATION INDUSTRIAL PRODUCTION AND RETAIL SALE

4.1 Measurement of Economic Damages Resulting From a Decrease in Import and Export of Freights

When measuring the economic damages caused by transportation interruption, we focused industrial production activities and retail sales. Status of freight import and export greatly influences regional economic activities including goods production and sales. When a region is considered as one economic unit, freight import and export can be regarded as "input" and "output", respectively. The freight import regarded as "input" of an economic unit is indispensable for economic activities, so that its economic impact range is extensive. Depending on the kind of industry, forms of economic activities using imported freights vary.

In this research, we classified industries into the following three categories and measured the economic impact of transportation interruption on the respective category of industry. We assumed that transportation volume is in proportion to the transaction value that requires transportation of goods. In addition, even if a transportation is interrupted, we assumed that the trading ratio between industries which mutually trade raw material or retail sales and others is constant, and that other goods cannot be substituted for raw materials of a certain product as well as that production factors (capital, labor and location etc.) other than freight transportation status are constant. The manufacturing industry discussed in this study includes agriculture and fishery.

4.1.1 Measurement of Economic Impact in Manufacturing Industry

A manufacturing industry produces certain goods and obtains profits. If the amount of imports from outside of the area where the industry is located decreases, it results in reduction of necessary raw material supply, which may be even led to goods production halt. The amount of the damage brought about by the production halt can be derived from the expense composition of the inter-regional input/output table. Here, the ratio that the target industry’s purchase amount of raw materials from other industries is assumed to be constant even at the time of transportation interruption. In that case, the production amount is supposed to depend on an item whose material supply change ratio γ comes to be the minimum.

For instance, in chocolate production, cacao and sugar will serve as the raw materials. Chocolate cannot be produced only with cacao. That is, even if the amount of cacao import does not decrease, when the amount of sugar import decreases, the volume of chocolate production will decrease. If this applies to the expense composition of the inter-regional input/output table, the damages of Industry *j* would be determined by the damages of a relevant industry whose material import amount from the outside of the area decreased most. Therefore, we measured the amount of the damages from the Leontev type production function. The formula to calculate the amount of the damages is shown as follows.

$$\Delta XI_j^s = X_j^s \left\{1 - \min\left(\gamma_{1j}^{rs}, \gamma_{2j}^{rs}, \cdots, \gamma_{ij}^{rs}\right)\right\} \quad (7)$$

ΔXI_j^s: the damages of an Industry *j* whose material import decreases
γ_{nj}^{rs}: the material supply change ratio between Industry *n* in Region *r* to Industry *j* in *s*

4.1.2 Measurement of the Economic Impact of Transportation Interruption on the Retail Industry

Retailers obtain profits selling certain goods. The profits cannot be obtained when the goods to be sold do not exist. The amount of damage of the retail industry can be derived from the expense composition of the inter-regional input/output table like the damages of the manufacturing industry. However, different from the manufacturing industry, the damages of the retail industry will be caused only by goods traffic decrease. For example, when the amount of sugar import decreases, the amount of sugar sales decreases in proportion to the sugar import decrease. However, even if the sugar import is decreased, if the amount of cacao import is not decreased, the amount of cacao sales will not change. That is, the only retail industry which sales the items whose import decreased would suffer damages. Therefore, the amount of the damage of industry *j* is shown as follows.

$$\Delta XI_j^s = \sum_i (1 - \gamma_{ij}^s) x_{ij}^s \quad (8)$$

ΔXI_j^s: the damages of Industry *j* whose material import decreased in Region *s*
γ_{ij}^s: the material supply change ratio from Industry *i* to *j* in Region *s*
x_{ij}^s: the expense composition from Industry *i* to Industry *j*

4.1.3 Measurement of Economic Impact of Transportation Interruption on the Service Industry

The service industry obtains profits providing others with a certain service. Some goods transported from the outside of an area may deeply relate to the service but others may not. Since service industries vary in their business status, it is difficult to consider all service industries identically. There will be few cases that certain imported goods directly affect a service. Moreover, overestimation of damages should be avoided in the measurement. Therefore, in this study, the service industry was supposed not to be influenced by freight traffic decrease, which is shown by the following formula.

