A STUDY OF A NETWORK ANALYSIS MODEL FOR FREIGHT DEMAND

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ABSTRACT

Cooperation reinforcement with maintenance of a road network corresponding to upsizing of a trucks and marine transportation / aviation is indispensable to support international distribution. It is necessary to accurately evaluate the roles and functions of the present road network in international distribution in order to effectively allocate limited funds for road maintenance.
This study examines a method of estimating freight flows on the road by focusing on international marine containers whose importance has increased in recent years due to rising imports of final goods. The study then uses the method to evaluate the roles and functions of roads from a number of perspectives: the number of trucks by export and import, the weight of the freight, and the unit price of the freight. In this report, we focus on Tokyo and Yokohama Bays and report the results of our evaluations.

1. INTRODUCTION

To date, the effects of road improvements have been measured mainly quantitatively, such as the amount of traffic demand. However, it is equally important to consider the merits and demerits of road improvements in terms of the quality and function of road usage, that is, in terms of how roads are used and what functions they perform.

In the United States, freight demand is evaluated with a model analysis called the Freight Analysis Framework (FAF). Specifically, FAF is used to evaluate the quality and function of road use from the perspective of freight flow.

This study examines a method of estimating freight flows on the road by focusing on international marine containers whose importance has grown in recent years as a result of increased imports of final goods. The study then uses the method to evaluate the roles and functions of roads from a number of perspectives: the number of trucks by export and import, the weight of the freight, and the unit cost of the freight.

In the discussion below, first we review a method of estimating freight used in Japan and the FAF used in the U.S. We then describe the method for preparing road network data and the technique for preparing freight OD data. After that, we introduce the method of distribution we used and report on our results of evaluating the international marine containers at Tokyo and Yokohama Bays.

2. METHOD OF ESTIMATING EXISTING FREIGHT DEMAND

In this section, we review the results of a typical method of estimating freight demand used in Japan and the FAF used in the U.S. In Japan, there is not enough consideration given to freight vehicles at the stage of road planning when traffic demand estimates are made. As a result, few proposals are based on systematic methods of estimating freight demand. In this study, mainly examination it did with the method of thinking FAF as a reference.

2.1. Domestic Freight Demand Forecast Model (Council for Transport Policy Model)

In making inter-regional freight volume forecasts, we often estimate the amount of flow per unit weight. Also, since freight volume is directly proportional to the economic situation, economic forecasts must be placed at the top level of any forecast flow chart. Figure 1 is an example of a long-term forecast flow chart for domestic freight transport demand ［1］ that exogenously presents a comprehensive national development plan and a national economic frame. However, since the indices related to the economy are expressed in terms of monetary units such as regional gross production, they must be converted into freight demand (the weight-money conversion ratio). Usually, a production value is obtained from an inter-industrial linkage table, while a conversion ratio is calculated from a logistic table. The estimated flow chart obtained after the freight volume is estimated is the same 4-stage estimation method used in calculating person trips. However, as noted earlier, since weight is the unit we estimate, further conversion by type of transport mode is essential when it is important to know the traffic volume.

2.2. FAF in the U.S. ［2］

In this section, we introduce the Freight Analysis Framework (FAF), which is used in the U.S. to estimate freight demand. Research on FAF was launched in 1999 by the United States Department of Transport, Federal Highway Administration (USDOT, FHWA). The database for analysis is being built by the Oak Ridge National Library (ORNL).

2.2.1 Outline of FAF

- Establish a method for evaluating the flow of freight concerning infrastructure related to logistics.
- Develop a comprehensive database concerning freight transport based on various types by database, both in government and in the private sector.
  - → Distribute freight OD among road links and others and prepare a “Freight Flow Map” showing GIS.
  - → Forecast freight flows in 2010 and 2020 based on the actual performance recorded in 1998.

2.2.2 FAF Output

The current status and future link freight volume are shown diagrammatically in Figure 2.

2.2.3 Steps for preparing commodity distribution data in the current status (1998)

Inter-county OD commodity distribution data of FAF by product type by modes of transport are prepared according to the following method:

