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MODEL DEVELOPMENT FOR EAST ASIAN CONTAINER SHIPPING CONSIDERING MULTIFARIOUS USE OF VESSELS AND PORTS

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Abstract

Container shipping in the eastern Asian region has been rapidly increasing. Enlargement of the size of vessels seeking economies of scale encouraged the concentrated use of large ports, and raised the volume of hierarchical movement of freight, namely hubs and spokes operation with efficient transshipment. We propose an integrated network model which can reproduce and estimate the volume of flows and the transport patterns under various policy impacts such as the improvement of port facilities and port operation. And we discuss the characteristics of Asian ports based on the outputs of the model. Finally an impact study of port improvement initiatives is introduced as an example of model-application.

INTRODUCTION

Container shipping in eastern Asian region has been rapidly increasing recently due to its amazing economic growth. Large ports in this region such as Hongkong, Singapore, Kaoshiung (Taiwan) and Busan (Korea) now take major positions among the world's top container ports every year, replacing European, American and Japanese ports. Enlargement of the size of vessels in 1990s, seeking economies of scale, encouraged the concentrated use of large ports equipped with deep berths and efficient logistic systems, and increased the hierarchical movement of freight, namely hubs-spokes operation with efficient transshipment. Growing freight transport market and stronger competition sometimes brought frequent and direct operation using medium size vessels, as well as so-called "global alliances" of shipping companies. On the other hand the significant shift of calls of large vessels from Kobe (Japan) to Busan which was observed after the Hanshin Earthquake (1995) aroused concern for improving efficiency of port operations in order to keep up with other Asian ports. However, dispute remained on whether investment policy should focus on local ports or on major ports.

Under these dynamic and critical backgrounds we propose in this paper an Asia-range simulation model which can help in estimating of the effects of various policy impacts, such as the improvement of port facilities and port operation, upon the sea-traffic flow pattern, the container flow pattern and the use of ports. The model will also be useful for the assessment of the present situation of container shipping which is usually not easily analyzed just simply through existing data. Firstly in this paper, the framework of study and the basic structure of the model is introduced. Secondly, model parameters are estimated. Thirdly, several hypotheses of assignment which represent the characteristics of container transport market are compared from the viewpoint of correspondence of the model's results with the actual flow patterns. Fourthly, the characteristics of various Asian ports are discussed regarding the model output. Finally, an impact study of some port improvement options is introduced as an example of the application of the model.

FRAMEWORK OF THE MODEL

Definition of problem on a network context

Our problem is defined as reproducing and forecasting the movement of containers in the international market including the transshipment between vessels and the multifarious use of vessels of different size, when inter-port origin-destination flows (OD flows) and various characteristics of container transport are given. We express the complicated movement of containers as traffic flows on a comprehensive network. This network covers all ports, all transport routes and all shipping companies, and consists of various nodes and links (cf. Figure 1) as follows:

nodes:	(1) origin nodes:	for each port
	(2) destination nodes:	for each port
	(3) arrival nodes:	for each port by vessel-size category
	(4) departure nodes:	same as above
	(5) dwelling nodes:	same as above

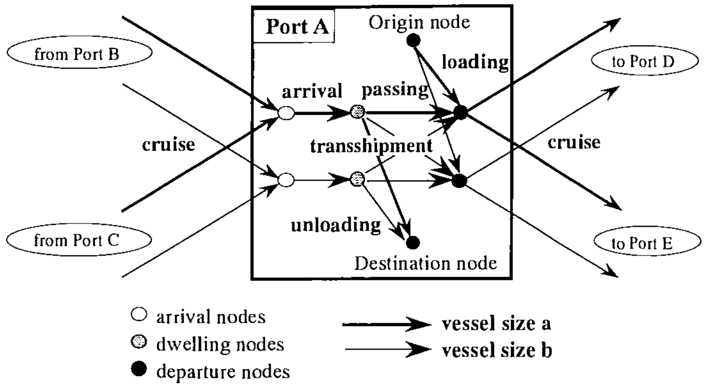

Figure 1 - Conceptual structure of the network in the model

links:	(1) cruise links:	between each ports by vessel-size category
	(2) loading links:	for each port by vessel-size category
	(3) unloading links:	same as above
	(4) arrival links:	same as above
	(5) passing links:	same as above
	(6) transshipment links:	between each vessel categories for each port

Every link has its corresponding flow-dependent or independent link cost. Containers will be carried from an origin port to a destination port through paths on the network according to path cost which is defined as the sum of link cost on the paths. Therefore, our problem is defined as a traffic assignment problem of OD flows on a network under a particular set of link costs.

