A MODAL SHIFT MODEL FOR THE LOGISTICS NETWORK SYSTEM IN JAPAN

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Abstract
The possibility of a shift away from road to railway and marine transportation is discussed by analyzing the behavior of cargo shippers and by clarifying the factors involved in the choice of transport mode in terms of transport distance, time, cost, freight lot size and other related factors. The analysis procedures were conducted using logit models. As a result, factors influencing the modal choice could be identified and it was found that a considerable portion of currently existing transportation could be converted to container transport by ship or rail. The scale of feasibility for this shift and the considerable reduction of CO_2 emissions gained by this shift were estimated. Furthermore the influence on modal split of changes in transport cost and freight lot size was investigated by means of sensitivity analysis.

Keywords:
Modal shift, Logit model, CO_2 emissions, Freight transport, Logistics network

1 INTRODUCTION

The volume of Japan's domestic cargo transportation for fiscal 2002 came to 5.9 billion tons, or 570.7 billion ton-kilometers, of which trucks carried 90.6% in tonnage, or 54.7% in terms of ton-kilometer. The breakdown in modal share is as follows: 48.0% by commercial trucks, 42.6% by private trucks, 1.0% by rail, 8.4% by marine, 0.0% by air in ton, and 46.0% by commercial trucks, 8.7% by private trucks, 3.9% by rail, 41.2% by marine, 0.2% by air in ton-kilometers. Figure 1 shows the changes in modal split of freight transport in major countries. Freight transport in Japan has been characterized by an increase in truck operations for domestic freight traffic. Trucks carry nearly half of freight tonnage, especially over short-distance hauling, though these vehicles are less efficient and cause more damage to the environment. The prevalence of less efficient trucks is one of the major causes of energy inefficiency in the traffic sector. A conversion from trucks to railway or ships would make it possible to bring about improved cargo efficiency. In view of the environment and transport efficiency factors, a shift from trucks to railway or ships is desirable.

In this paper, the possibility of a shift from road to railway and marine transportation between the Tokyo metropolitan area and the remote areas of Japan is discussed by analyzing the behavior of cargo shippers and clarifying the factors involved in the choice of transport mode by transport distance, time, cost, freight lot size and other related factors. The analysis procedures were conducted using logit models.

As a result, factors influencing the modal choice could be identified and it was found that a considerable portion of currently existing transportation could be converted to container transport by ship or rail. In addition, the scale of feasibility of this shift was estimated. The greater the increase in rail and marine transport, the more the loading efficiency would improve, and this in turn would lead to a reduction in CO_2 emissions. The influence on modal split of changes in transport cost and freight lot size was investigated by means of sensitivity analysis. Finally, the CO_2 emission reduction brought about by changes in transport cost are shown.

There are several earlier papers dealing with modal shift /split models. Matsuo [1] provides the modal shift model between trucks and ferry ships at middle and long distance transportation, and applies discriminant analysis to the model. Motsuo and Fukuda [2] discuss logit models between trucks and ferry ships for rough data between prefectures. Tanaka, Shibazaki and Watabe [3] present a logit model between Hokkaido and prefectures in Kanto area. Most studies have focused on modal share and its variation. However, they have not explicitly clarified the evaluation of the environmental influences by a modal shift.

2 LOGIT MODELS

In this study, logit models for freight traffic to estimate cargo owner behavior were built and these models were applied to predict the modal split between road traffic and railway containers, and also between truck and ferry traffic for each relevant origin-destination pair. The models used the assumption that a cargo owner would choose the mode offering the maximum benefit to the firm, a factor that can be measured by utility. The basic principle of the logit model is that people behave rationally: they are constantly trying to maximize their utility [4]. This utility can be described with a utility function, which is divided into two components: strict utility and a stochastic element. The higher the utility, the more likely that alternative will be chosen. The models are also used to test the effects of some policies related to the development of freight transportation systems.

