A Vulnerability Scanning Methodology Applied To Multiple Logistics Transport Networks in Hokkaido

Qianqian DU[1], Nobunori AIURA[2], Takashi NAKATSUJI[3], Kunihiro KISHI[4]

[1]Graduate School of Engineering, Hokkaido University, Sapporo, 060-8628, Japan
(Kita 13, Nishi 8, Kita-ku, Sapporo, Japan)
E-mail: duqianqianzju@gmail.com
[2]Hokkai School of Commerce, 062-8607, Sapporo, Japan
(6-6-10 Toyohira, Toyohira-Ku, Sapporo, Hokkaido 062-8607, Japan)
E-mail: aiura@hokkai.ac.jp
[3]Faculty of Engineering, Hokkaido University, Sapporo, 060-8628, Japan
(Kita 13, Nishi 8, Kita-ku, Sapporo, Japan)
E-mail: naka@eng.hokudai.ac.jp
[4]Faculty of Engineering, Hokkaido University, Sapporo, 060-8628, Japan
(Kita 13, Nishi 8, Kita-ku, Sapporo, Japan)
E-mail: kishi@eng.hokudai.ac.jp

Transport is a fundamental part of logistics activities, which play a critical role in society development. The safety and reliability of logistics transportation networks significantly impact those activities. Network vulnerability assessment has been applied in passenger transport mode. However, the methodology to assess vulnerability of logistics transportation networks should be developed in a different way to passenger or other transport modes because of its specific requirements for trip success. This paper proposes a methodology suitable for application in logistics transportation network vulnerability assessment. Logistics value is included in the generalized cost of logistics transportation in order to evaluate the performance of logistics transportation networks. Moreover, network vulnerability assessment is impacted by the nature of the component degradation. Here, the performance of logistics transportation networks is evaluated in different transportation facility degradation scenarios. A vulnerability scanning algorithm is applied in both link and node degradation scenarios. In order to reduce computational demands, an efficient vulnerability scanning algorithm is applied to the simulation and a computer program is developed to make this methodology feasible in large scale networks. Finally, this methodology is applied in a real logistics transportation network in northern Japan, based on the future high-speed railway planning. The assessment of vulnerability of future logistics transport network in northern Japan may provide direction of transportation network vulnerability resistance planning to road network administration. The research was also undertaken to assist logistics managers, researchers and transportation planners to define and comprehend the basic views of vulnerability of logistics transportation networks and their various applications.

Key words: *logistics transportation network, vulnerability, logistics time value*

1. INTRODUCTION

1.1 Vulnerability of logistics transport network

Logistics activities serve as the bridge between production and consumption which is usually separated by time and distance. They play one of the most important roles in the modern society, especially in the economic. They play one of the most important roles in modern societies. For example, the total logistics costs incurred by organizations in the United States in 1997 were $862 billion, corresponding to approximately 11% of the United States' gross domestic product. This cost was higher than the combined annual United States government expenditure in social security, health care services, and defense. Its main objective is to get the right materials to the right place at the right time while optimizing the total operational costs of this process[1)]. Increasingly competitive markets are making it imperative to manage logistics systems more efficiently. Transportation services link a set of facilities in a logistics system. These transportation services move materials between facilities using vehicles and equipment including trucks, tractors, containers, cars, and trains. The operation of transportation determines the efficiency of moving products. The progress in techniques and management principles improves the moving load, delivery speed, service quality, operation costs, the usage of facilities and energy saving.

In the logistics transport networks, there are thousands of links and nodes and complex transit system between different transport modes. The reliable connection between each element is becoming increasingly important. However, there are indeed many threats that may cause the logistics system to fail or to degrade severely. The threat can be cyclical disruption like daily congestion or unexpected events like traffic accidents, structural breakdowns, natural hazards like extreme weather conditions, or more rare events like terrorist attacks, as well as closures due to maintenance activities to mention but a few. The vulnerability of transportation networks under these threatens has been the subject of growing attention in recent years. There have been many articles defining transport vulnerability from different aspects. However, among present research about vulnerability assessment, logistics transportation networks have not yet been treated as specific objects even if theirs definitions of trip failure and degradation are different from passenger transport. What matters most for the logistics case is different from the passenger case. In passenger transportation, the best outcome is getting from origination to destination by using the intended route and means of transport at the desired time of departure, and arriving at a desired time. The worst case for the user would be when, there is no route at all from the origin to destination. In the freight transportation networks, the best case is similar to passenger transport network, however the trip failure is not limited to when there is no route between origin and destination. Some detour or increase in cost may cause the product to be damaged or have excessive cost resulting in selling failure which also means the logistics transport fails. Logistics transportation networks are more sensitive to time and cost compared to passengers transport[2). The methodology to assess vulnerability of logistics transportation network should be developed in different way from passengers or other transport mode. This paper attempts to find a methodology properly address the character of logistics transportation network vulnerability. The first question before the vulnerability assessment is what criterion should be used to judge when the facilities are vulnerable or not. As mentioned above, a specific criterion should be applied in logistics transportatiHere logistics value is included in the total logistics transportation cost to evaluate the performance of logistics transportation networks. Here a generalized cost of logistics transport network is proposed to meet the above requirement. On the other hand, another question on conducting vulnerability assessment is what facilities should be evaluated. This depends on both the risk of component failure and the structure of network. The risk is difficult to evaluate because it depends on the failure incentives, so it is better to do the vulnerability assessment for every component of the network and the vulnerability classification of facilities will provide direction to strengthen the weak parts of the network. A vulnerability scanning algorithm is applied in both link and node degradation scenarios. Thousands of modes and links make the simulation very time consuming even given the excellent performance of modern computer technologies. An efficient vulnerability scanning algorithm is developed to solve this problem, and is already applied in a real logistics transportation network in Japan.

