An Economic Loss due to Bottlenecks for Domestic Automobile Transportation of International Maritime Container Cargos in Japan

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Introduction

In Japan, vehicular transportation by semi-trailers and similar means accounts for more than 95% of total domestic transportation of international maritime containers. Restrictions are being eased for heavy containers with gross weights exceeding the general limit values specified in the Road Structure Ordinances and high-cube containers with a height of 9’6”. However, Japan still faces many traffic-related problems originating in the poor road environment of the country.

To realize efficient transportation of international maritime cargos, it is necessary to implement effectively infrastructure construction projects which consider the linkage between ports and roads. Therefore, it is necessary to clarify actual conditions in the domestic flow of international maritime cargos and port selection behavior and construct a transportation route/shipping (or landing) port selection model for international maritime cargos which also considers road bottlenecks, such as narrow roads, outdated bridge and tunnel specifications, tight curves, etc. impassible to large vehicles. Including the models developed previously by the authors (Ieda, *et al*., 2000 and Watanabe, *et al.*, 2000), none of the shipping/landing port selection models or transportation route selection models developed thus far, or analyses of the current condition of hinterland transportation (for example, Watanabe, et al., 1989) and road traffic features in coastal areas has considered bottleneck problems affecting large vehicles such as semi-trailers. As one exception, a Japanese Ministry of Construction (2000) study attempted to quantify the effect of eliminating bottlenecks, but this work must be considered inadequate, such as the study included only high-cube containers and the method of establishing transportation routes was arbitrary. Moreover, because virtually no other country has as many physical restrictions on land transportation of international maritime containers as Japan, little research of this type can be found outside Japan.

This paper therefore investigates the effect of bottlenecks in the Japanese road transportation network, considering international maritime containers as a representative international maritime cargo. First, the current condition and system of traffic restrictions on vehicular transportation using semi-trailers, which accounts for the majority of domestic transportation of such containers, is summarized. Bottlenecks in the actual transportation network are then extracted, and the economic loss due to detours around these locations are calculated.

Current Condition of Domestic Transportation of International Maritime Containers and Traffic Regulations in Japan

Current condition of hinterland transportation of international maritime container cargos. Figure 1 shows a breakdown of the main means of transportation of all arriving/departing container cargos between the Japanese shipping port (or landing port; same in the following) to the container packing place (or unpacking place; same in the following) obtained from the National Import/Export Container Cargo Flow Survey (1998). Fig. 1 also includes containers which were packed at container terminals or quays located adjacent to the shipping port. As mentioned in the introduction, with both imports and exports, approximately 95% of all containers are transported by automobiles such as semi-trailers. Figure 2 shows the hinterland transportation distance from the shipping port to the container packing place by means of transportation. As can be understood from this figure, with both imports and exports, vehicular transportation by semi-trailer is more frequently used for short distances than other means of transportation such as railway or coastal vessel.