A disaggregate model such as a logit model is based on individual behavior. Therefore it takes into account important characteristics of the decision-maker that make a richer model specification possible. A better understanding of intermodal competition is accomplished due to the fact that these models use the actual attributes of modes and characteristics of the goods to be transported for generating estimates. The principal limitations of disaggregate models are the considerable amount of data required, difficulties compiling this data on individual mode choices, and the complexity of defining all attributes that determine choice. Fortunately, data using a three-day-survey collected from the 7th Physical Distribution Census, which was carried out in fiscal year 2000 [5], could

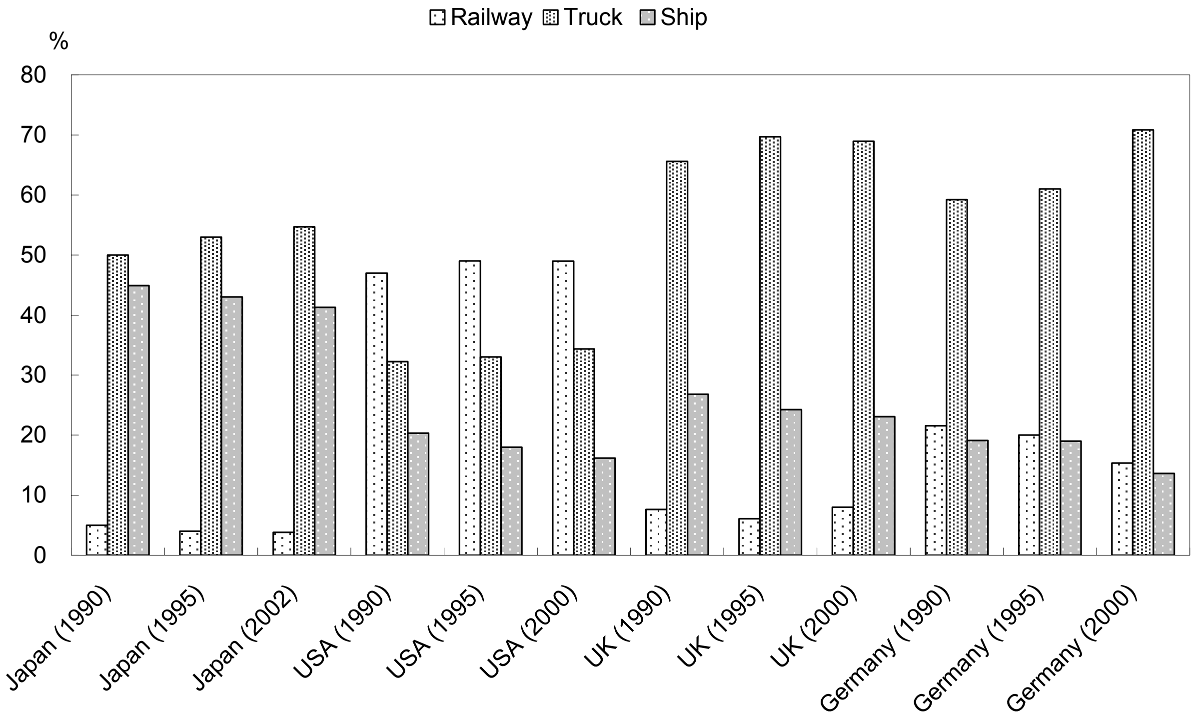

Figure 1: Changes in modal split of freight transport in major countries.

be obtained. These data are based on the origin-destination zones divided into 227 areas by mode.

The probability of choosing freight mode *i* in the logit model can be expressed as follows.

$$P_{in} = \frac{\exp(V_{in})}{\exp(V_{in}) + \exp(V_{jn})} \quad (1)$$

$$V_{in} = \sum \theta_{ki} a_{kn} \quad (2)$$

- P_{in} : the probability of choosing mode *i* by item *n*.
- θ_{ki} : a parameter for explanatory variable *k*.
- a_{kn} : explanatory variable *k* of item *n*.
- V_{in} : utility which is obtained by mode *i* of item *n*.