1.2 High-speed rail freight

There is a large difference in both speed and costs between the traffic modes. Rail freight services are usually considered as "faster than road but cheaper than air" transport mode. Rail freight could even replace road and air between airports if the high-speed rail is introduced to freight transport and an effective, express intermodal transport system is developed [3)] .

In the railway context, the term "high-speed" is by most people associated with passenger traffic, not with freight traffic probably because it was passenger trains which gave the term high-speed a concrete meaning and which attracted the attention of a broad public. First out were the Shinkansen trains in Japan launched in the 1960s, followed in Europe by the French TGV in the beginning of the 1980s. Since then high-speed passenger services have been introduced in several countries and constitutes today has become an important part of railways business. When it comes to freight, however, high-speed traffic is somewhat an exotic niche activity for the railways; or it is seen as a future product in rail traffic; something to come, rather than an existing phenomenon. Actually, high-speed rail freight trains have been developed, such as the TGV Postal Train at speeds of 270km/h, and Swedish B-Postal Freight Train and German container trains at speeds less than 200km/h, which are also called Semi-high speed rail freight[4)].

Under the background of high-speed rail freight development, high-speed rail freight trains are planned to be introduced to Hokkaido, the most northernmost and second largest island of Japan. This high-speed rail freight will be the first rail freight train in Japan. Hokkaido Railway Company and Japanese government decided to extend high-speed railway from Honshu (another island of Japan) to Hokkaido while the passenger demands greatly increase with the economic development. However, it will have to share the Seikan tunnel which is the only rail tunnel connecting these two islands[5)]. This situation probably cause safety issues because the traditional freight train running on the narrow gauge can be dislodged by the strong airflow when the high-speed passenger train passes by. "Train-on-Train" concept was proposed by Hokkaido Railway Company in 2006 for the purpose of introducing high-speed freight trains in some way. This concept involves loading traditional narrow gauge (1.067m) container wagons onto specially built standard gauge (1.435m) wagons of high-speed trains, which can be visually explained by "Train-on-Train". These rail freight wagons will be operated at around 200km/h. The high-speed train will greatly improve the efficiency of logistics transport system. However, how planning the high-speed rail freight system to get the best benefit at the least construction and maintenance cost still needs discussion. This paper proposes a methodology to evaluate performance of future the high-speed rail logistics network in northern Japan, and then assess the vulnerability of this future logistics transport network consisting of highway, railway, and shipping route.

2. LITERATURE REVIEW

Transportation network vulnerability has received more and more attention in recent years as the threat increases. However, even the definition of vulnerability has not yet been clearly identified. It is still confused with reliability, risk, accessibility and so on even if some research has tried to untangle these relationships. Accessibility is a term depending on the context in which it is used. Jones [6)] defined it as a term related to the ease of reaching a destination, and concerns the opportunity provided by the transport system for people to take part in a particular activity from a given location. Risk is generally associated with something that entails negative consequences for life, health or the environment. Berdica [7)] defined risk as a combination of two parts. One is the probability for an event of negative impact to occur, and another is the extent of the resulting consequences once this event has taken place. Transport network reliability is a subject of considerable research interest in recent years. Taylor [8,9)] focused on congested urban road networks and the probability that a network will deliver a required standard of performance when the reliability is assessed. This can be affected by fluctuating link flows and imperfect knowledge of drivers when making route choice decisions. Richardson and Taylor measured link travel time reliability using the coefficient of variation of the distribution of individual travel times. Yang et al. [10)] assessed network performance in terms of service quality provided to travellers on a day-to-day basis by measures of travel time reliability. Thus travel time reliability can be seen as a measure of demand satisfaction under congested conditions [11)] .

Individuals from specific locations in a region may participate in activities such as employment, education, shopping, trade and commerce that take place in other physical locations in and around the region and by using a transport system to gain access to those locations [12)]. Taylor and D'Este [13)] have defined vulnerability by using this notion. A network node is vulnerable if loss (or substantial degradation) of a small number of links significantly diminishes the accessibility of the node, as measured by a standard index of accessibility. A network link is critical if loss (or substantial degradation) of the link significantly diminishes the accessibility of the network or of particular nodes, as measured by a standard index of accessibility.