$$\Delta XI_j^s = 0 \quad (9)$$

ΔXI_j^s: the damages of Industry *j* whose material import decreased in Region *s*

4.2 Measurement of Economic Impact of Export Decrease due to Transportation Interruption

Industries that are adversely affected by a decrease in export traffic volume as output is limited. The business relations between industries shown in the inter-regional input/output table represent monetary transactions. There are two types of transactions in the relations. One is a sort of transaction which involves goods transfer; another is that does not include goods transfer. The industry that dose not involve goods transfer will not be directly influenced by a decrease in freight export. In other words, only industries whose output is material goods are to be influenced by freight export decrease. In this sense, only manufacturing industry will be affected by freight export decrease. The inter-industrial retail sales amount can be estimated from the market composition in the industry input/output table. Here, suppose the composition of the selling ratio from industry *i* to other industries is constant. In that case, the amount of industry *i*'s damages caused by interruption of a transportation service is proportional to the freight traffic change ratio (α) derived by the formula below.

$$\Delta XE_i'^s = \left(1 - \beta_i^{sr}\right)\left(\sum_j x_{ij}^{sr} + F_i^{sr}\right) \tag{10}$$

$\Delta XE'^s_j$: The damages of Industry *i* caused by the export decrease in Region *s*
F_i^{sr}: Final demand of Industry *i* between Region *s* and Region *r*

The damages caused by retail sales reduction include those resulted from production decrease. When production of certain goods is decreased due to transportation interruption, the amount of the goods sales decrease is supposed to be equivalent to the goods production decrease. That is, the damages derived by the formula (10) include those caused by the decrease of import from the outside of an area. Thereby, the damages brought about by export decrease to outside of the area shown by the formula (10) exclude the effects of import decrease form outside of the area. Therefore, the economic impact of transportation interruption by focusing retail sales is shown in the following formula.

$$\Delta XE_i^s = \Delta XE_i^{s\,\prime} - \Delta XI_j^s \geq 0 \tag{11}$$

ΔXE_j^s: the damages of Industry *i* considering production decrease in Region *s*

5. APPLICATION TO A PRACTICAL CASE OF TRANSPORTATION INTERRUPTION DUE TO MT. USU ERUPTION

5.1 Alternative Routes and Transportations when Mt. Usu Erupted

Mt. Usu located in southwest Hokkaido erupted on March 31, 2000. This eruption interrupted a part of JR (Japan Railway) Muroran Line, and the interruption continued for about two months. (Figure.2) The interrupted section served for not only passenger trains but many freight trains. In the freight transport between Hokkaido and Honshu, rail freights amount to about mere 10% of the total by freight weight. However, products of agriculture, forestry and fishery that are main Hokkaido products are transported by rail, which also include a number of life relevant goods. Therefore, the JR Freight firm invested about 2,200 million yen, and secured the following alternative transportation routes. (Figure. 3 and 4)

