THE INTRODUCTION EFFECT OF HIGH-DENSITY INTEGRATED STOCKYARD INTO A PORT

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Abstract : This research aims to show the feasibility of constructing the high-density integrated stockyard system with the trucks driven by a new linear motor technology at a port located in Kitakyushu area. In this research, port choice behavior of freight owners and ship companies are clarified. And the model, by which the amount of handling of the container freights at ports is calculated, is constructed to estimate the efficiency of the high-density integrated stockyard. And finally, the change of the freight flow situation before and after this system is introduced into a port is analyzed.

1. INTRODUCTION

The construction of the distribution system that lighten the load of earth environment and bring the higher economic efficiency is required under the situation surrounding Japan. And now, a new distribution system at port is also needed as its element.

To answer such a need, a new distribution system at port using new linear motor technology, which has been developping originally in Kyushu University, was proposed. This is a system in which the containers are transported by the trucks driven on the linear motor guide way from freighter to high-density integrated stockyard (called 'HD' in this paper) automatically. The following three points can be indicated as the features of this system.

① It is possible to save labor, because the trucks with high loading efficiency can be driven automatically.

② The handling capacity of the containers per unit area can be larger because of multistory stock yard.

③This system enable us to access the containers at random, therefore it excels in the transshipment function needed for the distribution base, because of the stockyard with one layer in each floor and the trucks driven automatically.

Based on these features, constructing this system can be expected to bring the higher efficiency and the cost reduction in the distribution at ports. Moreover, the large-scale container freighters come to reach the pier, when the large depth berths are added to this system at the same ports. Therefore the international distribution cost and the port services can be improved.

In order to show the effect of this system, the following points are analyzed in this research.

① Port choice behavior of freight owners and ship companies are clarified.

② The model, by which the handling amounts of the container freights at ports are calculated, is constructed to estimate the effect of introducing the HD system into a specific port.

③ The change in the freight flow is analyzed under the situation that HD system is introduced into a specific port, based on the estimation model. And the effect of the introduction of the system is cleared.

2. HIGH DENSITY INTEGRATED STOCK YARD

2.1 Concept and effect of the system

The containers are piled into multi layer to store a large amount of containers in the container yard of a lot of ports now. However, this method is not only low in the efficiency of taking out the containers, but also has the danger of the collapse at the earthquakes. Then, HD system stores the containers by one layer in each floor of the stock yard which has many stories. And, the quay and the stock yard are connected by the transportation way where the linear trucks run. Moreover, the container goes up and down to the upper floors of the stock yard using the lift on the truck. The number of the lifts can be changed according to the size of the container. For example, 40feet container is transported using two lifts. In the stock yard, after the truck arrives at the destined storage place, it surfaces with the container, store the container in the stand, and descends afterwards. Such series of truck moving is controlled intensively and automatically by the computer.