This definition can then be further refined by the selection of specific indices of accessibility. Morris, Dumble and Wigan [14)], Koenig [15)], Niemeier [16)] and Primerano [17)] provide discussions of alternative indices. Taylor and D'Este [12,13)] proposed indices such as generalized travel cost and Hansen integral accessibility index to judge the vulnerability or as comparison in the case of strategic level networks.

Many researchers have tried to find a method for calculating a vulnerability index for a transportation network. That would be very helpful for transportation network management, road maintenance and repair, contingency planning or to assess regional or local effects of varying degrees of vulnerability within the network. The following presents methods proposed by researchers and is not meant to be exhaustive.

Jenelius et al. [18)] used the increase in generalised travel costs weighted by the satisfied or unsatisfied demand when network links are closed as a measure of vulnerability for a case study in Northern Sweden, using the terms of importance and exposure, similar to Nicholson and Du [19)], Importance reflects the significance of each link with regard to the network, and exposure reflects the increase in travel cost for a given location within the network. Together these measure provide substantial information to planners, road administrations and individual municipalities as to where the most vulnerable (exposed and or/important) links in the network are. Di Mangi et al. [20)] obtains a link weakness index by looking at how important each link is for the overall set of origin/destination pairs, by assessing how many o/d paths share the same link, based on probabilistic path choice models for calculating the paths. By weighing the weakness index with travel demand, the link exposure index is calculated for each link. In comparison it can be said that Di Mangi's method is more concerned with connectivity and less with increase in travel cost, and hence, Jenelius' method is more applicable in calculating the socio-economic impact of road network vulnerabilities. Husdal [21] suggests a weighted multi-criteria decision approach, where, link closures or degradations are assessed by various categories of effect and the severity of the impact, thus allowing for the assessment of individual effects or impacts.

3. METHODOLOGY

3.1 Generalized cost in logistics transport network

Transport vulnerability assessment is of particular concern when considering sparse, rural networks like logistics transport networks, because what by urban standards is a minor degradation such as car accident, resulting in queuing, delays and diversions may have severe consequences if occurring in a rural setting because the blocking may occur on the only access road for hours, even days or weeks. Before vulnerability of logistics transport network is assessed, there are two questions that should be answered in advance. What is the critical part in deciding the success of trip during the logistics transport? As mentioned above, the best transportation system provides a link between products and customers with minimum time and cost. However, in the real word these two are of a conflicting nature, i.e. transport is faster but also more expensive than shipping. Hence, any model or procedure developed to evaluate the performance of the logistics transport network must seek a trade-off between these costs. Most transportation network users are supposed to seek the shortest travel time route, however, travel time is not the only thing the users care about in logistics network. They may shift from the shortest travel time route when other factors such as economic cost are considered. This paper proposes the generalized cost in the logistics transport network C_g as the index to find the optimal route between each logistics origin (supplier place) and destination (market place). The generalized cost is shown as formula (1).

$$C_{g(i)} = C_{(i)} + T_{(i)} \times \alpha \quad (1)$$

$C_{g(i)}$: generalized cost of logistics transport in link i,

$C_{(i)}$: cost of logistics transport in link i,

$T_{(i)}$: logistics travel time in link i,

α: time value multiplier.

Typical cost elements related to the transport section include fuel consumption, driver payment in a highway network, and container payment in both railway and shipping network. Actually, these costs mostly depend on travel distance and transportation mode. So the travel cost and time in different transportation modes are calculated respectively. The time value is determined by the type of logistics referring to related research.

In the highway logistics transport network, trucks are supposed to be an available vehicle. For the simulation convenience, a truck's carrying capacity is fixed to 10 tons. Travel time $T_{h(i)}$ and cost $C_{h(i)}$ are calculated based on the distance shown as formula (2) and formula (3).

$$T_{h(i)} = \frac{l_i}{v_i} \quad (2)$$

Where,

$T_{h(i)}$: travelling time in link i in highway network,

l_i: length of link i,

v_i: average speed of f.

$$C_{h(i)} = l_i \times f + T_{h(i)} \times p \quad (3)$$

Where,

$C_{h(i)}$: cost of logistics transport in link i in highway network,

$T_{h(i)}$: travelling time in link i in highway network,

f: fuel consumption per kilometre,

p: driver's payment per hour.

In the railway network and shipping, travel time is not only simply related to distance between origin and destination (od) pairs, because the freight trains have their own schedules. Some extra time such as waiting time and transit time should also be included in the time consumption in these networks. The logistics transport cost mainly depends on the freight weight and distance. In this paper, travel time and cost in links of the rail and shipping network is determined according to time schedule and charge released by rail and ferry companies. The average of different companies is used.