Concerning container shipping studies, considerable descriptive analyses like (INAMURA *et al.*, 1997) were found previously about the actual situations of container transport. Model-oriented studies are rather limited. Most of them such as (KURODA *et al.*, 1997) or (IMAI *et al.*, 1997) deal with scheduling of the operation of vessels or the allocation of port facilities, using mathematical programming, for example, integer programming and gaming theory, however, are still not applicable enough in practical sense. Work by (FRIESZ *et al.*, 1986), regardless of its primitive framework, was one of the forerunners of studies which try to reproduce the complicated actual flow patterns through a network analysis. However, meaningful previous works could not be found, which, like this study, deal with the actual wide-range international container shipping problem on a comprehensive network frame in consideration of the scale effect in vessel size as well as of the congestion effect in relation to the level of port facilities.

Characteristics of link costs

Noticeable points of the problem under this framework are; identification of link costs and hypothesis of the traffic assignment rule. Concerning identification of link cost, we call reader's attention to two points. One is about the capacity of berths in each port. The number of berths are of course limited, and only longer and deeper berths can accept larger vessels, while smaller berths can serve only smaller vessels. When the arrival rate of vessels increases, waiting time for mooring grows, being dependent on the capacity of berths of each vessel size. Thus, the costs on arrival links increase as flow increases. Another is on the economies of scale of the use of vessels. Larger vessels are potentially efficient in terms of transport cost, since the cruising resistance of vessels rises to the second power with respect to size while the transport capacity of vessels increases to the third power. Also in a given vessel size, transport in larger quantity will be naturally advantageous, because its load factor may be improved, or even if it does not change, the better operation frequency caused by the denser flow may lower the transport cost for shippers. This feature makes the cost for cruise links to be a decreasing function of link flows.

Due to these two features of increasing and decreasing link costs, our problem becomes flow-dependent network assignment problem, which has to be solved through, for example, Frank-Wolfe's optimization algorithm (cf. (Sheffi, 1985)). Moreover our problem becomes a non-convex problem, since some part of links have decreasing function of flows. It means that the solution of our problem may not be unique but dependent on initial values of solving process. The practical interpretation of this context is that: the actual transport situation seems to be determined being strongly dependent upon its historical background, if the container market is somewhat ruled by the economies of scale and agglomeration. This seems reasonable, because the current predominance of some large ports, for example, Hongkong or Singapore among eastern Asian port cannot be explained just by their geo-politically and economically advantageous location, it deeply results from their earlier starting of the development of port and economy. Since every forecast for the future must be based on the present situation, we provide the current situation of container flows to the model as the initial solution.

Hypotheses of assignment rule

It is necessary to assume traffic assignment rules of OD flows on the network, upon which the principles of behavior of shipping companies, freight forwarders, and shippers must be reflected either explicitly or implicitly. First of all, we can discuss simple and ideal two cases; one is completely monopolistic shipping supply, another is completely competitive market. In the former case, it can be assumed that there is one decision maker of transport, who governs the whole international container transport, and wishes to minimize the total cost of transport on the whole network. So-called system optimum assignment rule (SO), intending to find a flow pattern which can minimize the total of all link costs, is appropriate for this situation. In the latter case, as the assumption implies that there are numerous small shipping companies, freight forwarders and shippers who all have no governing power on the market, shippers of each container will choose the path of transport including the choice of vessel size and of transport pattern (*e.g.* direct or with transshipment) so that they can minimize the cost along the path of each container transport. This situation is somewhat similar to typical road traffic simulation where each driver chooses their route so that they can minimize their own cost. Therefore, so-called user equilibrium assignment rule (UE) will be suitable for this case. Both can be calculated by using Frank-Wolfe's optimization algorithm.

The actual situation of container shipping which has several big global alliance groups seems to be in-between these extreme cases. We propose a new assignment rule of "by-group system optimum" (GSO) to simulate the actual situation as follows. Each shipping company group intends to minimize the total cost spent in the network of the group. Flows of arrival links, which represent the congestion effect of ports, are revised by the sum of arrival link flows of each group calculated by the model, and reflect on each group's assignment repeatedly until the summed-up arrival link flows will converge. These three different assignment hypotheses will be compared later.

Basic configuration of the model

The points of basic configuration of the model of this study are as follows.

1) Amounts of containers are counted in TEU (twenty-feet equivalent unit).
2) Twenty Asian large ports including eight Japanese ports are selected to comprise the network. Three composite ports are prepared to represent North America, Europe and Oceania.
3) Vessel size is classified into four categories by loading capacity of containers: over 4000TEU, 4000-2250TEU, 2250-1000TEU, and under 1000TEU. We determined the boundaries of these categories in consideration of the share of each categories in the whole capacity (TEU base) and

in vessel number. Berths in ports are also classified into two categories: those which can serve only for the smaller two categories of vessels and those which can serve for all vessels.