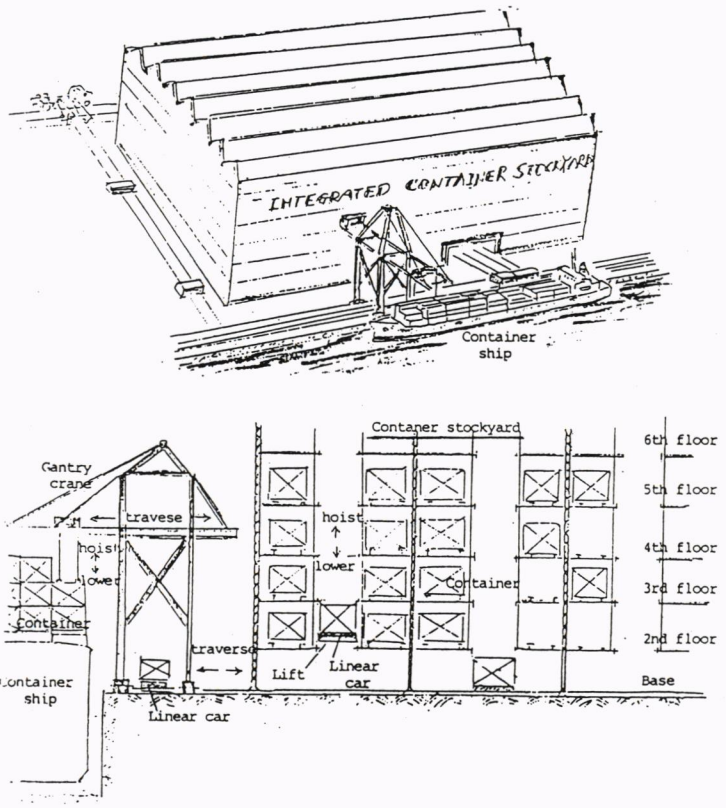

Fig.1 Concept of high density of integrated container stock yard

Many electromagnetic coils are buried under the transportation way both inside and outside of the stock yard, and a permanent magnet is installed at the bottom of the linear truck. Therefore, the magnetic field is changed by controlling the direction and the power of the current in the electromagnetic coil , and the truck can be given the surfacing power (repulsion power against the road) and the promotion power. This is the principle of synchronous linear motor.

One of the features of this linear motor is that a large output can be obtained even in a

low-speed running, unlike a general linear motor, because the repulsion power between the permanent magnet and the electromagnet is used as the surfacing power. Therefore, it is also possible enough that a linear truck runs on the slope way, and it is possible to transport the container directly to the upper floor of the stock yard, not using the lift. Moreover, the truck can easily move to the front, back, left and right according to the direction where the magnetic coil is arranged and buried. Therefore the truck can run squarely at the intersection of the transportation way. This feature cause the great decrease in the demanded area of the transportation way . On the other hand, if the wheels are installed to the truck, the electric power for surfacing and driving could be saved. The control of the surfacing power enable the right-angled running at the intersection using the wheels of caster type at the time. Consequently, installing the wheels don't increase the demanded area on the transportation way in this system.

Finally, an important feature of this system is described.
Because of one layer system, the handling work of taking out a target container from the lower layer is not needed, so it takes shorter time to take out the container of the yard in this system than in the multi layer yard system. Therefore, the safety and the taking out efficiency of the container is extremely high in this system. This random access not only greatly decreases the loading time, but also improves the handing over efficiency from the freighters to the land conveyance, the transshipment efficiency among the freighters, and as its result, this improvement of connecting function of ports in the distribution base can be expected.

2.2 Loading efficiency of the system

T.SHINODA *et al*(1998) analyzed this system from the respect of the loading efficiency at a port, where the container of about 300,000TEU is handled during a year. And this system was compared with SC system and TC system using the petri-net simulation. The result is shown in Table1. The followings are clarified.

Table 1 Comparison of the features among 3 systems

Handling System	storage Efficiency (TEU/m²)	needed area (m²)	Maximum Performance (containers/h)	number of labor (person)	efficiency of taking out
SC system	0.0250	32243	41	11	0.750
TC system	0.0383	16122	37	33	0.474
HD system	0.0457	10747	31	0	1.000

SC: Stradle Carrier, TC: Transfer Crane, HD: High Density Stock Yard

(1) A comparatively wide area is needed for the SC method, though the loading efficiency is high. In case of the container number is larger, the loading efficiency become lower, because of the increase of the SC running distance.
(2) TC system does not demand so much area for the stock yard, because the loading efficiency is comparatively high, and the storage efficiency is also high, though it is inferior to the SC method. However, a lot of labors are needed to operate the transportation equipment.
(3)HD system does not need the operators who control the transportation equipment, and it is possible to contribute to the labor saving because this system assumes the transportation truck operated automatically. Though the loading speed of this system is not necessarily high, the storage efficiency is the most excellent in three methods, and it is advantageous under the condition of Japan where a wide area cannot be secured for the stock yard. Moreover, there is an advantage that the connection with the land transportation mode is high because the efficiency of taking out of the container is highest in these systems.