3.2 High-speed rail freight planning based on generalized cost

Under the background of the Hokkaido high-speed railway planning, the generalized cost of logistics transport is used as a measurement to evaluate the performance of Hokkaido railway logistics network. Based on the total generalized cost, this paper attempts to propose an optimal plan for the high-speed rail freight network with least C_t. The total logistics transport cost combines logistics demand with generalised travel cost between each od pair shown as formula (4). Generalized cost between each od is calculated according to shortest route that is searched by Dijsktra algorithm shown in formula (5).

$$C_t = \sum_{od}^{OD} C_{g(od)} \times d_{od} \quad (4)$$

Where,

C_t: total logistics transport cost,

od: one od pair,

OD: od set including all od pairs,

$C_{g(od)}$: generalize cost of logistics transport between od pair,

d_{od}: demand between od pair.

$$C_{g(od)} = \sum_S C_{g(i)} \quad (5)$$

Where,

$C_{g(od)}$: generalized cost between od pair,

$C_{g(i)}$: generalized cost in link i,

S: set if links in the shortest route between od pair.

3.3 Vulnerability scanning of comprehensive logistics transport network

Different vulnerability indices have been developed as shown in the literature review. Most indices are functions related comparison between its normal performances and the performances after its partial parts degrade [12,13]. This paper uses the ratio form shown as formula (6) to express the vulnerability of road network facilities. The vulnerability V(i) under the degradation of component i can be defined as follow:

$$V(i) = \frac{\Delta C_t}{C_t} = \frac{C_{t(i)}{}' - C_t}{C_t} \quad (6)$$

$V(i)$: vulnerability index of component i,

ΔC_t: total logistics transport cost difference,

C_t: total logistics transport cost,

$C_{t(i)}{}'$: total logistics transport cost after degradation happen to component i .

Vulnerability scanning is applied in a multiple logistics transport network including highway, railway, and ferry. Component i represents two type facilities of transport network. Link and node vulnerability is scanned under different od pair distribution and amount level in the case study.

4. CASE STUDY

4.1 Study network

Under the background of high-speed rail freight introduction to the present logistics network, the methodology mentioned before has applied in the real logistics transport network in Hokkaido. These logistics network has both export and import demand, and the former has obviously more volume that the latter because this area has 25% cultivated land of Japan and only 4.3% population of Japan. Hokkaido contributes 12% of the total agricultural export of Japan, and about 20% of domestic calorie supply. The export logistics from Hokkaido also has typical seasonal character. The peak month is September whose logistics export is more than 3 times of low ebb month in May.

In the high-speed railway planning case, the logistics transport network consists of 900 km express highway, 6361km national highway, 4533 km prefecture arterial highway, and 3176 km railway shown as FIGURE 1. In the vulnerability scanning, it also includes 5 ferry routes between 3 ports of Hokkaido and Honshu except the network shown in FIGURE 1.

As for the details of the logistics traffic data, Hokkaido is divided into 14 areas according to the administrative divisions. These 14 areas are agriculture products origins and industrial products destinations and they are located as shown as red circles in FIGURE 1. There are 10 freights stations those are joins between the highway network and the railway network they are located as shown as purple circles in FIGURE 1.

To simplify the analysis, only those logistics transport exporting from Hokkaido to other part of Japan and importing to Hokkaido islands are focused on. The industrial products origin/ agriculture products destination is Honshu specifically located in Aomori freights terminal by railway and Oarai port near Tokyo in Honshu.