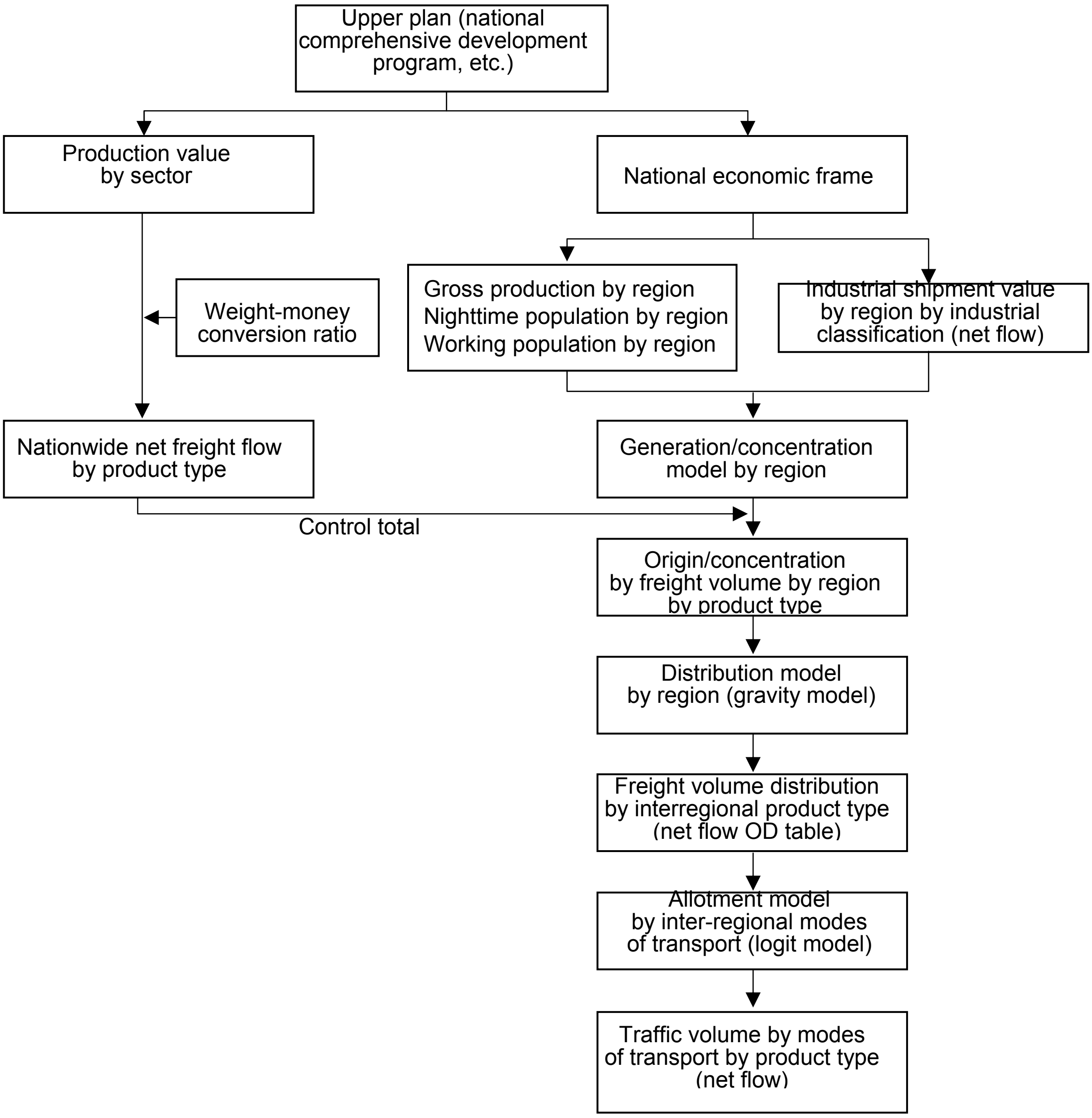
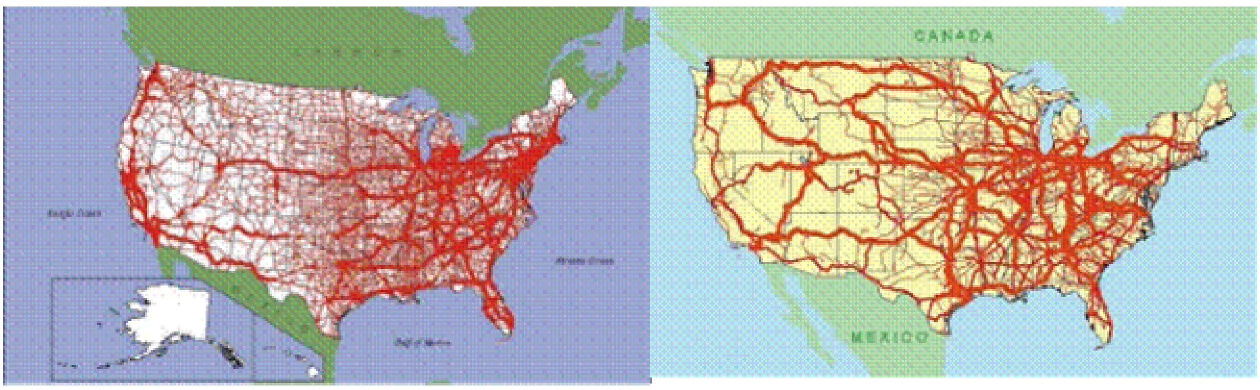


Figure 1 – Prediction of inter-regional freight traffic volume



Truck freight flows
(2020, truck traffic volume/day)

Rail freight flows
(1998, ton)

Figure 2 – FAF output

○ **Estimate of production volume in each state by industry or by product type**

- Prepared on the basis of the U.S. Census Bureau's Annual Survey of Manufacturers and its Census of Manufacturers, both of which show the manufacturing activities of each state.
- Since the above statistical figures represent production volumes in dollar terms, convert them to tons by using the Reebie conversion factor [*1]

↓

○ **Estimate the production and consumption volume of domestic traffic**

- Estimate the domestic traffic activities by linking production and consumption patterns to transport.
- Analyze the estimate of the domestic traffic activity by using the industrial activities of each state (industrial production index, trade association, updated in industrial reports).

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○ **Allocation of traffic volume to regions in terms of country unit**

- Regionalize the traffic volume by using information on place of business (address, employment situation, business content), population data, and rail charge factor (production and traffic estimates).
- Judge the inter-regional relationship by using the I/O pattern.

→ OD estimates by product type

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○ **Estimate of traffic volume by modes of transport**

- Estimate the inter-county table by modes of transport by using domestic production figures and traffic performance data in term of county unit.

◆ Preparation of domestic modal database

- Organize information regarding seven modes of transport using information ranging from place of shipment to destination on a county level (modes of transport: reserved truck, combination truck, private truck, railroad, rail-truck intermodal, aviation, vessel).

◆ Preparation of international modal database

- OD estimate of export and import freight in terms of county unit by employing transport performance data beyond national boundaries.
- Transport performance data uses freight transport performance, international marine transport performance, and international aerial transport performance recorded at Canadian and Mexican borders.

→ OD estimate by product type by modes of transport

Steps for preparing commodity distribution data in the current status (1998) in FAF

3. PREPARATION OF ROAD NETWORK DATA USED IN THE PRESENT STUDY

3.1. Zoning

In this study, focusing on the estimated volume of traffic in Japan as a whole, we divided the entire country into 207 zones in terms of local living area. In addition, with regard to the zones behind Tokyo and Yokohama Bays (urbanized parts of Tokyo), the two areas analyzed in this study, since it is necessary to understand in detail the freight flows at the two bays, we applied a more clearly defined zone unit of the aggregate zone B.