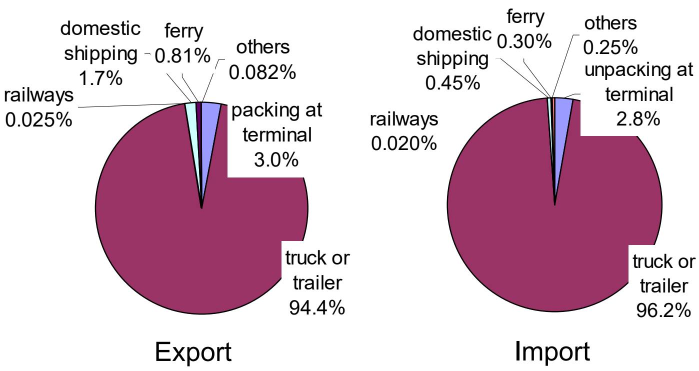

Fig. 1 Main means of domestic transport of intl. maritime containers in Japan

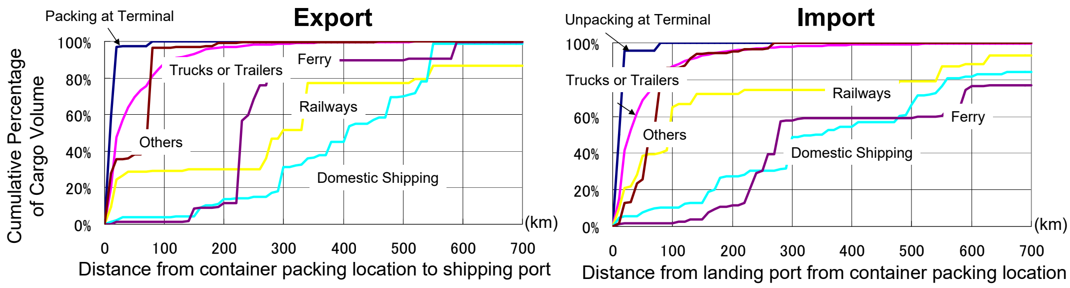

Fig. 2 Distance between shipping/landing port and container packing/unpacking place by means of transportation

Breakdown of standards and current condition of international maritime containers. Table 1 shows an example of an international maritime container standard as specified by the ISO. As shown in the table, the sizes of international maritime containers fall mainly in three classes, 20ft, 40ft normal, and 40ft high-cube containers. The maximum gross weight (including tare weight of the container) of the respective containers is also specified, as in the table. For a share of international maritime containers by size, 20ft and 40ft containers generally each account for one-half of total volume. However, the percentage of high-cube containers in all 40ft containers is unknown. Figure 3 shows the breakdown by size (unit base) of international maritime containers handled in one week in 2002 at a container terminal at one of Japanese major ports. In the annual total for this port, 20ft containers accounted for approximately one-half of both imports and exports. In the shares shown in the figure, in particular, that of exports tended to differ from the overall trend in the year. However, the shares of 40ft normal and 40ft high-cube containers are only obtained from the data that is roughly 5:4 for both imports and exports. With a comparison of past results of the same survey (1986, 30:1, 1994, 10:1) by Japanese Container Association, it is clearly supported the fact that use of 40ft high-cube containers is growing explosively, presumably reflecting the cost-consciousness of shippers. Figure 4 shows the weight distribution of containers by size at the same terminal. With both imports and exports, the percentage of containers with large weights is high in the order 40ft high-cube, 20ft, and 40ft normal. In particular, in many cases, 20ft containers were packed as close as possible to the maximum gross weight, supporting a conclusion that 20ft containers are frequently used in transporting comparatively heavy cargos.

Table 1 Example of ISO container standard (dry container)

TYPE		20' (8'6" High Almi)	20' (8'6" High Steel)	40' (8'6" High Almi)	40' (8'6" High Steel)	40' (9'6" High Almi)	40' (9'6" High Steel)
External Dim	Length	6,058mm(19'10" 1/2)		12,192mm(40'0")		12,192mm(40'0")	
	Width	2,438mm(8'0")		2,438mm(8'0")		2,438mm(8'0")	
	Height	2,591mm(8'6")		2,591mm(8'6")		2,896mm(9'6")	
Tare Weight		1,790kg	2,220kg	2,870kg	3,740kg	3,000kg	3,920kg
Max. Payload		22,210kg	21,780kg	27,610kg	26,740kg	27,480kg	26,560kg
Max. Gross Weight		24,000kg		30,480kg		30,480kg	