The targeted transport modes are the consolidated truck freight services, such as parcel delivery services, and the chartered trucks for road traffic; railroad containers; and ferry service ships. The models estimate the probability of choosing a mode between two alternatives for freight traffic between the Tokyo metropolitan area and the remote areas of Japan (Hokkaido, Tohoku and Kyushu areas). Figure 2 shows the map of these areas. Table 1 shows the targets used by logit models. Model 1 targets freight transport between Hokkaido, Tohoku - Tokyo metropolitan area, Model 2 targets freight between Hokkaido - Tokyo metropolitan area. Model 2 does not include Tohoku because of the small amount of ferry freight between Tohoku - Tokyo metropolitan area. Model 3 and 4 target freight between Kyushu - Tokyo metropolitan area. The targets of modal choice in Model 1 and 3 are truck and railway container; those of Model 2 and 4 are truck and ferry ship. The explanatory variables considered in the logit models included the following:

- Access time from origin of shipment to the nearest freight station or port used for the mainline transport.
- Access distance from origin of shipment to the nearest freight station or port used for the mainline ransport.
- Trunk time for mainline transport.
- Trunk distance for mainline transport.
- Egress time from the cargo station or port in destination area to actual destination.
- Egress distance from the cargo station or port in destination area to actual destination.
- Total time between origin and destination.
- Total distance between origin and destination.
- Transportation cost.

Figure 2: Tokyo metropolitan area and the remote areas of Japan (Hokkaido, Tohoku and Kyushu area).

Table 1: Logit models.

Model	*Freight Transport*	*Modal Choice*
1	Hokkaido, Tohoku -Tokyo met	Truck and railway container
2	Hokkaido - Tokyo met	Truck and ferry ship
3	Kyushu - Tokyo met	Truck and railway container
4	Kyushu - Tokyo met	Truck and ferry ship

Table 2: Explanation variables, parameters and *t*- values.

Explanation variable	*Parameter and t-value*			
	Model 1	*Model 2*	*Model 3*	*Model 4*
Access Time	-0.0537 (-5.23)	-	-0.109 (-4.17)	-0.949 (-4.93)
Total Time	-	-0.0322 (-3.27)	-	-
Transport Cost	-0.00818 (-8.44)	-0.00377 (-2.85)	-0.00255 (-5.22)	-0.00499 (-7.91)
Log Lotsize	1.35 [train] (11.8)	-	1.24 (11.7)	1.18 (9.74)
Correction term	-3.59 [train]	-3.26 [track]	-1.65 [train]	-2.01 [train]

( ) is *t*-value [ ] is target

Table 3: Hit ratios and likelihood ratios.

	Model 1	*Model 2*	*Model 3*	*Model 4*
Track hit ratio	0.72	0.58	0.81	0.81
Railway hit ratio	0.85	-	0.69	-
Ferry hit ratio	-	0.62	-	0.79
Average hit ratio	0.79	0.60	0.76	0.80
Likelihood ratio	0.37	0.08	0.27	0.32

- Freight lot size (logarithmic value).

Appropriate variables were selected from these variables based on the results of model applications.

3 RESULTS OF APPLICATION OF LOGIT MODELS

A software program, LIMDEP/NLOGIT Ver3.0, was used to calculate results using this model analysis. The analysis was conducted for the four models, respectively. Table 2 shows the explanatory variables selected for these models and their parameters and t-values. Table 3 shows the hit ratios and likelihood ratios.

From these results, it was found that the factors influencing mode choice were the freight lot size of the goods, transport cost and the total transport time between the origin and destination, and access time to the nearest port or cargo station.

Freight lot size is an especially significant determinant of mode choice related to transportation between the Tokyo and Kyushu areas, whereas transport cost is a common significant determinant of mode choice for all areas. These factors have an influence on the selection ratio of a mode. The larger the lot size of the freight and the less the transport cost by railway and ferry, the more the share of railway and ferry containers.

4 SENSITIVITY ANALYSIS

Some sensitivity analyses based on the results of the applications were carried out. The influence on modal split of changes in transport cost and freight lot size was first investigated in the case of cargo shipped from Hokkaido, Tohoku or Kyushu to Tokyo.