*1 http://www.dot.state.oh.us/planning/Freight/report_adobe_hlm/FR1_Ohio%20Freight_Sect%201_Commodity%20Truck.pdf

3.2. Preparing network data

The following method was used to extract the inter-zone network data. First, we selected an aggregate zone B that includes the central cities of the 207 zones into which Japan was divided on the basis of local living areas, and set the central nodes of those cities as the central nodes of the 207 zones.

Next, we searched for the shortest paths among the 207 zones by using networks of all road types. As a result, among the roads below the general prefectural roads, we removed from the network those that were not being used whatsoever. We searched for the shortest paths among the reciprocal nodes that would be the zone centers by applying the Dijkstra Method to seek the paths with the least generalized cost.

Furthermore, with regard to the zones behind Tokyo and Yokohama Bays (the Tokyo urban area), since it is necessary to understand in detail the international marine container flows at the two bays, we added links to the temporary port roads and others that are not included in the network of the 207 zones.

By applying the above method, we extracted the links among national expressways, national highways and main local roads as well as the approximately 410,000 links comprised of other main arterial roads. The breakdown of the number of networks by road types is shown in Table 1.

Table 1 – Number of links by type of road as a target of analysis

Road Type	No. of Links
National expressways	22,351
National highways	141,224
Main local roads (prefectural roads)	130,058
Main local roads (city roads in specified cities)	6,069
Others	113,598
Total	413,300

3.3. Setting the time required for links

The required time was added to the aforesaid network links. Basically, the required time for links is calculated from the link distance by using the volume of traffic obtained as a result of existing distribution (i.e., the result obtained by distributing between B zones nationwide) and seeking the travel time per unit distance with the BPR function.

The travel time per unit distance by link is calculated using the following BPR function ［3］.

$$\bar{t} = 0.74\left\{1 + 0.48\left(\frac{X}{19.1c}\right)^{2.82}\right\}$$

Here, c : possible time traffic volume
X : daily traffic volume

4. PREPARATION OF OD DATE ON FREIGHT

In this study, we adopted the following method to prepare OD data by export and import of international marine containers at Tokyo and Yokohama Bays.

4.1. Preparation of OD data on international marine containers

By using the 2003 “Land Export and Import Freight Survey” data, we prepared container freight data (1 month value, unit: freight/ton) by Tokyo/Yokohama Bay by 8 product types by points of provenance/destination (by municipality) by export/import. Here, the term freight/ton refers to the tonnage of freight in port and harbor figures where capacity of 1.113 m^3 and weight of 1,000 kg are considered to be 1 ton, and the larger of the two is regarded as freight/ton.

4.2. Conversion from freight to metric ton

Freight-to-ton conversion was expanded to an annual value by using the “Export/Import Volume by Port and Harbor by Product Type” described in the “Annual Report on Port and Harbor Statistics” and the 1999 value (freight/ton unit) reported in the “Freight Volume of Container/Chassis Exports and Imports by Port and Harbor.”

The conversion from freight to metric ton was performed by calculating (Logistics Census/Port and Harbor Statistics) the converter for converting freight/ton from the export/import volume by product type described in the annual survey data (1999 value: metric ton unit) reported in the “Seventh Logistics Census” and the Annual Report on Port and Harbor Statistics (1999 value: freight/ton unit) and multiplying the result by the data on the aforementioned freight/ton annual value. Metric ton is a unit of weight where 1,000 kg equals 1 ton. Converters by product type and by export/import are shown in Table 2.

Table 2 – Results of freight-ton ⇒ metric ton converter estimates

Items	Converters		
	Exports	Imports	Total
Agriculture/fisheries	0.289	0.667	0.657
Forestry products	0.250	0.380	0.379
Mining products	0.511	0.827	0.824
Metal/machinery industry	0.405	0.420	0.408
Chemical industry	0.855	0.582	0.637
Light industry goods	0.442	0.547	0.519
Miscellaneous industry	0.102	0.191	0.164
Special products	0.140	0.189	0.170

4.3. Converting from metric ton to number of vehicles and price

The average distribution lot of trailers (22.15 ton/shipment) that can be ascertained from the results of the “Seventh Logistics Census” was used to execute the conversion from metric ton base to number of vehicles base.

In addition, the price per 1 freight/ton that can be ascertained from the “National Survey of Export/Import Container Freight Flow” was used to effect the conversion to price base. The price per 1 freight/ton by product by export/import is shown in Tables 3 and 4.

Table 3 – Price per 1 ton/freight (export container)

Items	Freight volume (100 freight ton)	Declared price (1 million yen)	Price per 1 ton (10,000 yen/ton)	(Remark) Results of 1999 survey
Agriculture/fisheries	224	4,019	17.9	15.9
Forestry products	2	48	19.8	9.0
Mining products	161	1,851	1.5	17.0
Metal/machinery industry	27,848	1,241,314	44.6	39.7
Chemical industry	12,404	252,176	20.3	21.2
Light industry goods	4,067	84,047	20.7	17.8
Miscellaneous industry	5,963	118,239	19.8	17.3
Special products	1,537	25,626	16.7	2.4
Total	52,207	1,727,320	33.1	29.5

Table 4 – Price per 1 ton/freight (import container)