4) Eight global alliance groups such as the group of MAERSK (Denmark) and SEA-LAND (USA) are selected for the model from the top so that they can cover more than 70% to 90% of the whole international container transport market in the major sea-routes.
5) The nodes and links of the network for a group reach approximately 300 and 2,700 respectively.
6) Link cost functions reflecting various kind of transport cost are prepared for each link.
7) Link flows are calculated under three different assignment hypotheses (GSO, SO and UE) for given inter-port OD flows of each shipping company group. In GSO there is the interference of flow and cost on arrival links between groups.
8) Since the problem becomes non-convex numerical optimization problem, we provide the current flow pattern as initial values.

FORMULATION AND ESTIMATION OF LINK COST FUNCTIONS

Formulation of link cost functions

We formulated following link cost functions based on interview surveys with some of the shipping companies. Cruise-link cost and arrival-link cost are flow dependent, while costs on loading, unloading, transshipment and passing links are flow independent. Cruise-link cost function can be used both for the whole flow based calculation and for group-based flow calculation. On the other hand, the arrival-link cost function is applied just for the whole flow. Thus, at group-based assignment in GSO hypothesis an iterative procedure is required: 1) group-based assignment, 2) summation of group-based flow on arrival links and convergence check, 3) revise of arrival-link flow, then back to 1).

Cruise link cost

Suppose i denotes origin port, j: destination port, k: category of vesselsize, n: shipping company group, and when link a is a cruise link between port i and j by vessel size k of company group n, we formulate cost for one TEU on this cruise link as follows:

$$C_{1a} = \frac{a_{1k} + a_{2k}}{f_a \cdot cap_k} \cdot l_a + v_t \cdot \left\{ \frac{l_a}{v} + b_1 \cdot \left(\frac{T \cdot f_a \cdot cap_k}{2q_{ak}} \right)^{b_2} \right\} \qquad (1)$$

when C_{1a} : cost for one TEU on cruise link a (1,000 JPY/TEU),
q_{ak} : annual flow at cruise link a for vessel size k (TEU) ,
l_a : distance between port i and port j (Nautical Miles),
v : speed of vessels (knots),
cap_k : loading capacity of vessel-size category k (TEU/vessel, average in each category),
f_a : load factor on link a,
T : time period (1 year = 8,760 hours),
v_t : value of time for container transport (1,000 JPY/hour/TEU),
a_{1k} : unit operation cost of vessel size k (1,000 JPY/NM/vessel),
a_{2k} : unit vessel cost of vessel size k (1,000 JPY/NM/vessel), and
b_1, b_2 : parameters concerning operation-interval cost (b_1, b_2>0).

The first term of eqn (1) means monetary cost of cruise for one TEU which consists of operation cost including fuel and personnel cost and capital cost of vessels. The first term in the bracket means time consumption during cruise, and the second represents cost for shippers relating operation interval on link a. We introduced parameters b_1 and b_2, considering that substantial time-cost for shippers may be not always proportional to the operation interval.

Arrival link cost

When link a is arrival link at port i of vessel size k, cost for one TEU at arrival link a is formulated as follows:

$$C_{2a} = \frac{f_{pik}}{f_a \cdot cap_k} + v_t \cdot w_a \cdot \frac{24}{h_i} \qquad (2)$$

when C_{2a} : cost for one TEU on arrival link a,
f_{pik} : port charge at port i for vessel size k (1,000JPY/vessel),
w_a : expectation of waiting time for mooring on link a, and
h_i : operation hour at port i (hours/day).

The term of $24/h_i$ represents the inconvenience brought by the restriction of operation hours in some ports. The expectation of waiting time which is derived from queuing theory can be approximated by power function of the ratio of arrival rate and the product of number of windows and service rate (cf. (MISHIMA *et al.*, 1996)). If we approximate the service rate by the reciprocal of mean time required for load/ unload/ transshipment, waiting time w_a can be formulated as follows:

$$w_a = b_3 \cdot \left(\frac{t_{anc} \cdot r_m}{n_{bmk}} \right)^{b_4} \quad \text{if} \quad \frac{r_1}{n_{b1k}} < \frac{r_2}{n_{b2k}},$$

$$= b_3 \cdot \left(\frac{t_{anc} \cdot \sum_m r_m}{\sum_m n_{bmk}} \right)^{b_4} \quad \text{if} \quad \frac{r_1}{n_{b1k}} \geq \frac{r_2}{n_{b2k}}. \qquad (3)$$

when n_{bmk} : number of container berth of category m at port i, berth category m=2 can serve for all vessels, m=1 can serve just for vessels of smaller category k=1 or 2,
t_{anc} : time required for load/ unload/ transshipment at port for a vessel (hours/vessel),
r_m : arrival rate of vessels classified by berth category (vessels/hour), and
b_3, b_4 : parameters relating waiting time for mooring (b_3, b_4 >0).