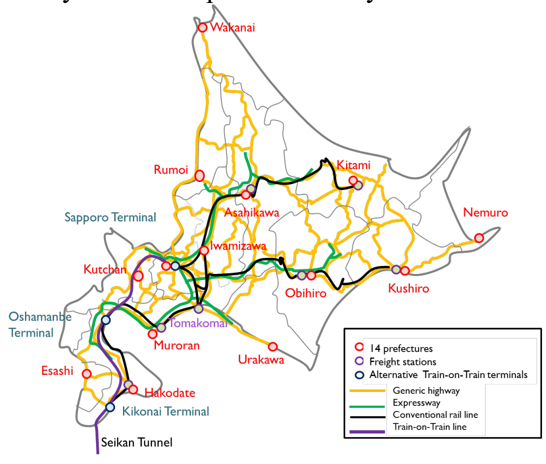

Figure 1 Hokkaido future logistics transport network

4.2 High-speed rail freight network planning based on generalised cost

Where should the high-speed rail freight trains introduced? That is consequent question after "Train-on-Train" concept is proposed. Several places are listed to be potential "Train-on-Train" terminals that will mainly decide the high-speed rail freight way network. This paper tried to find the optimal scheme for high-speed rail freight way. The high-speed railway is expected to firstly arrive at Kikonai, followed by Oshamanbe, and Sapporo when it is extended from Honshu Island through Seikan Tunnel. Considering of the "Train-on-Train" construction and maintenance cost, three scenarios are analysed which consist of one "Train-on-Train" terminal, two "Train-on-Train" terminals, or three "Train-on-Train" terminals. The methodology mentioned above to calculate total logistics transport cost is applied in the case. It should be noted that the time value α has different values in export and import. Most of export logistics from Hokkaido is agricultural products and food, and most import logistics is materials of industry and commodity. According to related research of time value in logistics industry, time value of agricultural products and food is 240 JPY/hour, and time value of materials of industry and commodity is 3240 JPY/hour. The total logistics transport cost is calculated under different logistics demand of export and import from and to Hokkaido by railway. The saved total logistics transport cost is showed in FIGURE 2. "s", "k", and "o" represents the scenarios that the train on the terminal is constructed in Sapporo, Kikonai, and Oshamanbe, and the high-speed railway will extend from Honshu to these places. "s, k", "s, o", and "k, o" represents the scenarios that there will be two "Train-on-Train" terminals constructed in two places of the three. "s, k, o" represents the scenarios that there will be three "Train-on-Train" terminals constructed in Sapporo, Kikonai, and Oshamanbe shown as FIGURE 1. FIGURE 2 shows the saved total generalized logistics transport cost by high-speed railways to the present rail logistics transport network. "s, k, o" scenario reduce most sum cost(23 million JPY/day) of export (6.5 million JPY/day) and import (16.5 million JPY/day) scenarios. But other options may keep better balance of construction and maintenance cost and their benefits, such as "s, k" has approaching cost saved (6.7 million JPY/day in export, 16.5 million JPY/day in import, 22.7 million JPY/day in sum) but one "Train-on-Train" terminal less that "s, k, o" scenario. If one terminal is constructed, "o" will be the optimal option with saved cost of 6.2 million JPY/day in export, 15.0 million JPY/day in import case, and 21.2 million JPY/day in the sum. According this result, optimal high-speed rail freight way can be planed based on the trade-off between its benefits and construction and maintenance cost.

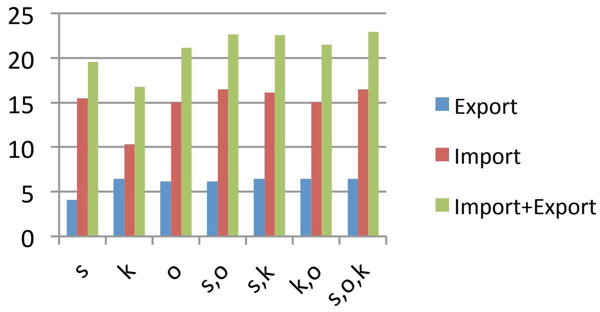

Figure 2 Saved total generalized cost of logistics transport (Million JPY/day)

4.3 Vulnerability scanning of logistics transport network

4.3.1 Diversities of logistics demands

To predict the vulnerability of future logistics transport network of Hokkaido, high-speed rail freight network planning is included in the vulnerability scanning analysis. Based on the results from section 4.2, the "s, k, o" is accepted as the high-speed rail freight network. Moreover, to represent the main logistics transport network of Hokkaido, 5 ferry routes between 3 ports in Hokkaido and Honshu, are also added. Finally, the vulnerability scanning is applied in a multiple logistics transport consisting of highway, railway, ferry, and planning high-speed railway.

The logistics transport demands include all the logistics by these transport modes. Hokkaido is one of the most important agriculture products origins in Japan. And the export of agricultural and aquatic products is typical seasonal. September is the peak month and May is low ebb of Hokkaido logistics export according to historical data (from 2000 to 2010) shown as FIGURE 1. On these other hand, the import od may also different from export in demand distribution shown as FIGURE 4. This paper tried to assess the vulnerability under these varies of logistics demand. All the demands amounts are averaged to per day from the yearly amount in 2010 shown as FIGURE 4 shows.

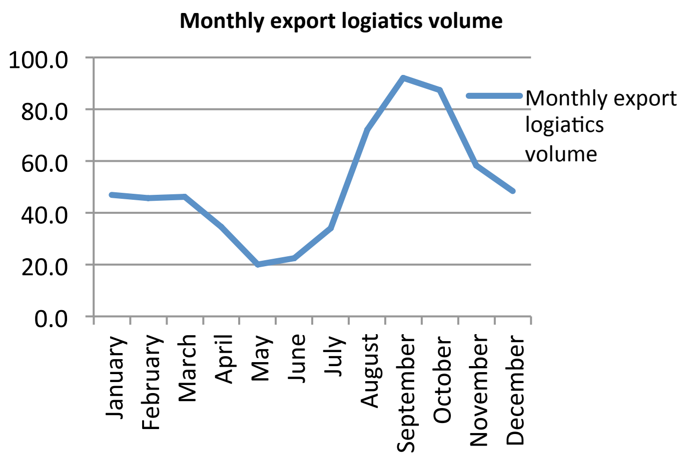

Figure 3 Averaged monthly export logistics demands (1000 Tons)