Items	Freight volume (100 freight ton)	Declared price (1 million yen)	Price per 1 ton (10,000 yen/ton)	(Remark) Results of 1999 survey
Agriculture/fisheries	7,056	173,326	24.6	20.9
Forestry products	2,263	14,728	6.5	5.2
Mining products	1,841	10,713	5.8	5.0
Metal/machinery industry	9,136	280,879	30.7	23.1
Chemical industry	7,131	139,738	19.6	13.9
Light industry goods	7,856	151,881	19.3	13.4
Miscellaneous industry	14,166	237,827	16.8	11.9
Special products	4,291	34,280	8.0	6.7
Total	53,740	1,043,374	19.4	14.6

Source: “FY1999 Report of Foreign Trade Container Freight Flow Survey, Ports and Harbors Bureau, Ministry of Transport,” “FY2003 Report of Foreign Trade Container Freight Flow Survey, Ports and Harbors Bureau, Ministry of Land, Infrastructure and Transport”

5. ROUTE DISTRIBUTION OF INTERNATIONAL MARINE CONTAINER FREIGHT

We examined the method for distributing the traffic volume of freight vehicles obtained from the aforementioned freight OD data. The method of distribution used in this study is an all-or-nothing method that minimizes the generalized cost. It applies the model for making route selections for large freight vehicles constructed by using data from the “Large Freight Vehicle Travel Route Survey,” a survey that supplements the Survey of Cargo Flow in the Urbanized Parts of Tokyo of 2003［4］.

5.1. Outline of route distribution model

In addition to such factors as the required time and cost, the travel routes for large freight vehicles are chosen by giving priority to roads that are easier for large vehicles to use, such as roads that require vehicles to be of a certain weight and height. The model we adopted for this study hypothesizes that users will feel that the required time is shorter and the cost less when they are driving in sections of the road with specified weight (perceived generalized cost). The model then estimates the parameter that shows the perceived generalized cost of the roads with specified weight so as to maximize the rate of duplication of the estimated travel routes and the actual travel routes.

The model formula is as follows:

$$GC = (\text{cost [yen]} + 80 \times \text{time [min.]}) \times 0.79^{\text{specified weight link dummy}}$$

Here,

GC: perceived generalized cost in each link

Cost: gasoline + toll charge

Specified weight link dummy: = 1 if the link is a road with specified weight; = 0 otherwise

Time: time required to drive through each link

Rate of duplication of route with shortest travel distance (estimated) and actual distance: 0.48

Rate of duplication of route with minimum generalized cost (estimated) and actual cost: 0.56

Rate of duplication of estimated value in the large freight vehicle route selection model and actual value: 0.65

6. QUALITATIVE EVALUATION OF ROADS STEMMING FROM INTERNATIONAL LOGISTICS

We reproduced the domestic flow of international freight and conducted a case study of road function evaluation by using the aforementioned road networks and the OD data of freight flows. Of the international marine container freight that arrives in Tokyo and Yokohama Bays, the target of our analysis is the freight shipped by motor vehicles on roads.

6.1. International marine container freight flows in Tokyo Bay

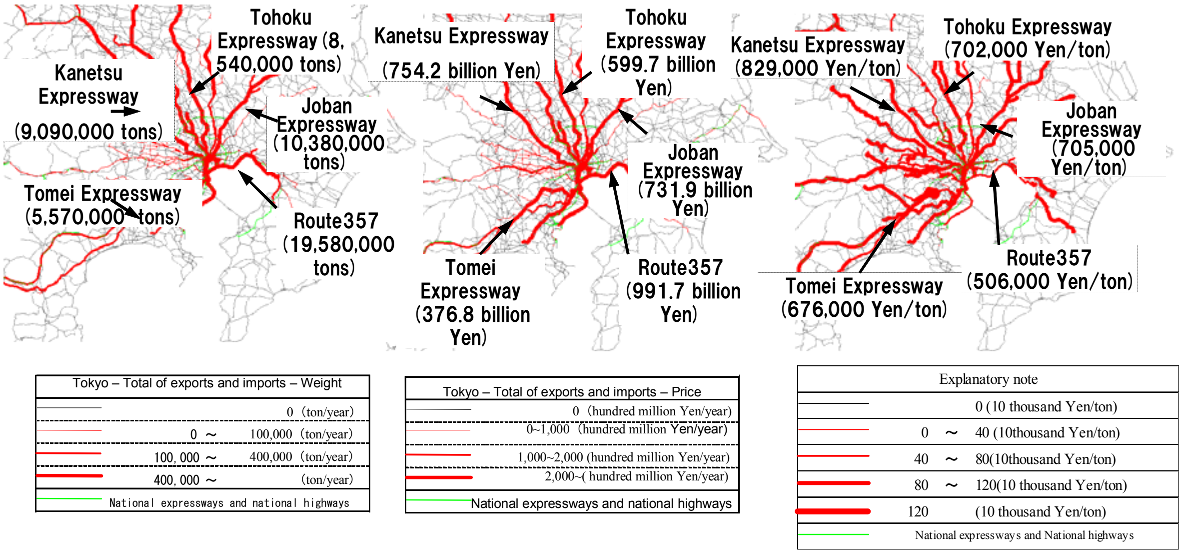
Figure 3 shows how export and import container cargoes related to Tokyo Bay are allocated in the road networks and the international marine container freight flows in terms of weight, number of vehicles, and price. Figure 4, focusing on specific links, shows the composition of products by exports and imports in terms of weight, number of vehicles and price. On the Tohoku Expressway, reflecting the difference in product composition, imports in terms of weight and number of vehicles are estimated to be higher than exports, but exports are estimated to be higher in terms of price.

On the Tohoku Expressway, the import volume is greater than the export volume when viewed in terms of weight and number of vehicles, but the export volume is greater in terms of price, thus reflecting the difference in the product composition of these two components of foreign trade.

6.2. International marine container freight flows in relation to Yokohama Bay

Figures 5 and 6 show the estimated effects of the flows of export/import containers in relation to Yokohama Bay.