As the freight lot size increases, the probabilities of choosing railway container versus trucks in a logit model is shown in Figure 3, and that of ferry ships versus trucks is shown in Figure 4. In the same way, probabilities of choosing railway container and ferry ships versus trucks,

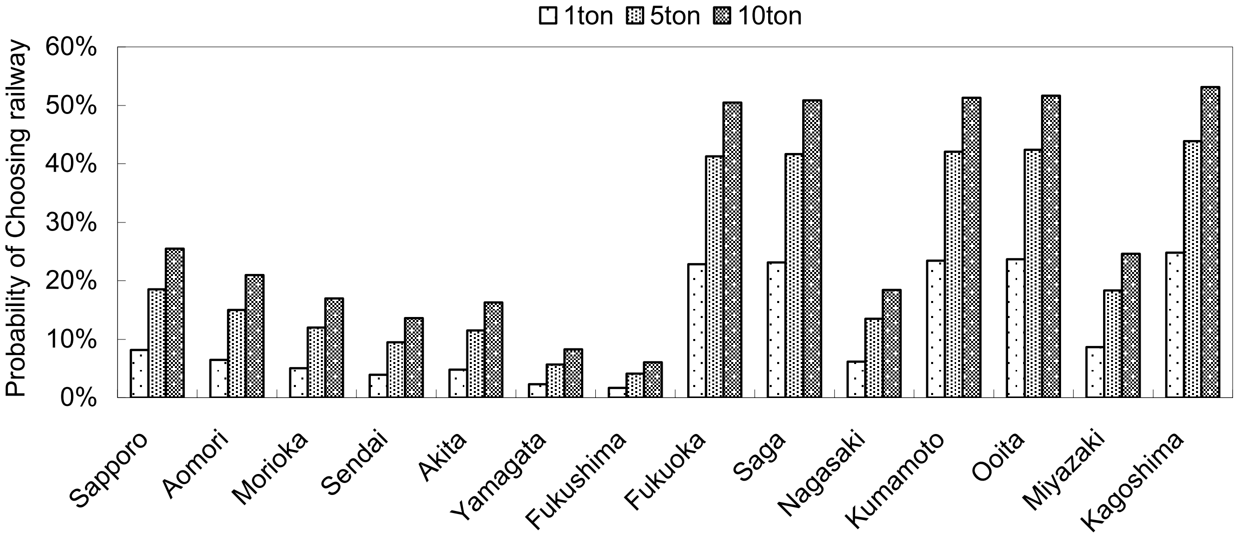

Figure 3: Probabilities of choosing railway versus trucks, increasing lot size.

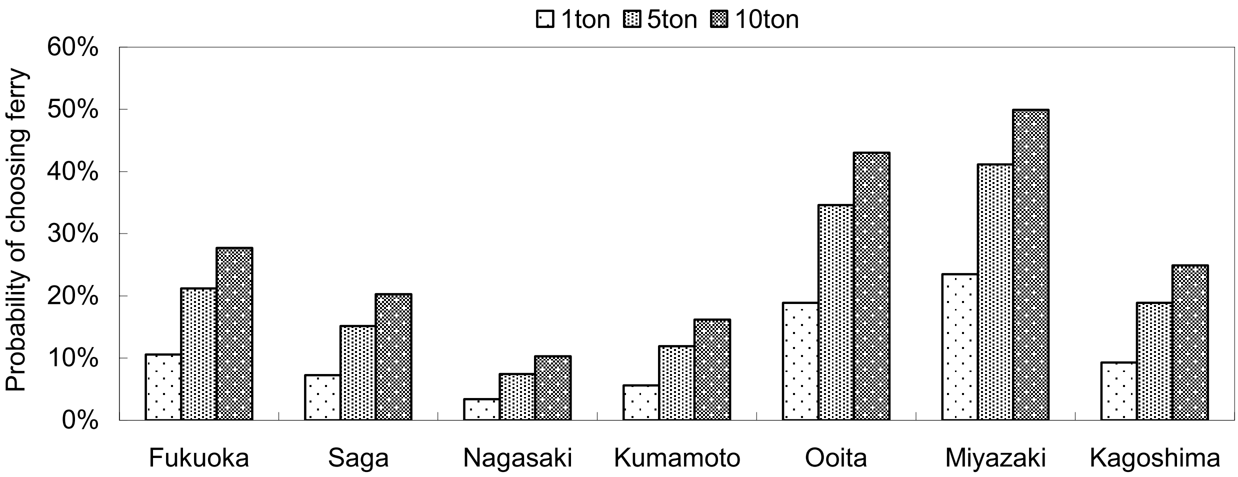

Figure 4: Probabilities of choosing ferry versus trucks, increasing lot size.