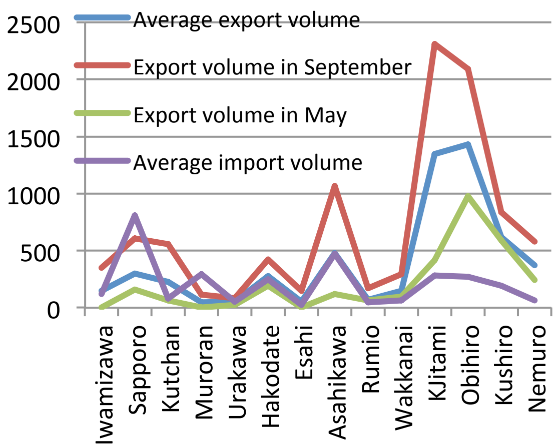

Figure 4 Diversified logistics demands (Tons/Day)

4.3.2 Link vulnerability scanning

Dijkstra algorithm is applied in c++ program to find the shortest route between each od pair which is one of the fundamental steps of vulnerability evaluation. In the link vulnerability scanning, the shortest routes between all od pairs are searched at first. C_t is calculated as the contrast parameter. The link i's capacity will be degraded to be 0 and the total generalized cost ${C_t}_{(i)}'$ is calculated again when its vulnerability index V(i) is evaluated. This procedure is conducted for each link in the links set of shortest routes between all od pairs. The links outside of the shortest routes set are not necessary to do the calculation because ${C_t}_{(i)}'$ is calculated based on the shortest route and their degradation will not influence the result of shortest routes searching. This efficient algorithm can finish the links vulnerability scanning in a reasonable time period.

According to the vulnerability scanning, finally the links vulnerability is classified to several categories. When some od pairs can't connect at all because of links failure, these links are marked by "Most critical" links. Those links are marked by "Relatively critical", when their failure resulting in ΔC_t more than 10 million which means the logistics transport generalized cost increase by over 10 million JPY/day. It is marked by "Critical", when ΔC_t is between 1 million and 10 million JPY/day. And "Important" is marked between 0.1 million and 1 million JPY/day. If the lost is less than 0.1 million JPY/day, it seems in the acceptable range and with "Light" influence to the total cost.

In order to understand the vulnerability features under diverse logistics demands. The link vulnerability scanning is implemented in these logistics demands.

Under average export demand, there are 1058 links (17.2% of total) are in the shortest routes set. 7 links shows non-substitutable in the network. When anyone of them is disrupted, some of the od pairs can't connect at all. 8 links shows "Relatively critical" for the logistics transport with increased total cost C_t by over 0.43%. 382 Links show "Important" with increased total cost C_t by between 0.0043% and 0.043%. Some links included in the shortest routes set but having light influence to generalized cost ($\Delta C_t < 0.1$ million JPY/day) are classified to "Light" together with links out of set of shortest routes. Comparing to average export demand, there are more vulnerable links in "Critical" and "Important" categories under the September export logistics demand but fewer vulnerable links in these two categories under May export logistics demand. TABLE 1 shows the result of link vulnerability scanning of export demands.

TABLE 2 shows the scanning result of import demands. There are 843 links (14.2% of total) are in the shortest routes set which is less than the export case. The "Most critical" category is still 7 links. The "Relatively critical" category increases by 15 links comparing to export cases.

Table 1 Result of link vulnerability scanning in export case

Export					
Vulnerability classification			Average	September	May
Shortest routes set (17.1%)	Most critical	$V(i)$	-	-	-
		No.	7	7	7
	Relatively critical ($10<\Delta C_t$)	$V(i)$	>0.43%	>0.25%	>0.73%
		No.	0	0	0
	Critical ($1<\Delta C_t<10$)	$V(i)$	0.043%~0.43%	0.025%~0.25%	0.073%~0.73%
		No.	8	39	5
	Important ($0.1<\Delta C_t<1$)	$V(i)$	0.0043%~0.043%	0.0025%~0.025%	0.0073%~0.073%
		No.	382	528	264
Others	Light ($\Delta C_t<0.1$)	No.	5743	5566	5864

Table 2 Result of link vulnerability scanning in import case

Import			
Vulnerability classification			Average
Shortest routes set (14.2%)	Most critical	$V(i)$	-
		No.	7
	Relatively critical (10<ΔC_t)	$V(i)$	>0.09%
		No.	15
	Critical (1<ΔC_t<10)	$V(i)$	0.009%~ 0.09%
		No.	60
	Important (0.1<ΔC_t<1)	$V(i)$	0.0009%~ 0.009%
		No.	275
Others	Light (ΔC_t<0.1)	No.	5783

4.3.3 Conclusions of link vulnerability scanning

There are 185 links less in the shortest routes set under import logistics demands than export logistics demands because the different time values of import and export logistics change the link impedances and then the shortest routes set between the same od pair are different. This also leads to another result that links failure in import network causes more total generalized cost increased. Even though the link under import case can cause more total generalized cost, their $V(i)$ are smaller that means the lost is a smaller proportion of the total amount. The links numbers in "Critical" and "Important" categories increase from May to September scenarios in export demand. This result shows the vulnerable indices increase as the demand amount. As for "Most critical" category, the result doesn't change as the demand distribution and amount level. There are same 7 links in this category showing that "Most critical" links are not impacted by traffic factors. Any of them have to keep unblocked to make od pairs connected.