The volume of freight flow on National Route 16 is very large. To compared with other routes, this volume reaches from 4 to 6 times as large with weight basis, and from 6 to 13 times as large with price basis. Especially the export of metal/machinery industry were so high that the gap with price basis had bee estimated large.



Transportation volume (total of exports and imports)

Traffic Flow (Traditional viewpoint)

Prices (total of exports and imports)

Value Flow (New viewpoint)

Prices per ton (total of exports and imports)

Figure 3 – The flow of export/import containers in relation to Tokyo Bay (Estimated)

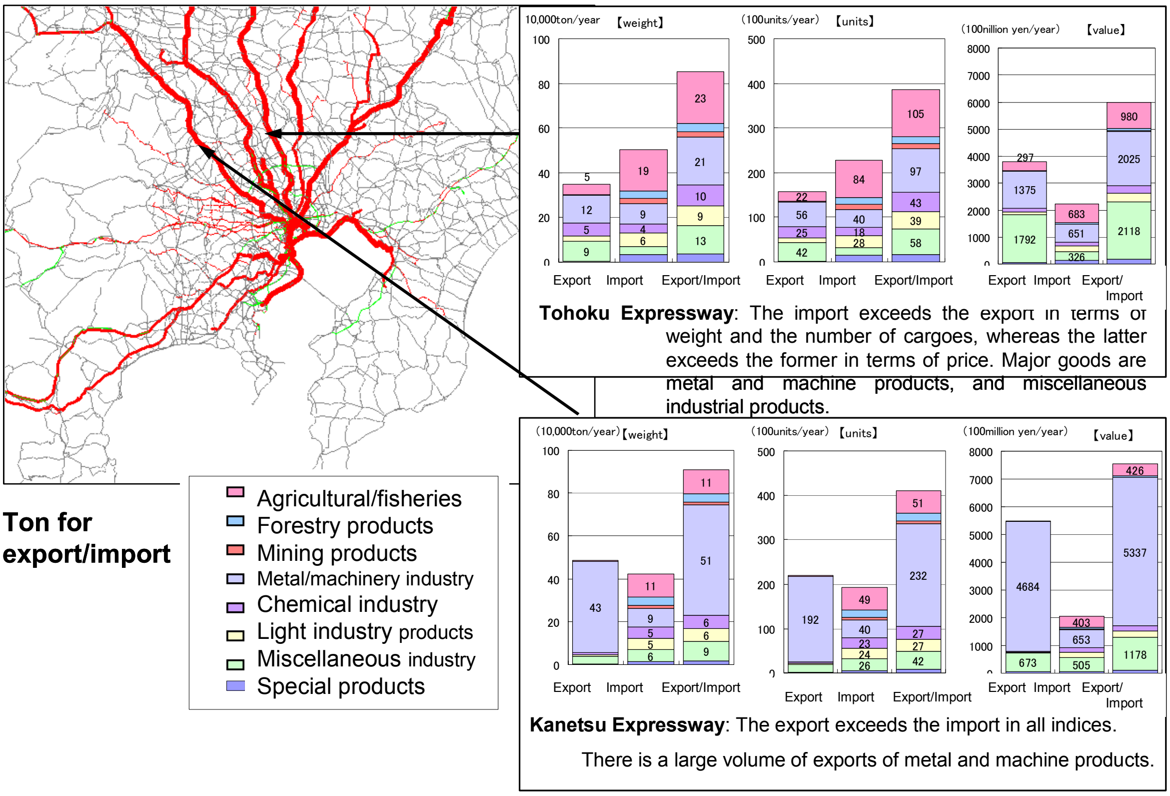
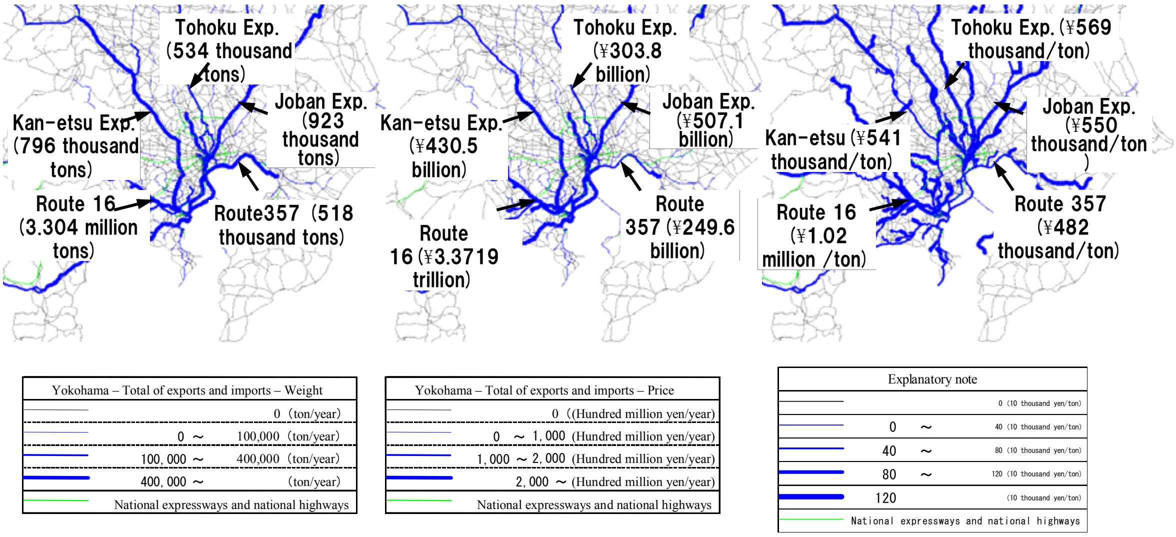


Figure 4 – The flow of export/import containers in relation to Tokyo Bay (in terms of weight, number of vehicles and price by product)