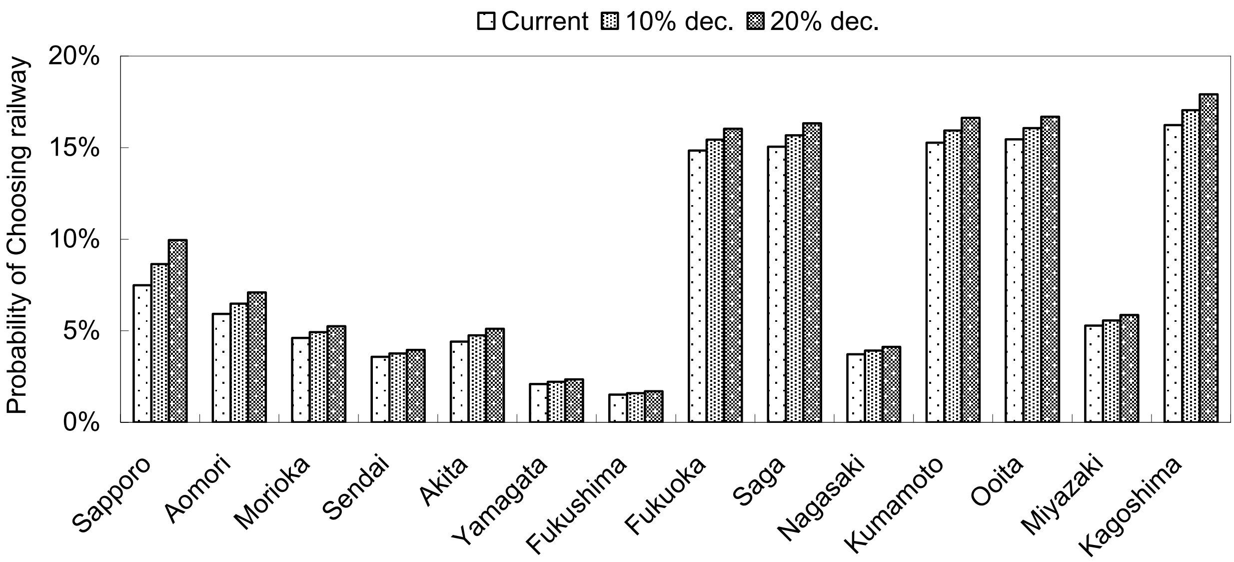

Figure 5: Probabilities of choosing railway versus trucks, decreasing cost.

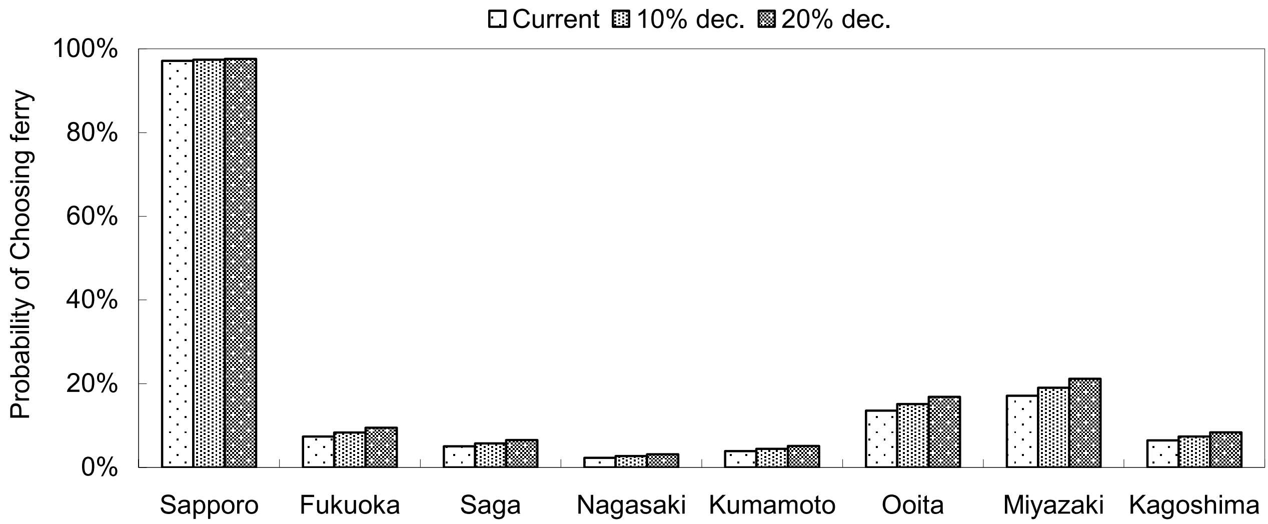

Figure 6: Probabilities of choosing ferry versus trucks, decreasing cost.