Table 3 Result of node vulnerability scanning in export case

Export					
Vulnerability classification			Average	September	May
Shortest routes set (18.0%)	Most critical	$V(i)$	-	-	-
		No.	22	22	22
	Relatively critical (10<ΔC_t)	$V(i)$	>0.43%	>0.25%	>0.73%
		No.	2	2	2
	Critical (1<ΔC_t<1 0)	$V(i)$	0.043%~ 0.43%	0.025% ~0.25%	0.073%~ 0.73%
		No.	14	46	8
	Important (0.1<ΔC_t< 1)	$V(i)$	0.0043% ~0.043%	0.0025% ~0.025%	0.0073% ~0.073%
		No.	383	530	268
Others	Light (ΔC_t<0.1)	No.	5471	5236	5538

4.3.4 Node vulnerability scanning

Link vulnerability scanning is proposed based on the single link disruption pattern that supposes the attacks from nature or human society only result in single link disrupted. However, the attack are usually area covering and result in several links nearby disrupted. So the node vulnerability scanning is proposed to represent the area vulnerability in some way. The node actually in the paper represents intersection whose failure can lead several links nearby also to fail.

Similar algorithm is applied in node vulnerability scanning to link vulnerability scanning. The shortest routes between all od pairs are searched at first and the nodes set of shortest routes are obtained, then C_t is calculated as the contrast parameter. When the node i is disrupted, all the links connected to it will also be disrupted and the total generalized cost ${C_t}_{(i)}'$ is calculated again when its vulnerability index $V(i)$ is evaluated. Similarly, all these procedures are conducted for each node in the set of shortest routes between all od pairs.

The node vulnerability scanning is also applied under diverse logistics demands. Under average export demand, there are 1052 links (18.0% of total) are in the shortest routes set. Non-substitutable nodes are 22. When anyone of them is disrupted, connecting links' failure caused by its failure will result in some of the od pairs disrupted. 2 nodes show relatively critical for the logistics transport with ΔC_t over 10 million JPY/day. 14 nodes are in "critical" category and 383 nodes are in "Light" category. There are also some nodes included in the shortest routes set but having light influence to generalized cost ($\Delta C_t < 0.1$ million JPY/day) are classified to "Light" together with nodes out of set of shortest routes. Table 3 shows the result of node vulnerability scanning of export demand.

Table 4 shows the node vulnerable scanning result of import demand. There are 885 links (15.2% of total) are in the shortest routes set which is less than the export scenario. The "Most critical" category is still 7 links. The "Relatively critical" and "critical" categories increase much comparing to export scenarios. This result shows the similar tendency to the link vulnerability scanning that the link numbers in "critical" and "important" categories increase as the demand amount level in export scenarios whose distribution tendency are similar.

Table 4 Result of node vulnerability scanning in import case

Import			
Vulnerability classification			Average
Shortest routes set (15.2%)	Most critical	$V(i)$	-
		No.	22
	Relatively critical ($10<\Delta C_t$)	$V(i)$	>0.09%
		No.	15
	Critical ($1<\Delta C_t<10$)	$V(i)$	0.009%~ 0.09%
		No.	70
	Important ($0.1<\Delta C_t<1$)	$V(i)$	0.0009%~ 0.009%
		No.	272
Others	Light ($\Delta C_t<0.1$)	No.	5455

4.3.5 Conclusions of node vulnerability scanning

The category of "Most critical" has not only the same links numbers but also the same links in any demand shown as same as in link vulnerability case. This result can be explained that these "Most critical" links are essential to the logistics transport network and determined by the topology of network and doesn't get any impact from traffic factors. Higher export demands increase the links number of the same vulnerable category. There are 22 nodes in "Most critical" category, showing that node failure results in more serious impact to the whole network, comparing to link vulnerability scanning results.

5. CONCLUSIONS

The methodology proposed in this paper is applicable to large scale, and intercity logistics transport networks. In these networks, users usually choose the shortest routes between od pairs, and traffic congestions rarely happen in the intercity roads. On the other hand, the shortest route algorithm is also efficient when the complete vulnerability scanning calculation is applied in network analysis.