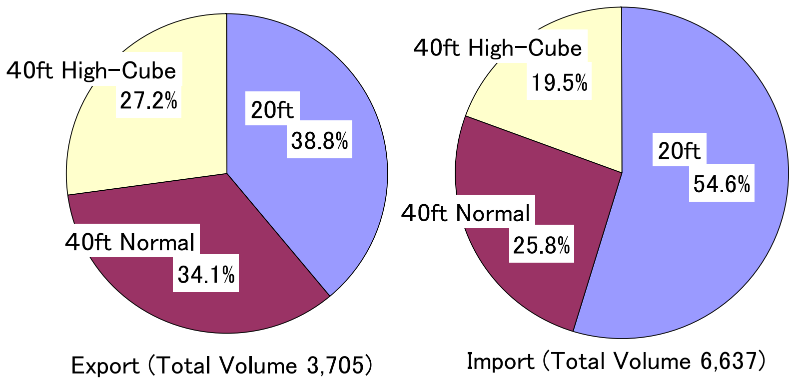

Fig. 3 Breakdown of containers by size at one terminal of Japanese major ports

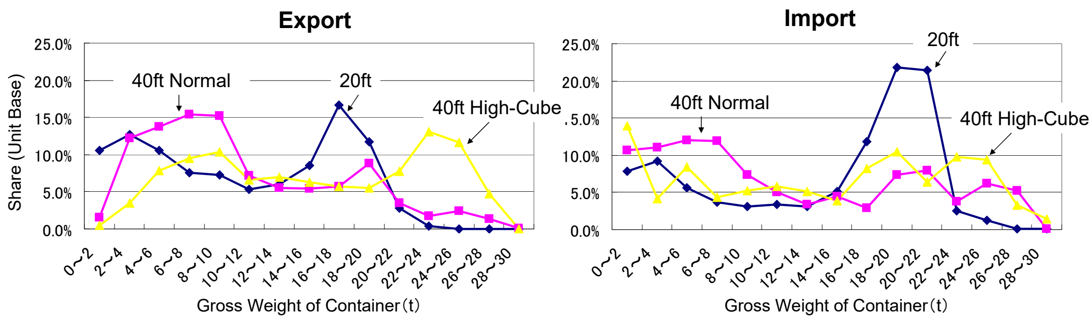

Fig. 4 Weight distribution of containers by size

Expressway use ratio of semi-trailers for international maritime container transportation. The Ministry of Construction plans to construct approximately 14,000 km of high standard arterial roads with speed limits of 80 km/hr or higher nationwide. All of these high standard arterial highways (called expressways in the following) are being constructed as toll roads. On national highways, which account for approximately 80% of the total expressway system, semi-trailers for international maritime container transportation are charged a toll of ¥67.65/km. Figure 5 shows the use ratio (weight base) of expressways in land transportation by automobiles such as semi-trailers of international maritime containers, as obtained from the National Net Cargo Flow Survey (2000), arranged in zones by distance from the cargo shipping area to the export port. Although this national survey is the only survey which shows freight transportation routes including international maritime container cargos in Japan, including use or non-use of expressways, it must be noted that the sample size is small because the sampling study was carried out on a 3-day shipment base for representative industries. In any case, from Fig. 5, it can be understood that the expressway use ratio tends to increase as the transportation distance increases up to 200 km, but conversely, with longer-distance cargos, shippers do not use expressways.

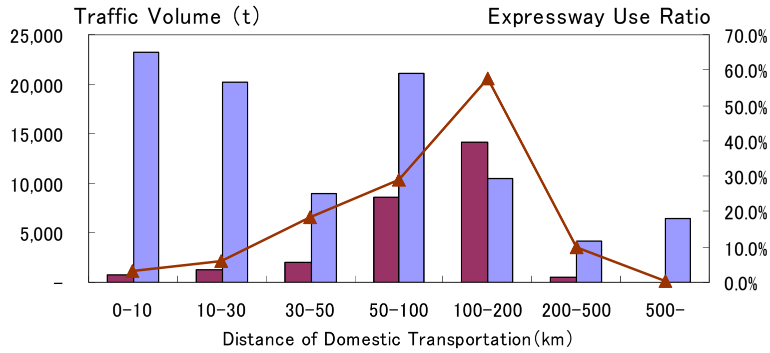

Fig. 5 Traffic volume by automobiles for intl. maritime containers by transport distance (1998, 3-day period; unit: freight-ton) and expressway use ratio

Summary of system regulating traffic by semi-trailer combination vehicles for international maritime containers. General limit values placing restrictions on vehicle height, weight, etc. are specified by vehicle restriction ordinances, as shown in Table – 2. Vehicles which exceed any one of the general limit values shown in the table are considered special vehicles and must receive a special vehicle license in accordance with ministerial ordinances specifying procedures for vehicle licensing, and are required to use national expressways or roads designated by the Road Administration (here, called designated roads). In the case of semi-trailers for international maritime containers, a variety of exceptions are recognized within the above category of special vehicles, and regulations on weight and by class of roads requiring license applications are more lenient than with other vehicles. Non-designated roads can also be approved for traffic, provided there are no structural problems (these roads may be termed quasi-designated roads). Table 3 summarizes the necessity of special vehicle license applications by gross weight and road class for semi-trailers transporting international maritime containers. Table 3 also shows guidelines for the relationship between container gross weight and the necessity of license applications, assuming a standard weight for the trailer and the tractor pulling it. High-cube containers with heights exceeding the general limit value are also subject to special vehicle licensing. However, in this case, an application for the travel route must be submitted in advance, and travel is permitted only by the approved route (here, called designated route). Figure 6 shows a flow chart of the application procedures for special vehicle licenses and approval of designated routes. As of April 2003, Japan had approximately 50,200 km of designated roads nationwide (including national expressways) and a gross total of approximately 236,000 km of designated routes, comprising roads with an actual total length of about 30,000 km.