Figure 2. Damage to JR Muroran Line

Figure 3. Freight Transportation Network Between Hokkaido and Honshu

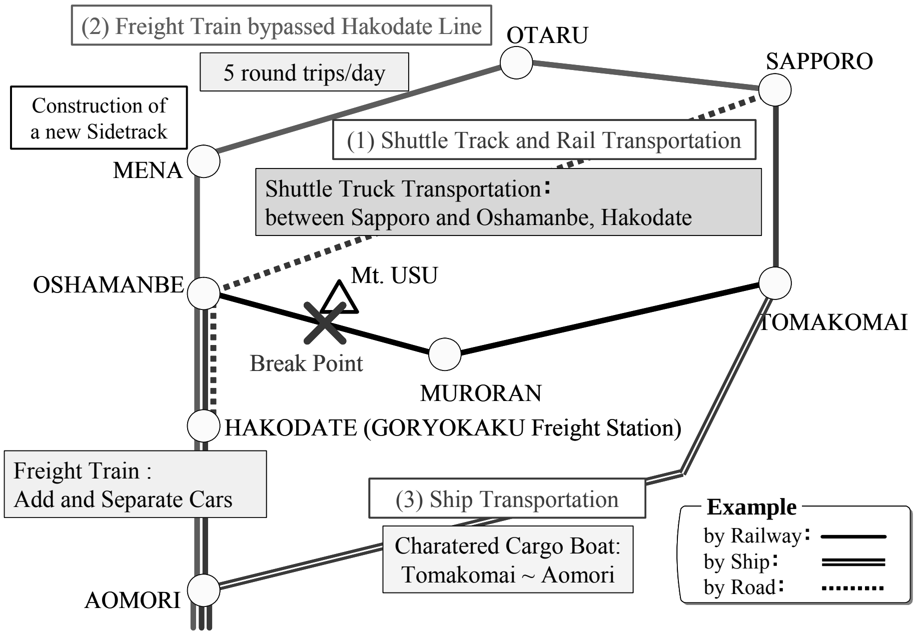

Figure 4. Alternative Routes and Rail Freight Transportation Modes When Mt. Usu Erupted in 2000

(1) Shuttle truck transportation, and rail transportation to and from Goryokaku Sta.

Because the rail transport interruption in the Muroran Line, the alternative truck transportation service between Goryokaku freight station in Hakodate and the Sapporo freight terminal started from March 29, 2000. Moreover, in addition to the alternative truck transportation, temporary freight train service started connecting Goryokaku freight station and rail freight depots all over Japan. The freight trains of 5 round trips ran per day. However, problems such as overdue of cargo transport period had occurred at the Goryokaku freight station. Therefore, a temporary container home was installed at Oshamanbe station close to Hakodate on April 21, and operation no. of freight trains was increased to seven round trips per day. As a result, the section of the alternative truck transportation was shortened to improve the alternative transportation efficiency.

(2) The freight train which bypassed the Hakodate Line.
The freight trains which bypassed the Muroran Line via Hakodate Line (Sapporo-Otaru-Oshamanbe) started operating from March 30, 2000. Not only freight trains but passenger trains were bypassing via Hakodate Line. That is, the Hakodate line via which the trains bypassed the interrupted section had played a role of an alternative route in railroad transportation. However, it had the problem that the Hakodate Line section's rail specification standard was low. Since it was not available for a train consisted of a long line of cars coupled together, short trains usually ran. Therefore, in the Goryoukaku freight depot, cars were added or separated to the freight train which bypassed the Hakodate Line. Moreover, since the Hakodate Line section was single track, the same no. of train operation as usual was not possible.

(3) Ship transportation as an alternative transportation mode
Transportation by chartered cargo boat also started from April 1, 2000. Cargo boats operated between Tomakomai port in Hokkaido and Higashi-Aomori port in Honshu, and other sections. The operation continued till June, 2000 when the rail transportation interruption was restored.

The freight traffic by detour train was dominant immediately after the eruption. However, the alternative truck transportation increased after May when the enough number of trucks were secured. On the other hand, the freight traffic by alternative sea transportation remained minor. The long interval of sea transport operations was supposed to be the reason. The railroad operation in the interruption section was resumed on April 29. Although this was limited to daytime, the freight traffic was recovered even to 90% of the usual operation. 24 hour operation was resumed on June 8 and the number of train operations which run the interruption section was mostly restored to the usual status. At the same time, operation of detour train service and the alternative sea transportation came to the end.

5.2 Application of the Damage Measurement Method to the Case of the Network Interruption due to Mt. Usu Eruption

At the time of Mt. Usu eruption, the JR Freight firm made efforts to maintain the transportation capacity. Therefore, the fall of transportation capacity was restrained to the minimum. Nevertheless, the decrease in the amount of freights transported by rail to and from Hokkaido brought about serious damage to the regional economy. Before the Mt. Usu eruption, there were examples that rail freight transport service stopped due to heavy rain or heavy snowfall disasters. However, the longtime interruption of rail freight transport caused by Mt. USU eruption was unprecedented. We applied the proposed damage measuring approach to the case of Mt. Usu eruption, and clarified the economic impact of the rail transport interruption.