Table 4: CO_2 emission coefficients (2000 year, g-CO_2/ton km).

Commercial truck	178
Small-size commercial truck	819
Private truck	372
Small-size private truck	3,049
Railway	21
Ship	40
Air	1,483

when the transport costs by railway and ferry decrease, are shown in Figure 5 and 6. It can be seen that the influence of freight lot size is relatively large and this factor is crucial for the modal shift from road traffic to railway or ships

5 CO_2 EMISSION REDUCTION RATES

When transport costs by railway and ferry decrease, logit models can be used to estimate: CO_2 emission reduction rates derived from transport volume; CO_2 emission coefficients; and the variance in the rates of probability of choosing railway container or ferry ships versus trucks.

Table 4 shows the CO_2 emission coefficients for each transport mode. CO_2 emission coefficients of truck and air are scores of times more than railway and ship. When transport costs decrease 10% and 20% from current transport costs, the CO_2 emission reduction rates are derived for pairs of each origin and destination area. Then the CO_2 emission reduction rates for the freight from each prefecture to the Tokyo metropolitan area are calculated. The CO_2 emission reduction rates are shown in Figure 7 in the case of railway versus trucks, and in Figure 8 in the case of ferry versus trucks.

6 CONCLUSIONS

Various action plans have been put together to achieve the Kyoto Protocol's targets for the reduction of greenhouse gas emissions. A modal shift from trucks to rail and marine transport is considered a means to this end. Japan's official Outline for Promotion of Efforts to Prevent Global Warming, formulated to achieve the Kyoto Protocol's targets for the reduction of greenhouse gas emissions, sets a goal of reducing 4.4 million tonnes of carbon dioxide emissions through modal shifting. To achieve this goal, truck shipments of approximately 20 billion freight tonne-kilometers need to be switched to railways and coastal shipping. However, the rail and shipping shares of total shipments are in a state of continuing decline.

In this paper, the possibility of a modal shift from road to railway and marine transport, between the Tokyo metropolitan area and the remote areas of Japan, are discussed by analyzing the behavior of cargo shippers. The factors involved in the choice of transport mode by transport distance, time, cost, freight lot size and other related factors are clarified. These analyses were conducted using logit models.

Results of the statistical analyses showed that factors influencing the modal choice could be identified, and it was found that a considerable portion of freight could be converted to container transport by ships or rail. Significant factors for the modal shift were freight lot size, access time to the nearest cargo station or port, total time between origin and destination areas and transport cost.

The influence on modal split of changes in transport cost and freight lot size was investigated by means of sensitivity analysis. It was found that when the freight lot size by railway or ferry increases, modal shift from trucks to railway or ferry accelerate, especially in the case of large-scale