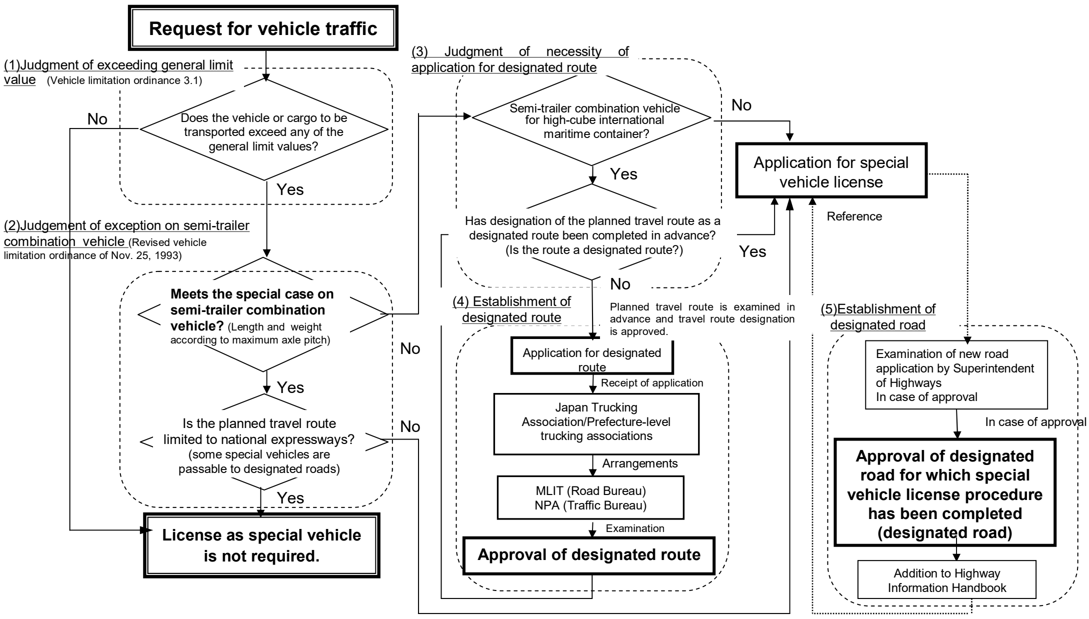

Fig. 6 Flow of application procedures for special vehicle licenses for combination vehicles carrying international maritime containers

Table 2 General limit values of vehicle specifications

Size	Width	2.5m
	Length	12.0m
	Height	3.8m
Weight	Gross Weight	20.0t
	Axle Load	10.0t
	Adjacent Axle Load	18.0～
	Unit Load per Travel	5.0t
Minimum Turning Radius		12.0m

Table 3 Summary of necessity of application for special vehicle license for combination vehicles carrying international maritime containers