We calculated the rail freight volume between Honshu and Hokkaido on the basis of the data of the Railroad Statistics Annual Report and that of other transportation modes referring to inter-regional freight flow investigations. However, the classification of transportation goods differs between the Railroad Statistics Annual Report and the inter-regional freight flow investigation. Further, these classifications differ from the classifications of the inter-regional input/output table. For using the damage measurement method that is proposed in this study, it is necessary to match the classifications of transportation goods and industries. We organized transportation goods that are included in the Railroad Statistics Annual Report and the inter-regional freight flow investigation as 32 goods. Comparing the 32 goods with 46 industries in the inter-regional industry input/output table, we extracted 28 industries which are associated with freight transportation and classified them as corresponded to relevant goods.

Table 2. Integration of Industries and Transportation Goods

INDUSTRY (Input/Output Table)	TRANSPORTATION GOODS (Freight Flow Investigetion etc.)
Agriculture	Grain
	Vegetable and Fruits
	Other Agricultural Production
	Stock Farm Products
Forestry	Wood
	Firewood and Charcoal
Fishery	Marine Products
Mining	Coal
	Mineral Ores
	Sand and Gravel
	Limestone
Food and Tobacco	Foodstuffs
Textile Industry	Textile Products
Furniture and Equipment	Daily Goods
Pulp and Paper	Paper and Pulp
Publication and Print (Paper Manufacuture)	
Chemicals	Pharmaceutical Products
	Chemical Fertilizer
	Other Chemical Products

INDUSTRY (Input/Output Table)	TRANSPORTATION GOODS (Freight Flow Investigetion etc.)
Petroleum and Coal Product	Petroleum Products
Ceramic, Soil and Stone Product	Cement
	Ceramic Products
Steel Products	Steel
Nonferrous Metal Product	Nonferrous-metal
Metal Product	Metal Products
General Machine	Machine
Machine for Office	
Consumer Electraical Machine	
Electro and Communications Machine	
Other Electrical Machine	
Car	
Precision Machine	
Leather and Leater Product	Ohter Industrial Product
Rubber Porduct	
Other Manufacture	

As mentioned above, we identified the freight traffic rate change per fiscal year. The transportation modes between Hokkaido and Honshu are rail, cargo boat, and truck brought by car ferry. When Mt. Usu erupted, ports were scarcely damaged. Therefore, transportation by cargo boat and car ferry was not influenced by the eruption. We derived the freight traffic rate change of rail transport separating it from the rate of other transportation modes. The freight amount transported by cargo boat, the alternative transportation which JR Freight Company carried out was included in the freight amount transported by rail. To calculate the rate of rail freight volume, the freight volume before Mt. Usu eruption needed to be identified. The rail freight volume of the last fiscal year before the eruption could be useful. However, the freight volume between Hokkaido and outside Hokkaido varies every fiscal year by transportation mode. Therefore, using the value of a specific fiscal year was not supposed to be appropriate. We applied regression analysis and estimated the rail freight volume by goods item when the transportation did not stop service.

5.3 Economic Impact Caused by Network Interruption

By using the proposed method, we calculated the direct economic damages by transportation network interruption at the time of Mt. Usu eruption. The calculation result identified the amount of damage that the rail freight volume decrease directly brought to the rail freight users. The damages caused by decrease in freight import volume are shown in Table.3 and those brought by decrease in freight export volume are shown in Table.4. The total amount of direct damage was about 50 billion yen. As a result of the decrease in rail freight import, the damage in "food and tobacco" industries was serious. And, the paper industry and agriculture ranked behind it. Because these are main industries in Hokkaido and their production volume is huge, their damages were supposed to amount to be greater compared with other industries. Agriculture suffered serous damages as a result of the freight export reduction. And, the textiles industry ranked behind it. It means that the interruption of rail transportation significantly influenced agriculture which is the key industry of Hokkaido. Agriculture needs frequent product export. In addition, fresh agricultural products cannot be stored long so that they are required to be shipped out shortly after harvested and the shipping timing cannot be changed. These agriculture specific factors made its damage amount larger than that of others.