3. THE ESTIMATION MODEL FOR THE HANDLING AMOUNT OF CONTAINER FREIGHTS IN THE PORTS

In this chapter, the port choice model was constructed, based on a relation between the freight owners and the ship companies. And using this model, the handling amount of containers in the ports and the port functions improved by HD system were estimated.

3.1 The Concept of the model

The handling amount of the international container freights at ports is determined by the ship companies which place the container ships and the freight owners who use the container ships. Though the ship companies and the freight owners seam to be mutually independent existence, a relation between them could be considered. That is, the freight owners choose the ports from the viewpoint of the sea routes, the number of container ship services, and the distances to the ports, on the other hand, the ship companies place ships considering the amount of handling freights at ports which is the result of the freight owner's port choice.

In relation to this problem, K.Kuoda *et al*(1996) applied a game relation between the freight owners and the ship companies to analyze the flow of the domestic container freights. In this thesis, the port choice by freight owners is modeled on the minimization of the transportation cost, and the placing feeder ships by the ship companies is modeled on the profit maximization in the entire transportation network. N.Fujino *et al*(1995) uses the game relation between the freight owners and the ship companies to estimate the service frequency in the international container sea routes. In the thesis, the port choice of freight owners is expressed using a victim model, and the ship placing is modeled using non-cooperation game of maximization of the acquisition freight volume.

Then, in this research it is aimed to construct the following port choice model based on the game relation between the freight owners and the ship companies. The victim model, where the time-value distributions of some kinds of freight are built in, is used, because the transportation cost and time have a definite influence to the port choice of freight owners. And, it is possible to use the waiting time of the freight owners which is determined from the ship placing, the ship companies have the tendency that they place the larger-scale container ships to acquire more freights and to make transportation more efficient. In order to express this tendency, it is assumed in this model that the ship companies choose the port to maximize the income as far as the profit is positive. This behavior means that they place ships starting from larger-scale ones with higher efficiency, within the range where the fare income exceeds the transportation cost and the number of ships placed does not exceed the capacity at each port. Consequently, the handling freight volume in each port is given as a result of balanced behavior between the freight owners and the ship companies.

The purpose of this research is to understand the effect of constructing the HD system and the large depth berths. Therefore, it is analyzed how three variables, the loading cost, the loading time and the number of berths, affect the change of the freight volume and the total cost in the transportation network.

3.2 Port choice model of the freight owners

The object and the assumption of the analysis is as follows.
(1) The origin and destination points of the domestic container freights are 46 prefectures except for Okinawa.
(2) There assumed six ports where the freights are handled. They are the Kanto port (Tokyo and Yokohama), the Chukyo port (Nagoya and Yokkaichi), the Hanshin port (Osaka and Kobe), the Kitakyushu port (Shimonoseki, Kitakyushu, and Hakata), the Niigata port, and the Shimizu port.

(3) Only freights from or to North America (United States and Canada) and Korea are dealt.
(4)Eight import articles (foods, fiber, material of metal, raw materials, minerals, chemical products, machinery, and other goods), and seven export articles (foods, fibers, chemical products, the nonmetal, the metal, the machinery, and other goods) are assumed.

In the port choice model of the freight owners, the transportation cost which freight owners pay consists of the land transportation fare from the arrival and departing prefectures to the ports, customs fee and the sea transportation fare based on the distance. The transportation time of the freight consists of land transportation time, customs clearance time, loading time, sea transportation time, and waiting time at the port. The freight owners choose the port based on the victim expressed equation(1).

$$S=C+\omega T \tag{1}$$

Where S: Victim volume,
ω :Time value
C: Transportation cost (land transportation fare, customs fee, sea transportation fare),
T: Transportation time(land transportation time, customs clearance time, loading time, sea transportation time and freight owners' waiting time)

Time value of the freight is assumed to follow the logarithm regular distribution, and the average (μ) and standard deviation (σ) are estimated respectively according to the countries, the kinds of articles and import or export. The combination of (μ) and (σ), which minimize the total square of the difference between the estimation volume and the actual volume of the container freight, is adopted in this model.