Logistics generalized cost is proposed to describe the link impedance in logistics transport network. It considers the economy influence of transport network in logistics industry. Total generalized logistics transport cost is a global index from the view point of all users' benefit. It provides road network administrations assist for benefit-cost-analysis. High-speed rail freight planning in northern Japan is analysed in total generalized logistics transport cost. The trade-off between the benefits of high-speed railway and its construction and maintenance cost can be found in the result.

Link and node vulnerability scanning methodology is applied in the future logistics transport network consisting of multiple transport modes such as highway, railway, ferry and planning high-speed railway. The assessment of vulnerability of future logistics transport network in northern Japan may provide direction of transportation network vulnerability resistance planning to road network administration. From the result of link and node vulnerability scanning, their vulnerability is not only decided by the topology of the network but also closely related to the demand amount or distribution and link impedance. But the "Most critical" part of the network, whose failure will disconnect some od pairs, is determined by the topology, and is not influenced by other traffic factors. These links should be strengthened in planning stage, for example some alternate links are added into the network to improve the structural reliability. The links or nodes in higher vulnerable category should be noticed by road administrations and have priority to be recovered than the lower category when they face to threaten or attack.

There are much work should be improved based on this work. Visual results and detailed comparison between node vulnerability scanning and link vulnerability scanning can be realised by assistant map technology such as GIS. This work also can be expand to consider partial function failure of link, because the attack from nature or human society doesn't result in only 100% links or nodes disrupted and larger attacked area result from some disaster like flood or snowstorm.

REFERENCES

1) Y.Y. Tseng, W.L. Yue, M.A. Taylor, The role of transportation in logistics chain, in, Eastern Asia Society for Transportation Studies, 2005.
2) A.S. Fowkes, P.E. Firmin, G. Tweddle, A.E. Whiteing, How highly does the freight transport industry value journey time reliability—and for what reasons?, International Journal of Logistics: Research and Applications, 7 (2004) 33-43.
3) S. Ohnell, J. Woxenius, An industry analysis of express freight from a European railway perspective, International Journal of Physical Distribution & Logistics Management, 33 (2003) 735-751.
4) G. Troche, High-speed rail freight: Sub-report in Efficient train systems for freight transport, (2005).
5) T. Kitagawa, Extending the Shinkansen network, Japan Railway and Transport Review, 40 (2005) 14-17.
6) S. Jones, Accessibility measures: a literature review, in, 1981.
7) K. Berdica, An introduction to road vulnerability: what has been done, is done and should be done, Transport Policy, 9 (2002) 117-127.
8) M.A. Taylor, Dense network traffic models, travel time reliability and traffic management. II: application to network reliability, Journal of Advanced Transportation, 33 (1999) 235-251.
9) A. Richardson, M. Taylor, Travel time variability on commuter journeys, High Speed Ground Transportation Journal, 12 (1978).

10) H. Yang, H. Lo, W.H. Tang, Travel time versus capacity reliability of a road network, Reliability of Transport Networks, (2000) 119-138.
11) Y. Asakura, Evaluation of network reliability using stochastic user equilibrium, Journal of Advanced Transportation, 33 (1999) 147-158.
12) M.A. Taylor, G. d'Este, A. Nicholson, Critical infrastructure and transport network vulnerability: developing a method for diagnosis and assessment, (2004).
13) M.A. Taylor, G.M. D'Este, Transport network vulnerability: a method for diagnosis of critical locations in transport infrastructure systems, Springer, 2007.
14) J.M. Morris, P. Dumble, M.R. Wigan, Accessibility indicators for transport planning, Transportation Research Part A: General, 13 (1979) 91-109.
15) J.-G. Koenig, Indicators of urban accessibility: theory and application, Transportation, 9 (1980) 145-172.
16) D.A. Niemeier, Accessibility: an evaluation using consumer welfare, Transportation, 24 (1997) 377-396.
17) F. Primerano, M. TAYLOR, TOWARDS A POLICY SENSITIVE ACCESSIBILITY MEASURE, in: AUSTRALASIAN TRANSPORT RESEARCH FORUM (ATRF), 26TH, 2003, WELLINGTON, NEW ZEALAND, 2003.
18) E. Jenelius, T. Petersen, L.-G. Mattsson, Importance and exposure in road network vulnerability analysis, Transportation Research Part A: Policy and Practice, 40 (2006) 537-560.
19) A. Nicholson, Z. Du, Improving transportation system reliability: a framework, in: 17TH ARRB CONFERENCE, GOLD COAST, QUEENSLAND, 15-19 AUGUST 1994; PROCEEDINGS; VOLUME 17, PART 6, 1994.
20) M. Di Mangi, A. Luongo, Transportation Network Vulnerability Indicator for Risk Evaluation and Exposure Reduction, Proceedings of European Transport Conference, (2005).
21) J. Husdal, The vulnerability of road networks in a cost-benefit perspective, in: Proceedings of the Transportation Research Board Annual Meeting (TRB 2005), Washington DC, USA, 2005, pp. 9-13.