Table.3 Economic Impact from Decrease of Import Freight Traffic (Million YEN)

	β	S_T	Minimum γ	Impact
Agriculture	1.000	0.142	0.998	3,161
Forestry	1.000	0.334	0.996	747
Fishery	1.000	0.015	0.996	1,246
Mining	0.992	0.007	1.000	33
Food, Tobacco	0.931	0.277	0.996	11,136
Textiles	1.000	0.844	0.996	381
Furniture	0.000	0.000	1.000	28
Paper Industry	1.000	0.348	0.996	3,999
Chemicals	1.000	0.241	0.992	1,095
Petroleum and Coal Product	0.589	0.001	0.995	2,610
Soil and Stone Product	1.000	0.070	0.994	1,924
Steel Product	1.000	0.007	1.000	37
Nonferrous-metal Product	1.000	1.000	1.000	1
Metal Product	0.000	0.000	1.000	70
Machine Industry	1.000	0.029	1.000	160
Other Industrial Product	1.000	0.234	0.998	898
Construction an Repair Industry			1.000	487
Social Project			1.000	374
Other Industry for Construction			1.000	86
Commerce			0.991	13
TOTAL				28,484

Table 4. Economic Impact from Decrease of Export Freight Traffic (Million YEN)

	β	S_T	Minimum γ	Impact
Agriculture	0.937	0.409	0.974	15,741
Forestry	0.999	0.298	1.000	0
Fishery	1.000	0.028	1.000	0
Mining	1.000	0.003	1.000	0
Food, Tobacco	0.975	0.181	0.995	0
Textiles	0.538	1.000	0.538	4,697
Furniture	0.000	0.000	1.000	0
Paper Industry	1.000	0.070	1.000	0
Chemicals	0.908	0.276	0.975	0
Petroleum and Coal Product	1.000	0.000	1.000	0
Soil and Stone Product	0.907	0.009	0.999	0
Steel Product	1.000	0.000	1.000	0
Nonferrous-metal Product	0.506	0.350	0.845	587
Metal Product	0.000	0.000	1.000	0
Machine Industry	1.000	0.035	1.000	0
Other Industrial Product	1.000	0.131	1.000	0
TOTAL				21,024

In the total amount of direct damages including those caused by freight import and export reduction, the amount of the damage for agriculture was most serious. And, the food and tobacco industries ranked behind it. The direct damages of these two industries amounted to about 60% of the whole damages. Comparing the damages caused by freight import and export reduction, the freight import reduction resulted in more serious damage than the export's, and as a result, a variety of industries in Hokkaido suffered the damage. It means that the amount of freight import to Hokkaido exceeds that of export from Hokkaido, and the damages that were brought about by the freight traffic reduction was limited to the industries which export their products from Hokkaido. Mt. Usu erupted in spring. If it erupted in autumn when agricultural freight export especially increases because the autumn is the harvest season, the agricultural damages due to the reduction of freight export would be worse.