As an example of the result, the combination of (μ, σ) of import container freight in the South Korea route is shown in Table2 . And, the comparison of the total container volume calculated based on (μ, σ) with the total actual volume is shown in Fig.2. Thus, it is understood that the estimation accuracy of the model is high enough concerning the handling volume of the freight.

Table 2 Estimated (μ, σ) value in Korea route of import container freight

From Korea

	foods	Fibers	material of metal	raw materials	Minerals	chemical products	machinery	Others goods
Average(μ)	10	8	-48	-1	-50	-50	5	7
s.d.(σ)	7	12	26	16	66	40	3	6

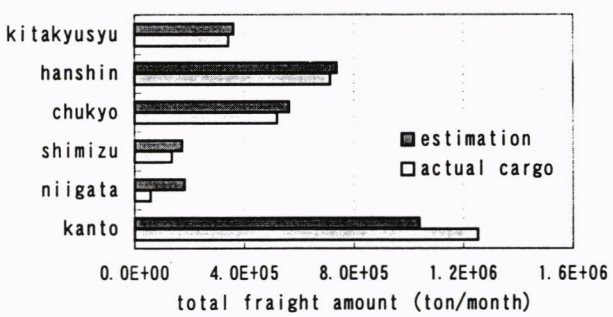

Fig.2 Comparison Estimated volume with actual volume in total container freight

3.3 Port choice model of ship companies

In the port choice model of the ship companies, each ship is in competing relation with other ships. The ship companies are going to place ships till the profit come to zero at the port within the capacity of berth, because the ship companies pursue the maximum income. As a result of this behavior, the total of the profit of each ports approaches 0. Therefore, the mathematical model is shown as equation (2).

$$\text{Maximize} \quad Bi \qquad (\text{for all } i) \tag{2}$$

subject to the restrictions

$$Bi - Ci > 0 \quad (\text{for all } i),$$

$$Sij < Kij \quad (\text{for all } i,j)$$

Where Bi : the income obtained by calling to port i,
Ci : the cost necessary to call to port i,
Sij : the ship number placed with size j to port i,
Kij : capacity of berths for the container ship of size j in port i