Transportation volume (total of exports and imports)

Prices (total of exports and imports)

Prices per ton (total of exports and imports)

Traffic Flow (Traditional viewpoint)

Value Flow (New viewpoint)

Figure 5 – The flow of export/import containers in relation to Yokohama Bay (Estimated)

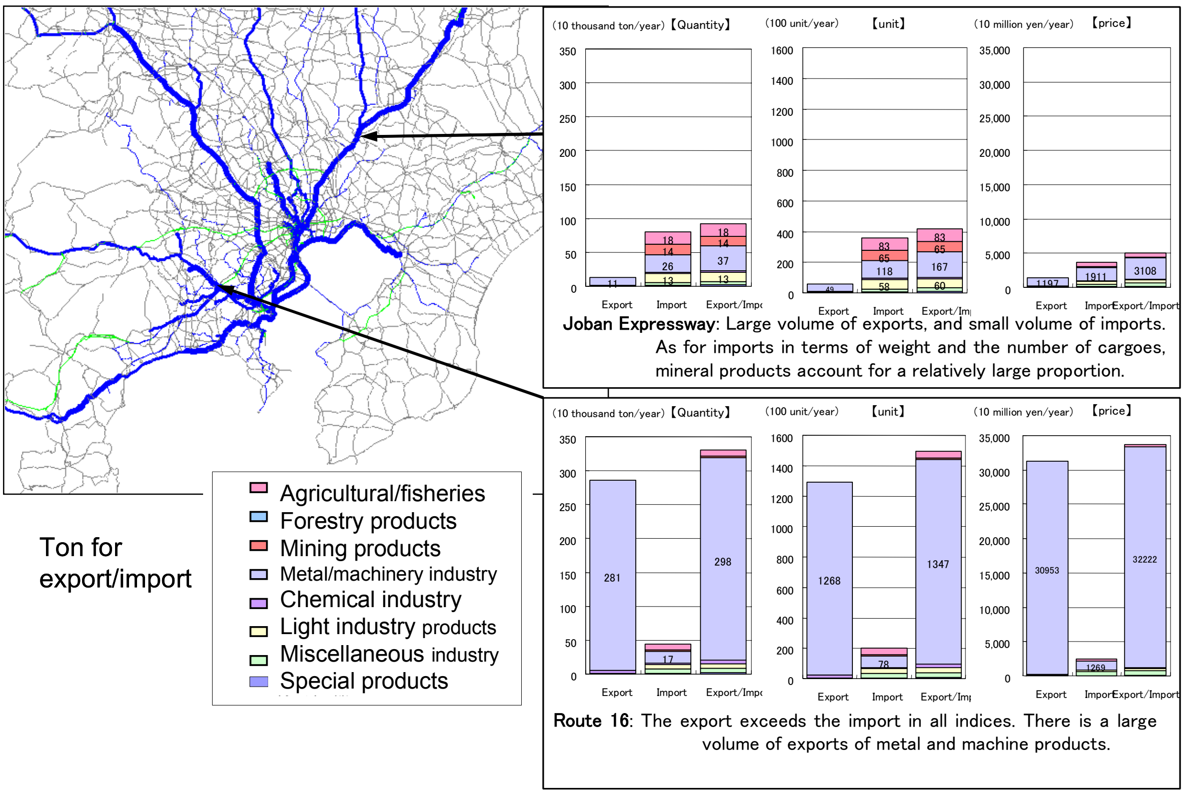


Figure 6 – The flow of export/import containers in relation to Yokohama Bay (in terms of weight, number of vehicles and price by product)

6.3. Effects of building road networks that contribute to international freight transport

In the urbanized areas of Tokyo, due to the lack of ring roads, the load on the flow of through traffic and certain general roads is very large, causing traffic congestion and other environmental problems.

In this section, we present the results of evaluating the effects of building ring roads in Tokyo and a ring highway north in Yokohama(missing link), which presumably will become important routes for the flow of export/import containers in relation to Yokohama Bay. The results were evaluated by using the present model.

Figure 7 shows a significant change in the freight flow in relation to Yokohama Bay by building the two missing links indicated by the red dotted line.

6.3.1 Reducing inward traffic

We estimated that the inward traffic to three districts in the Metropolitan area of freight originating and arriving in Yokohama Bay would be decreased by 51 percent by building ring roads in the Tokyo area (④), while the rate of use of the link within the three districts in the Metropolitan area would be reduced by half.