Container class	Total length of combination vehicle	Max. height	Max Distance between axle (m)	Maximum gross weight of Vehicle (t)	Assumed weight of tractor + trailer (including crew)	Gross weight of container (assumed) (t)	Necessity of application for special vehicle license: National expressway	Necessity of application for special vehicle license: Designated roads (including quasi-designated roads)	Necessity of application for special vehicle license: Other roads	Necessity of application for designated route	Remarks
20ft	～12m	3.8m	—	20t	10t (breakdown: tractor, approx. 7.0t; trailer, approx. 3.0t)	～10	No	No	No	No	Case where vehicle is below general limit values.
			8～9	25		10～14.5	No	No	Yes	No	Case where only weight exceeds general limit values; corresponds to new standard vehicle
			9～10	26		14.5～16					
	12～17m		10～11	27		16～17	No	No	Yes	No	
			11～15	29～34		17～**24**	No	Yes	Yes	No	
			15～15.5	35～36		—	—	—	—	—	20 ft container: Full load is 24t (with tank containers, up to 30.48t is permissible).
40ft	～17m	3.8m	～8	20t	13.5t (breakdown: tractor, approx. 9.5t; trailer, approx. 4.0t)	～6.5	No	No	No	No	Case where total length is within designated value for semi-trailer combination vehicle
			8～11	25～27		6.5～13.5	No	No	Yes	No	
			11～15.5	29～36		13.5～22.5	No	Yes	Yes	No	
			—	36～44		22.5～**30.5**	Yes	Yes	Impossibl	No	
40ft high-cube	～17m	4.1m	～8	20	13.5t (breakdown: tractor, approx. 9.5t; trailer, approx. 4.0t)	～6.5	No	No	No	Yes	Case where height exceeds general limit values.
			8～11	25～27		6.5～13.5	No	No	Yes	Yes	
			11～15.5	29～36		13.5～22.5	No	Yes	Yes	Yes	
			—	36～44		22.5～**30.5**	Yes	Yes	Impossibl	Yes	

Calculation of Economic Loss due to Bottlenecks Affecting Semi-trailers for International Maritime Containers

Extraction of bottlenecks for semi-trailers for international maritime container in land transportation network. The CD-ROM version of the Road Information Handbook lists physical information such as the minimum width, minimum radius of curves, the nature of overhead obstacles, the weight limits of bridges, and also notes whether the road is a designated road or not, covering a total of 76,555 road sections nationwide, including national expressways, national highways, main regional roads, and general prefectural and municipal roads. In this research, links where semi-trailer for international maritime containers is physically impossible to pass were extracted based on information in the handbook. For other roads, even if a non-designated road, if traffic is physically possible on a non-designated road, the road is approved for traffic as a quasi-designated road. The designated road network including the quasi-designated roads prepared by this process is shown in Fig. 7. The length of the designated road network (including national expressways) totaled approximately 84,000 km. Similarly, designated routes which are passable by semi-trailers carrying high-cube containers were extracted. The designated route network, including quasi-designated routes, had a total length of approximately 98,000 km.