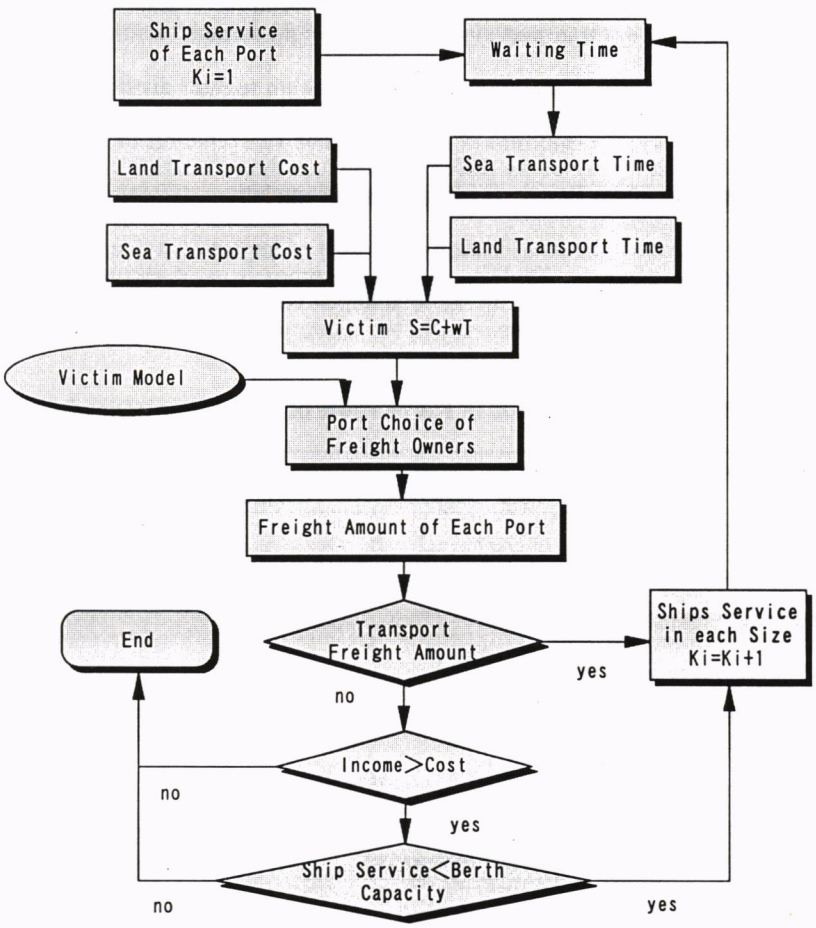

Fig.3 The concept chart of the analytical procedure

Bi is given as the total fare of the container at port i, and it is indifferent from the ship services of each ship size. On the other hand, Ci consists of the fixed expense such as the fuel expense, the port expense (guide fee, fee of entering port, and quay rental, etc.), and ship expense (capital expense and control expense, etc.), and the varied expense of the terminal expense (container loading fee etc.), the empty container expense, the device preparation expense, the container mending expense, and the freight insurance expense, etc. So, Ci differs according the port condition. And the cost required for a container is lower in a larger-scale ship. Therefore, if there are enough freights, larger-scale ships have a priority to be placed, but if not, a suitable size ship which correspond to the freights volume will be placed by the ship companies.

3.4 Ports choice model by freight owners and ship companies

The ports choice model of freight owners and of the ship companies have to be merged cooperatively, though they are constructed in 3.2 and 3.3 section respectively. Connecting the ports choice behavior of them, a feedback loop is built between freight volume and ship service by each port. Consequently, a balanced solution is obtained on the handling volume of the freights in each port. The number of ship is also obtained by each ship size in this balanced solution. The concept chart of this analytical procedure is shown in Fig.3.

4. THE EFFECT OF CONSTRUCTING HIGH DENSITY STOCK YARD

4.1 Analysis method

(1)Case of analysis
In this research, current loading cost (1.0), and current loading cost$\times$0.4,0.6,0.8 are adopted as the analysis cases. Similar four cases are adopted regarding the loading time. There are no large depth berths in Kitakyushu region now, so the large depth berth number (0), and berth number (1) are adopted as analysis cases. The above-mentioned analysis cases are combined into 32($2\times4\times4$) complex cases, and these all cases are adopted in the analysis.

(2)Evaluation index
Six indices were adopted in the evaluation. They are the amount of handling freights, the service of ships, the profit of ship companies, the time loss of freight owners, and total transportation cost in the whole system. Total time loss of the freight owners was calculated by subtracting the total transportation fare from the total victim volume which was expressed as equation (1). Moreover, to express the general cost which required to transport the freights in the whole system, the total transportation cost could be defined as the volume which is obtained by subtracting the total profit of the ship companies from total victim of the freight owners'.

4.2 Result of the analyses

(1)Change in the amount of handling of freight
The change in the amount of handling of the freight in the ports is shown in from Fig.4 to Fig.7. They are the results of calculation under the assumption that one large depth berth is constructed in Kitakyushu port. Considering from these figures, the freight handling amount in Kitakyushu port increases regardless of the change in the loading cost and the loading time, and, on the other hand, the freight handling amount of Hanshin, Chukyo, and Kanto port decrease. The decrease in the freight amount of Hanshin port is largest.
Fig.4 and Fig.5 show how the freight handling amount related to North America will change in each port, after the loading cost in Kitakyushu port decreases. The remarkable change appears, under the conditions of 0.8 or less cost reduction rate. Fig.6 and Fig.7 show a similar content concerning the loading cost related to Korea. The handling freight amount both for North America and Korea changes largely, as the loading time reduces.