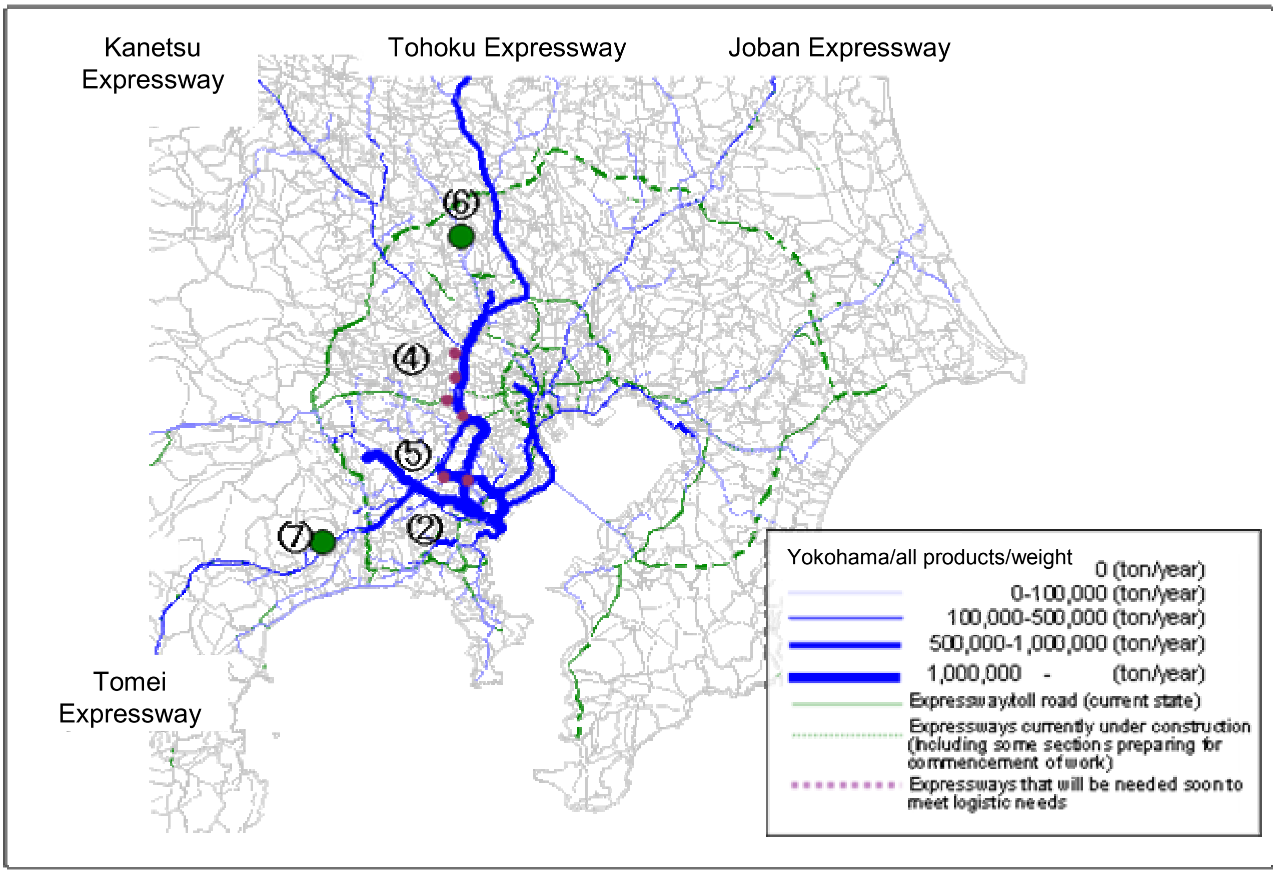


Figure 7 – The quantity of freight flow by links originating and arriving at Yokohama Bay (in terms of the sum of exports and imports)

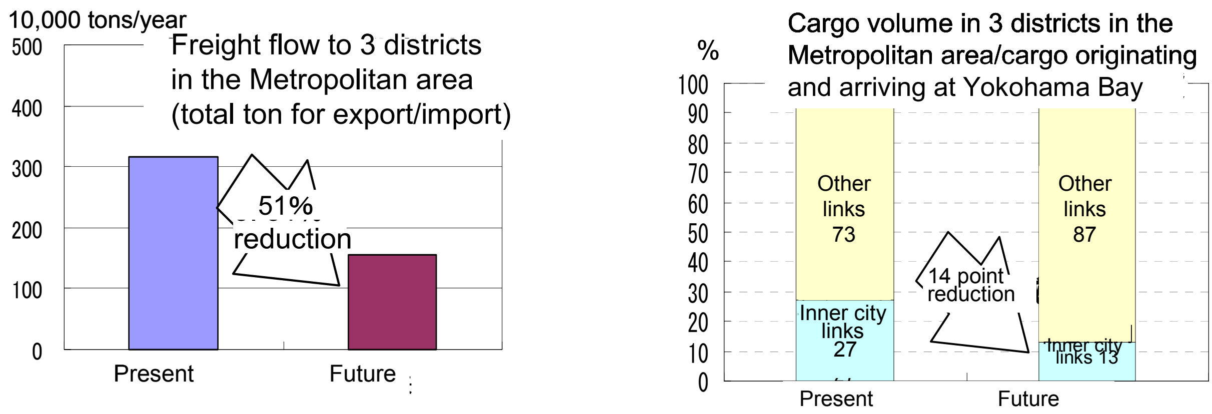


Figure 8 – Changing inward traffic to three districts in the Metropolitan area of containers originating and arriving in Yokohama Bay

6.3.2 *The role of development of roads and reduction of traffic on general roads*

Figure 9 shows the distribution results assuming that the proposed Tokyo ring roads and Yokohama ring highway north are built. On the Tokyo ring roads, the quantity of import flows is large, but on Yokohama ring highway north, the quantity of export freight flow diverted from National Route 16 is particularly large. In addition, Figure 10 shows the quantity of freight flow and the change of share on National Route 16.

We estimated that traffic load on National Route 16 would be decreased by 9 percent.