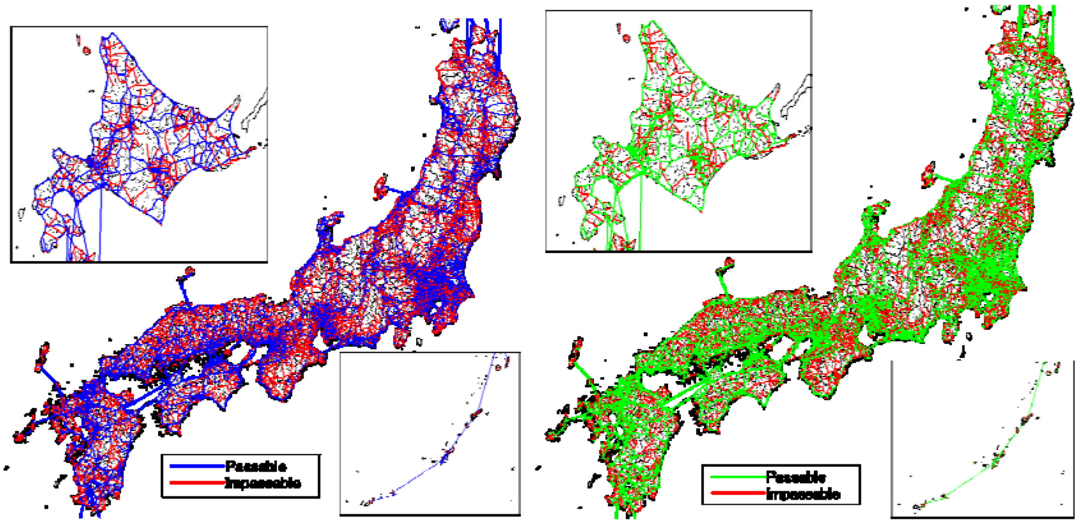

Fig. 7 National network of designated roads and designated routes

Calculation of economic loss due to detouring bottlenecks. The total transportation cost were calculated for with/no bottlenecks case; With-bottleneck case means searching the shortest routes in the national designated road (or designated route) network including quasi-designated roads, and no-bottleneck case means searching the shortest routes in the national road network passable for semi-trailers with normal (i.e. neither full-load nor high-cube) container, according to the Road Information Handbook. For no-bottleneck case, the following two scenarios are assumed. In scenario 1, where the ratio of full-load and high-cube containers remains unchanged with and no bottlenecks case, only the economic loss is considered due to detours around bottlenecks. In scenario 2, where all semi-trailers for international maritime containers which pass through the bottleneck point are assumed to carry full-load or high-cube containers with no-bottleneck case, economic effect of eliminating bottlenecks is also caused by reducing the number of containers being transported.

The results are shown in Table 4. Here, data from the National Import/Export Container Flow Survey (1998) was used as the amount of container cargo, considering respective municipalities as container packing places and respective ports as the shipping port. The shortest distance was also searched for both the case where expressway use is possible and impossible. Travel time was calculated from the distance and average speed in each section and converted to a monetary amount, and the route where the sum of this amount and expressway tolls and ferry charges was the shortest was searched. Total transportation costs are expressed as the sum of truck transportation cost, transportation time cost, and expressway tolls/ferry charges. The numerical values given in Guidelines for Evaluating Port and Harbor Investments were used for calculation of truck transportation costs and the time value of container cargos. In setting the ratio of special vehicles (with full-load or high-cube containers), a value of 1:1 was used for 20ft and 40ft containers. For other values, the results shown in Chapter 2 were used.

As shown in Table 4, the total economic loss nationwide due to the existence of bottlenecks affecting full-load containers is approximately 1 to 2 billion yen per year for Scenario 1 and more than 40 billion yen per year for Scenario 2. From the fact the economic loss for Scenario 2 is more than ten times as Scenario 1, it is clear that the economic effect of eliminating bottlenecks in enabling shippers to convert to full-load containers is far greater than the simple effect of eliminating detours. The total loss nationwide due to bottlenecks affecting high-cube containers was approximately 1.2 to 1.5 billion yen per year for Scenario 1 and 16 billion yen per year for Scenario 2. It may be noted that the loss due to bottlenecks affecting high-cube containers was smaller than in the case of full-load containers. This is attributable to the fact that the total number of tunnels is smaller than that of bridges, which means that more roads are passable by vehicles carrying high-cube containers.

Table 4 Estimation of economic loss due to detouring bottlenecks (mil. Yen/year)
(Full-load Containers)

			Ration of Special Vehicle		Transportation Cost		Trnasportation Time Cost		Fare of Expressway		Total Cost			Econo-mic Loss
			20ft	40ft	20ft	40ft	20ft	40ft	20ft	40ft	20ft	40ft	Total	Total
Able to Use Exprssway	With Bottlenecks		62.7%	55.1%	80,084	133,660	3,477	6,184	1,262	1,344	84,822	141,189	226,011	
	No Bottlenecks	Scenario 1			79,647	132,971	3,471	6,169	1,130	1,206	84,248	140,346	224,594	1,416
		Scenario 2	41.6%	51.7%	46,688	124,818	1,926	5,793	672	1,132	49,286	131,742	181,028	44,983
Impossible to Use Expressway	With Bottlenecks		62.7%	55.1%	81,849	136,459	4,493	7,987	0	0	86,342	144,446	230,788	
	No Bottlenecks	Scenario 1			81,071	135,231	4,346	7,722	0	0	85,418	142,953	228,371	2,417
		Scenario 2	41.6%	51.7%	47,518	126,939	2,413	7,251	0	0	49,931	134,190	184,121	46,667

(High-cube Containers)