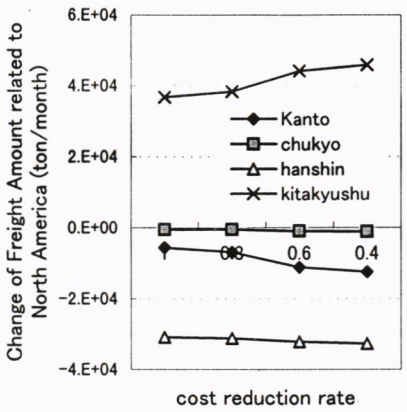

Fig.4 Change of freight amount by the loading cost reduction (North America)

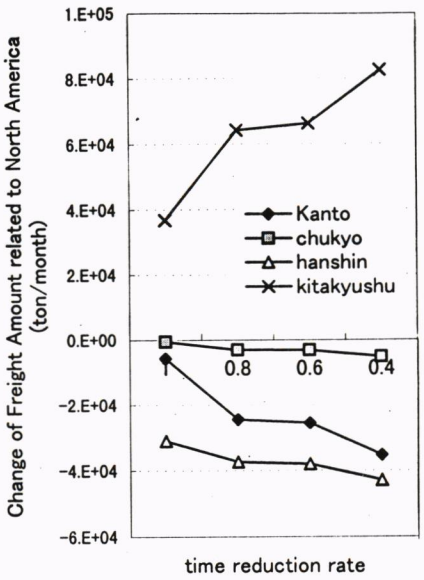

Fig.5 Change of freight amount by the loading time reduction (North America)

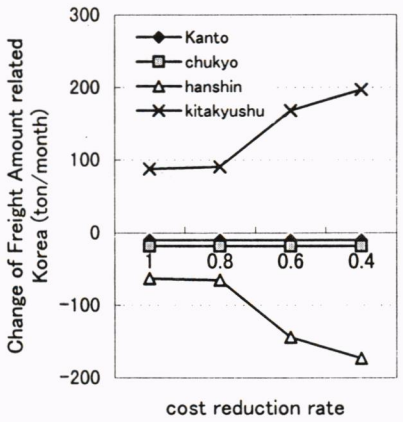

Fig.6 Change of freight amount by the loading cost reduction (Korea)

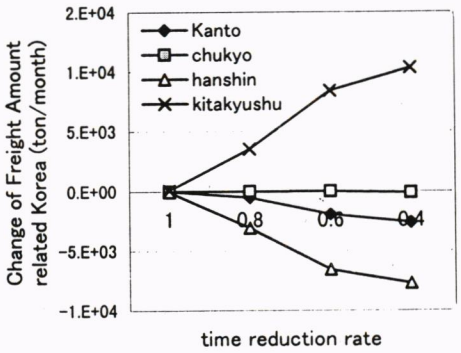

Fig.7 Change of freight amount by the loading time shortening (Korea)

(2)Change in number of container ship services

The number of container ship services at each port changes according to the freight handling volume. As shown in Fig.8, only the number of service of Kitakyushu port increases as the loading cost reduces, and the number of services of other ports are almost constant.

In this research, five sizes of the container ships are adopted to the estimation model. Here, to see the change in the composition of the container ship size, the change in ship service by shortening the loading time is shown in Fig.9. Thus, the 4000TEU-class container ships gradually take the place of 3000TEU-class container ships, and the service of 4000TEU-class container ship increases, as the loading time is shortened.