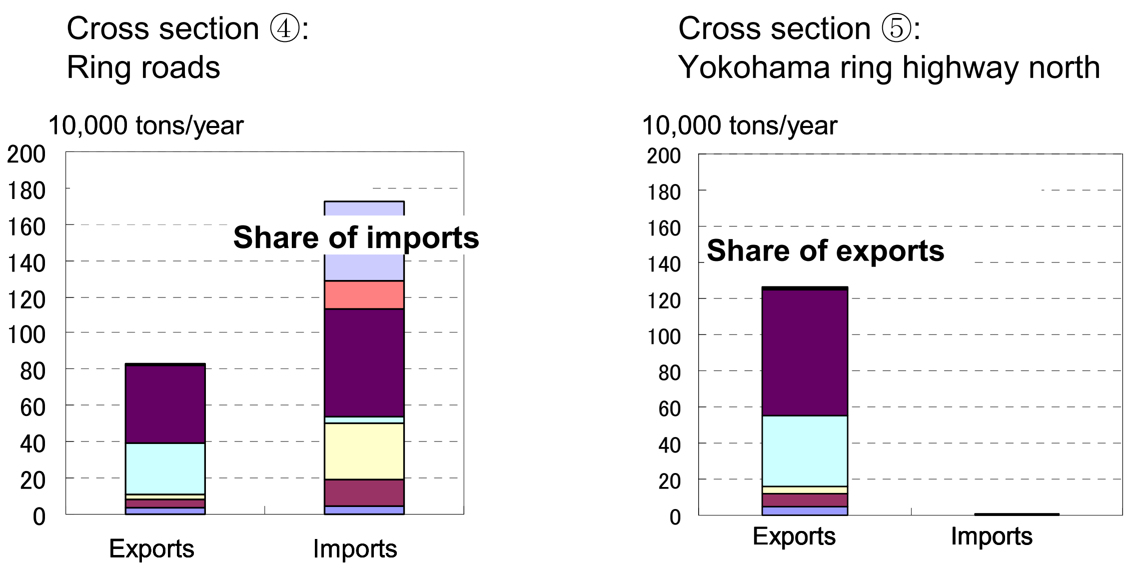


Figure 9 – The quantity of flow into constructed roads of containers originating and arriving in Yokohama Bay

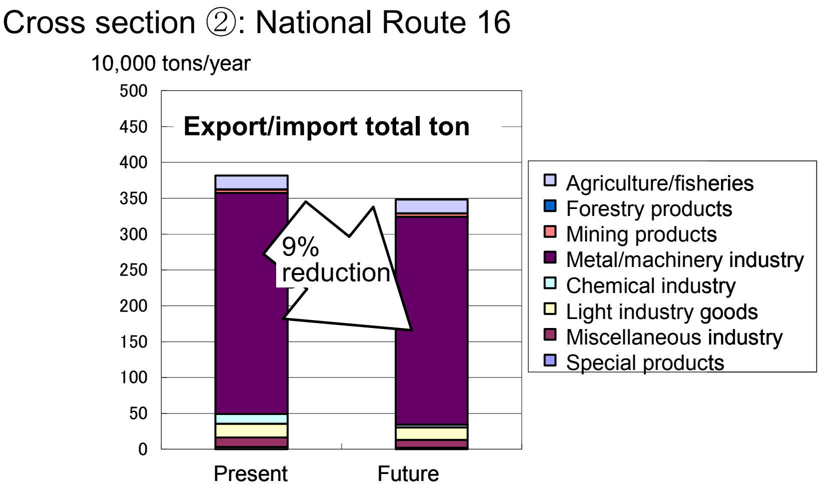
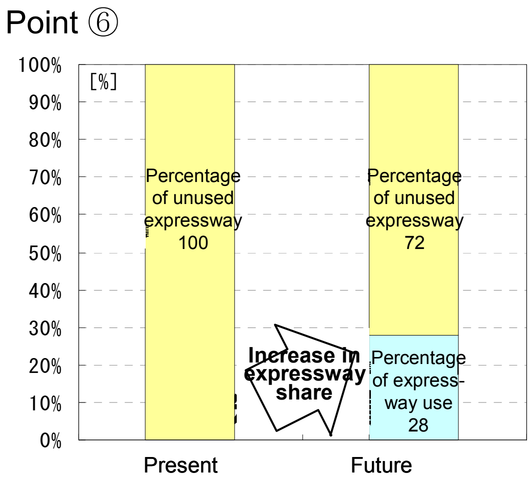


Figure 10 – Changes in the quantity of flow into National Route 16 of containers originating and arriving in Yokohama Bay

6.3.3 Reduction of driving time

Figure 11 shows the rate of change of expressway use in the freight flow between Yokohama Bay and Ageo City (⑥), Saitama Prefecture. The use of the expressway increased with the construction of the two routes, and as a result, the entire driving time was reduced by 35%, thus construction of the new routes would increase logistic efficiency.



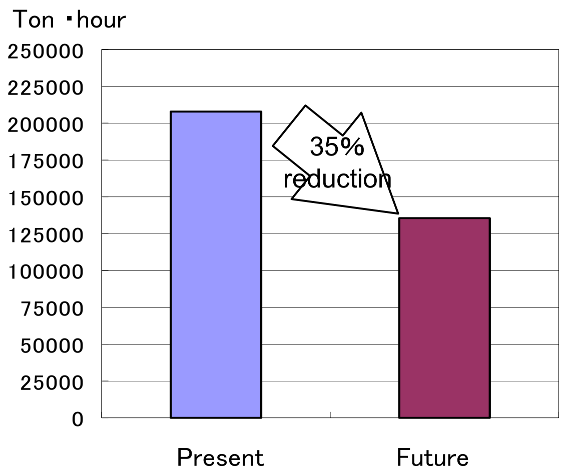


Figure 11 – Changing rate of expressway use between Yokohama Bay and Ageo City

7. CONCLUSION

In this study, we demonstrated the possibility of evaluating the roles and functions of international marine container freight transport on the road in terms of number of vehicles, weight in tons and price. We also confirmed the possibility of logistically presenting the needs and effects of road maintenance.

Characteristics of individual freights appeared in terms of linkage, export/import and product type even when the all-or-nothing method was used to minimize the generalized cost. The following points are remaining challenges in analytical techniques for improving the precision of the estimation results.

There is no assurance that the distribution results reported in this paper are consistent with reality. In the future, through a comparison with the route selection performance data of large vehicles, we will confirm the reproducibility of actual conditions and demonstrate the effectiveness and precision of our evaluation method as an analytical tool. It is also necessary to establish an analytical method through a comparison with several analytical tools including those that analyze the reflection of characteristics of route selection by product type and multi-route distribution method.

In future, we intend to conduct an analysis that goes beyond freight flows in relation to ports and harbors, but also targets freight flows nationwide.

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