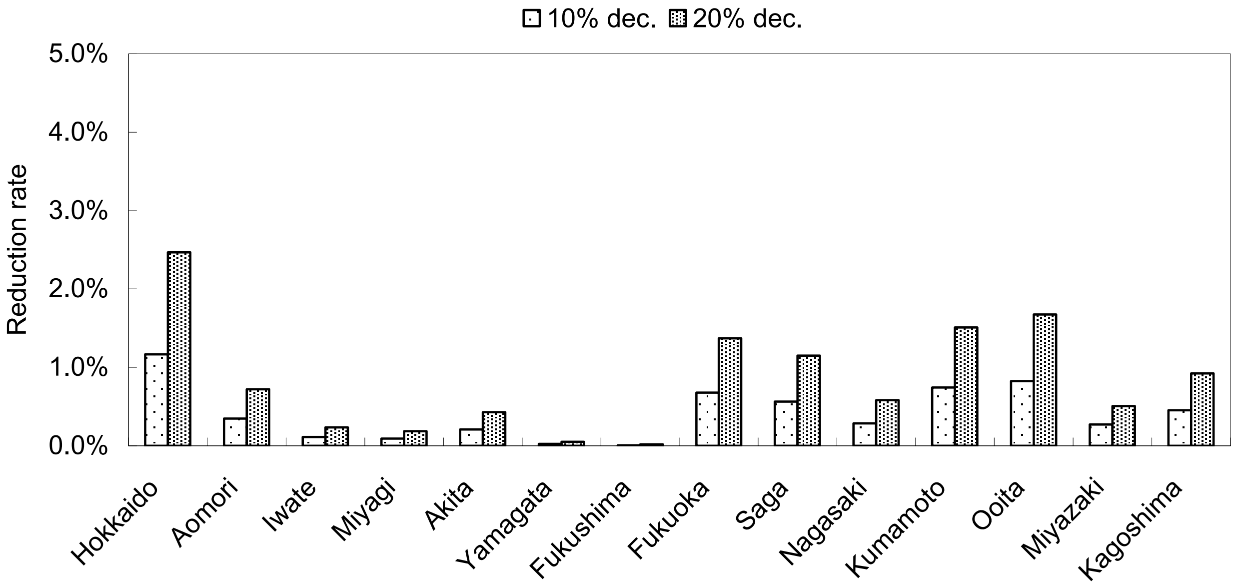

Figure 7: Total CO_2 emission reduction rate of choosing railway versus trucks, decreasing cost.

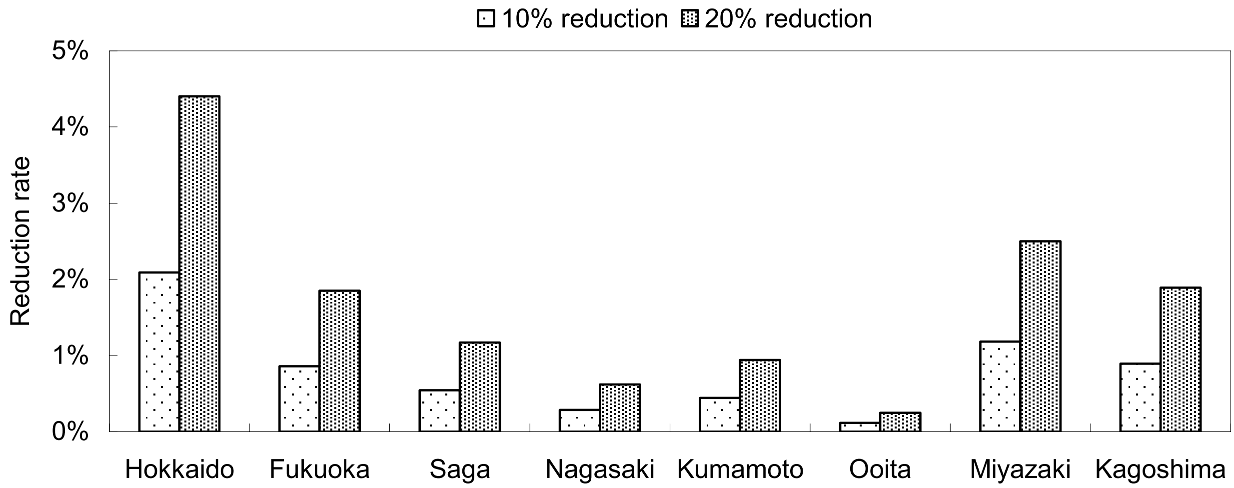

Figure 8: Total CO_2 emission reduction rate of choosing ferry versus trucks, decreasing cost.

mainline freight transport. Finally, the CO_2 emission reduction rate was estimated when transport costs decrease, and the environmental impact of the modal shifts from road to railway and marine transport was analyzed. In order to realize the modal shift, relevant objectives capable of being carried out should be considered.

Specific measures to promote the use of rail cargo include increasing the number of freight cars that can be joined together to enable higher-volume transport and the introduction of "super rail cargo," or express freight container trains, to drastically reduce shipment times. To enhance the contribution of waterways, the Ministry of Land, Infrastructure and Transport will look into policy restructuring to deregulate new business entry and consolidate the inter-linkages between domestic coastal and international shipping. As for awareness-raising, the ministry is considering various incentives targeted at cargo shippers and distribution businesses.

7 ACKNOWLEDGMENTS

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