(3)Change in profit of ship companies

The reduction of the transportation cost by the use of the larger-scale ships seem to

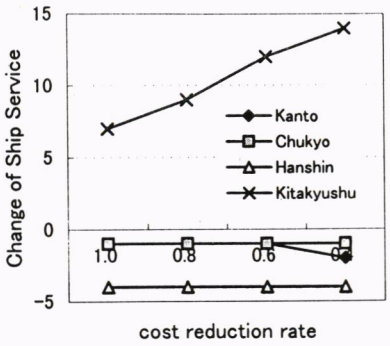

Fig.8 Change of container ship services by the cost reduction

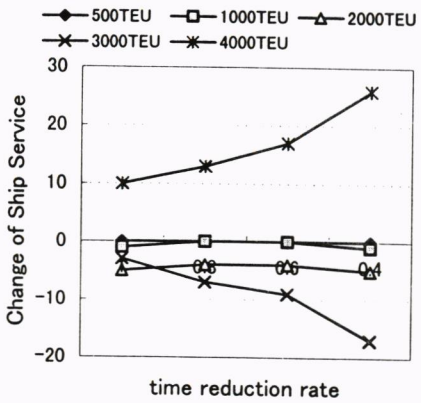

Fig.9 Change of container ship services by the time reduction

produce the profit of ship companies, because the total freight volume is assumed to be fixed and the rate of sea transportation fare is fixed in this analysis. Fig.10 shows the change rate (%) in the profit of the ship companies by the reduction in the loading cost and the loading time in case of constructing one large depth berth. Thus, it is understood that the profit of the ship companies increases as the loading time decreases, regardless of the height of the cost reduction rate. However, the profit of the ship companies don't rise even if the cost decrease, so the influence of the loading cost to the profit is not clear. This is not easy to understand immediately. The reason is thought as follows. That is, the ship companies is permitted in this model to place ships in a range in which the income exceed the cost. So, the margin of the ship companies that the decrease of the loading cost should produce, is absorbed by placing container ships to gain more freight. And this margin does not directly lead to an increase of the profit of the ship companies. Thus, it is understood that the decrease of the loading cost indirectly improves the level of service of the freight owners through the increase of the ship service.

(4)Change in transportation fare paid by freight owners
Because the distances between the ports and North America are almost same, the fare of the sea transportation almost becomes same in proportion to the transportation distance. Therefore, the transportation fare paid by freight owners is determined as the result of choosing the port. Fig.11 shows the change of the land transportation fare in case of constructing one large depth. In this case, the influence of the loading time is small, but the influence of the loading cost is large and its tendency is rather clear. Here, the land transportation cost increases as the loading cost decreases. The reason is thought as follows. That is, the freights which has been handled so far at ports in other region, come to be handled in Kitakyushu port where the loading cost decreases, and because of this, the land transportation distance increases. Such an increase in transportation distance should be undesirable on the environment, and these freights originally should be transported by the feeder transportation using the railway system and the domestic sea route.

(5)Change in time loss of freight owners and total transportation cost
The change rate of time loss in case of constructing one large depth berth is shown in Fig.12. About 45% of the total time loss is reduced by just constructing one large depth berth. In addition, the result shows that the time loss is reduced by about 70% in case of 80% loading cost. Moreover, the change rate of the total transportation cost obtained under the same conditions are shown in Fig.13 and Fig.14. They show the similar shape and they mean the same content concerning the effect, because the majority of the total transportation cost is consisted of the time loss.

For your information, the reduction volume of the time loss is converted in terms of

money, based on Fig.14. It may reach from about 400,000,000,000 to 700,000,000,000 yen/ month. From the above-mentioned result, it can be said that the number of large depth berths, the loading cost and the loading time have most remarkable influence to the time loss of the freight owners.