Table 5. Total Economic Impact in Hokkaido Area (Million YEN)

	Direct Impact	Indirect Impact	Total Impact
Agriculture	18,902	6,240	25,142
Forestry	747	489	1,236
Fishery	1,246	1,305	2,551
Mining	33	543	576
Food, Tobacco	11,136	2793	13,929
Textiles	5,077	148	5,225
Furniture	28	30	58
Paper Industry	3,999	1,837	5,836
Chemicals	1,095	873	1,968
Petroleum and Coal Product	2,610	644	3,254
Soil and Stone Product	1,924	255	2,179
Steel Product	37	125	162
Nonferrous-metal Product	588	64	652
Metal Product	70	194	264
Machine Industry	160	133	293
Other Industrial Product	898	485	1,383
Construction an Repair Industry	487	342	829
Social Project	374	0	374
Other Industry for Construction	86	0	86
Electric Power	0	1,031	1,031
Gas and Heat Supply	0	27	27
Water and Waste Disposal Service	0	165	165
Commerce	13	2,196	2,209
Finance and Insurance	0	2,317	2,317
Real Estate	0	364	364
Transportation	0	1,713	1,713
Communication and Broadcast	0	277	277
Official Business	0	43	43
Education and Research	0	427	427
Medical and Social Security	0	0	0
Other Public Services	0	66	66
Business Services	0	2,263	2,263
Services for an Individual	0	38	38
Others	0	712	712
TOTAL	49,508	28,139	77,647

In this study, we conducted the input-output analysis which regarded the amount of direct damage as the negative final demand. And, we calculated the indirect damages caused by the rail freight reduction at the occasion of Mt. Usu eruption. The amount of indirect damage and that of the total damage including the indirect and direct damage that were derived from the input-output analysis are shown in Table 5. The rail freight transportation interruption due to Mt. Usu eruption resulted in the total amount of the damage including that of the ripple effect amounted to about 78 billion yen. The gross product of Hokkaido shown in the inter-regional input/output table is about 50 trillion yen, and the total amount of the damage was equivalent to 0.2% of Hokkaido's gross product in 2000. We assumed that there was no direct damage to the service industry. Therefore, the direct damages tended to be larger for the primary and secondary industries than the tertiary industry, and the indirect damages tended to be larger for the tertiary industries than that for others. However, in "agriculture" and "food and tobacco" both direct and indirect damages were larger compared with those for other industries.

6. CONCLUSION

In this study, we developed an approach of measurement of network interruption's economic impacts, which uses the inter-regional input/output table focusing on the freight traffic reduction by stoppage of a logistical distribution network. The proposed measurement method is taking into consideration economic activities including production and sales, and the calculated damages are not limited to part of industries'. By applying the method to Mt. Usu eruption disaster, it was clarified that proposed method could be applied to an actual case of logistical distribution network interruption. As a result of applying the measurement approach to the Mt. Usu disaster, the identified economic damages in Hokkaido amounted to about 78 billion yen. As for damages by industry, the amount of damage of "agriculture" and "food and tobacco" amounted to the half of the whole, and it was clarified that the rail freight transportation interruption has largely affected these industries. However, the damages were those when JR Freight Company operated alternative transportations, thereby if JR Freight did not operate the alternative transportations, the amount of damages might be still larger. The JR Freight Company paid about 2.2 billion yen for operating the alternative transportations. Considering the amount of the direct disaster damage was about 50 billion yen, this investment was reasonable.

In this study, we measured the economic impact of the disaster focusing on freight traffic reduction. However, the adverse effect caused by freight transportation interruption is not only a decrease in freight traffic volume. Transit time increase and time delay to freight arrival will also seriously affect regional economic activities. At the occasion of Mt. Usu eruption, freight transit time increased since many cargoes stuck at freight stations. We need to build a method for calculating economic damage taking into account influences of time delay to freight arrival on economical activities. Moreover, the method proposed in this study includes a number of assumptions, and applicability of these assumptions to an actual case needs to be verified.

Although this study focused on Mt. Usu eruption, other than a case of a disaster, various cases of rail freight suspension between Hokkaido-Honshu could be considered. During the construction work of the Hokkaido Shinkansen which is being currently planned, the rail traffic may be restrained or even temporally suspended. And when it becomes available, rail freight traffic may be decreased because transportation capacity through the Seikan Undersea Tunnel is limited, while passenger transport service by Shikansen may be increased. Toward realization of the Hokkaido Shinkansen, it is important to consider how to maintain freight shipping traffic between Hokkaido and Honshu as well as passenger transport.

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