			Ration of Special Vehicle		Transportation Cost		Trnasportation Time Cost		Fare of Expressway		Total Cost			Econo–mic Loss
			20ft	40ft	20ft	40ft	20ft	40ft	20ft	40ft	20ft	40ft	Total	Total
Able to Use Exprssway	With Bottlenecks		0.0%	Ex.44.4%, Im.43.0%	0	105,480	0	4,842	0	977	0	111,300	111,300	
	No Bottlenecks	Scenario 1			0	104,299	0	4,846	0	945	0	110,091	110,091	1,209
		Scenario 2		Ex.38.5%, Im.37.1%	0	90,117	0	4,191	0	817	0	95,125	95,125	16,175
Impossible to Use Expressway	With Bottlenecks		0.0%	Ex.44.4%, Im.43.0%	0	107,516	0	6,164	0	0	0	113,681	113,681	
	No Bottlenecks	Scenario 1			0	106,072	0	6,066	0	0	0	112,138	112,138	1,543
		Scenario 2		Ex.38.5%, Im.37.1%	0	91,649	0	5,245	0	0	0	96,895	96,895	16,786

Calculation of economic loss at individual bottlenecks. When calculating the economic loss due to the existence of individual bottlenecks, it is necessary to calculate the difference between the total transportation cost with the existing transportation network and the transportation network after eliminating only the bottleneck in question. Because it is not realistic to make the above-mentioned calculation for every bottleneck, here, economic loss was compared for each of the pairs of container packing places and shipping ports (these pairs are termed "OD pairs"), and the bottlenecks were designated by comparing the shortest routes in with/no bottleneck case for several tens of OD pairs with the largest economic loss. For the bottlenecks extracted, the economic loss was obtained by adding the difference in the two networks for OD pairs. Among the individual bottlenecks obtained, Fig. 8 shows the detour routes of the bottlenecks which cause one of the largest economic loss nationwide in high-cube container transportation. Table 5 shows the economic loss at the same bottlenecks. From the table, it can be understood that the trend in the amount of loss in Scenario 1 and 2 is similar to that of the calculated national totals. However, because the absolute value of the loss differs by approximately one order of magnitude, it can be surmised that a relatively small number of bottlenecks accounts for the greater part of national loss.

Fig. 8 Sample of bottleneck for semi-trailers for high-cube container and detour route (in case of no use expressway)

Table 5 Estimation of economic loss due to detouring the sample bottleneck (mil. Yen/year)

		Ration of Special Vehicle		Transportation Cost		Trnasportation Time Cost		Fare of Expressway		Total Cost			Economic Loss
		20ft	40ft	20ft	40ft	20ft	40ft	20ft	40ft	20ft	40ft	Total	Total
With Bottlenecks		0.0%	Ex.44.4%, Im.43.0%	0	50.9	0.0	3.1	0.0	2.3	0	56.3	56.3	
No Bottlenecks	Scenario 1			0	47.9	0.0	3.6	0.0	1.0	0	52.5	52.5	3.8
	Scenario 2		Ex.38.5%, Im.37.1%	0	36.2	0.0	2.7	0.0	0.8	0	39.7	39.7	16.6
With Bottlenecks		0.0%	Ex.44.4%, Im.43.0%	0	208.1	0.0	28.6	0.0	0.0	0	236.7	236.7	
No Bottlenecks	Scenario 1			0	157.0	0.0	16.4	0.0	0.0	0	173.5	173.5	63.2
	Scenario 2		Ex.38.5%, Im.37.1%	0	118.7	0.0	12.4	0.0	0.0	0	131.2	131.2	105.5

Conclusion

This paper examined the system and current condition of traffic restrictions affecting vehicular transportation by semi-trailers, which accounts for the largest part of domestic transportation in Japan, considering international maritime containers as a representative international maritime cargo. Bottlenecks in the transportation network were extracted, and the economic loss attributable to the existence of these locations was calculated. Looking at Japan as a whole, it cannot be said that the economic benefit of eliminating bottlenecks is particularly large in comparison with the cost of road improvement project, at a minimum of several billion yen per bottleneck location, especially if only the effect of eliminating detour transportation is considered, as in Scenario 1. However, at certain individual bottlenecks, effects would exceed the cost of improvement. In the future, the authors intend to develop a transportation route/shipping port selection model for international maritime cargos which also considers traffic bottlenecks affecting large vehicles, and create a framework which enables simultaneous evaluation of infrastructure construction projects encompassing both roads and ports.

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