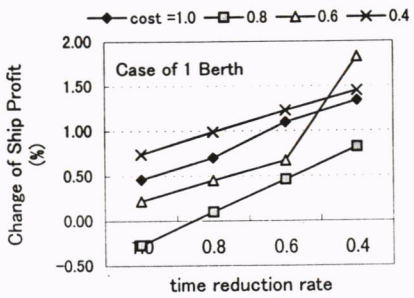

Fig.10 Change of the ship companies profit

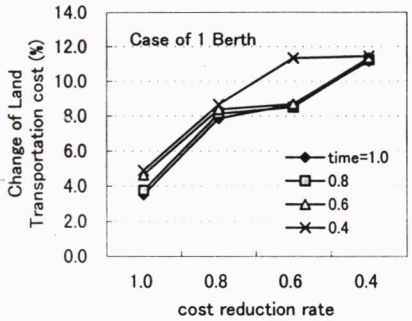

Fig.11 Change of land transportation cost

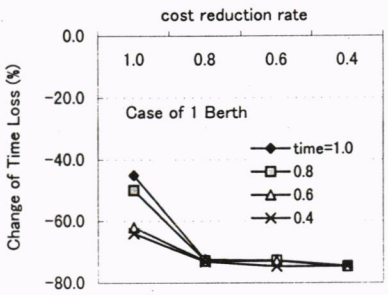

Fig.12 Change of time loss

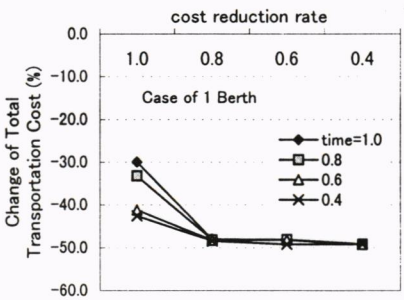

Fig.13 Change rate of total transportation cost

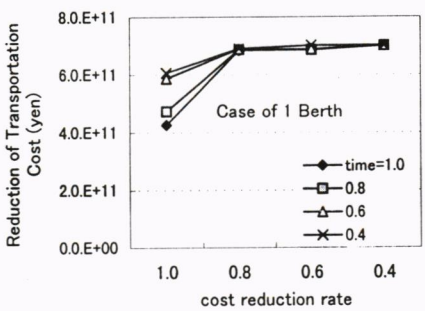

Fig.14 Change of total transportation cost

5. CONCLUSIONS

In this paper, we introduced the feature of the container loading system which combined the linear motor truck being developed now and the high density container stock yard, and then, the effect of shortening the loading time and the reduction of the loading cost at which this system mainly aimed was analyzed from some viewpoints, in addition to the

analysis concerning the construction effect of large depth berth's. The following six points is clear, as a result.

(1)The amount of handling of the freight : The amount of freight handling increases at the port in the Kitakyushu region because of the constructing the large depth berth, on the other hand, the amount of freight handling amount decreases at the ports in Hanshin, Chukyo and Kanto. The decrease in Hanshin port is especially largest. A remarkable change appears in the freight handling amount, when the loading cost of the port in the Kitakyushu region is reduced to 0.8 or less, in addition to the construction of the large depth berth.

(2)The number of container ship service : Only the number of service of Kitakyushu port increases according to the reduction of the loading cost. And the 4000TEU-class container ships gradually take the place of 3000TEU-class container ships, and the service of 4000TEU-class container ship increases, as the loading time is shortened.

(3)The profit of the ship companies : Regardless of the reduction rate of the loading cost, the profit of the ship companies increases as the loading time is shortened in case of constructing one large depth berth. Moreover, though the reduction of loading cost doesn't necessarily bring the increase of the profit of ship companies, it could bring an increase in the number of service of container ships, and has the function which improve indirectly the service to the freight owners.

(4)The transportation cost of freight owners : The change in the loading time affects the land transportation cost very little, but the change of the loading cost affect largely. And the tendency of the loading cost is clearer. The freights which had been handled so far by the ports in other region come to be handled in the Kitakyushu port, as the loading time is shortened, and then, the land transportation distance increased because of that .

(5)The time loss of freight owners and total transportation cost : About 45% of the total loss time is reduced by only constructing one large depth berth. In addition, when the loading cost decreases into 80%, about 75% reduction of the time loss can be expected. And the number of large depth berths, the loading cost and the loading time have most remarkable influence to the time loss of the freight owners.

(6)Conclusion : HD system should be constructed with one large depth berth, and it is considerably effective to improve the loading cost and loading time 80% or less.

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