Arrival rates of vessels r_m can be given by the following expression:

$$r_1 = \frac{\sum_{k=1}^{2} q_{ak}}{f_a \cdot cap_k \cdot T}, \qquad r_2 = \frac{\sum_{k=3}^{4} q_{ak}}{f_a \cdot cap_k \cdot T}. \qquad (4)$$

when q_{ak} : annual flow on arrival link a of port i for vessel size k for all shipping company groups (TEU), the whole arrival link flow q_a is the sum of q_{ak} by k.

Loading, unloading, transshipment and passing link cost

Cost on loading, unloading, and transshipment links consists of time and monetary parts, while cost for containers which will neither be unloaded nor transshipped at port i (passing link flow) is just of waiting time till departure. Therefore,

$$C_{3a} = d \cdot f_{li} + v_t \cdot t_{anc}. \qquad (5)$$

when C_{3a} : cost for one TEU on link a,
f_{li} : load or unload charge for one TEU at port i (1,000 JPY/TEU),
d : dummy variable; = 0 for passing links,
= 1 for loading and unloading links, and
= 2 for transshipment links.

Data processing

Three kinds of data are needed for model calibration: link flow data, inter-port OD data, and link cost data. However, the availability of data is quite limited in this field because of the fundamental deficiency of international statistics and business confidentiality of private companies. At the same time, original data collection or observation are also not feasible due to the wide geographical coverage of the problem. Therefore, we had to process the limited available data into our required data form as much as possible (cf. Appendix for detail).

In terms of link flow data, inter-port cruise link flows (TEU base) by vessel size and by shipping company group could be estimated from the operation table of container ships by route and by company, assuming that load factors of vessels are given. Load factors f are assumed in reference to the interview survey as following, that is, for intra-Asia lines f=0.8, for extra-Asia lines f=0.4 in Asian sections and f=0.8 in out of Asian region. We estimated inter-port OD flows by shipping company group using the present pattern OD flow analysis from available data sets such as the inter-state trading data, the port statistics, and partly from the inter-port OD flows. There is no systematic overall data on link costs. We gathered data through the interview survey and partly from company based statistics like (container market reports of MAERSK, 1996).

Estimation of link cost functions

Link cost functions mentioned in the previous section have many parameters, the most part of which were estimated through interview surveys with some of shipping companies and through some literature survey. Those parameters which do not depend on port are shown in Table 1. Monetary terms are at 1995 prices.

Some of parameters such as b_1, b_2, b_3, b_4 and v_t, which relate perceptional cost for shippers, had to be estimated through model calibration procedures so that the sum of the squares of the errors at cruise link flows (between output of the model and the estimated values described in previous section) would be minimized under each of three assignment hypotheses. Calibrated parameters are also shown in Table 1.

Table 1 - Estimated parameters of the model

Vessel Size (TEU)	v (knots)	t_{anc} (hours/vessel)	a_1+a_2 (1,000JPY/NM/vessel)	cap (TEU)
Over 4000	20	12	105	4260
2250-4000	20	12	83	2970
1000-2250	20	12	54	1530
Under 1000	20	12	28	580

Assignment Hypothesis	v_1 (1,000JPY/hour/TEU)	b_1	b_2	b_3	b_4
GSO	0.5	12.5	0.8	120	5
SO	0.8	14.5	0.7	120	5
UE	0.2	14.5	0.7	120	5

DISCUSSIONS ON THE RESULTS

Comparison of assignment hypotheses

Figure 2 shows the relationship between actual values and the output of the network model under particular assignment hypothesis with the best parameters in terms of cruise link flows by vessel size. It is clear that GSO hypothesis (group-based system optimum) provides comparatively better fitness to the present situation, while points of under-estimation and over-estimation are relatively more often observed in SO or UE hypotheses. Variation of flows in model-output under SO and UE hypotheses are significantly larger than that in GSO and in the present situation. In fact, the number of zero-flow cruise-links: never used cruise-links, increases in SO and UE hypotheses by 10%-20% in number more than that in the present situation and in GSO hypothesis. This means that flows in the ideally optimum situation (SO) and in the completely competitive situation (UE) will be more concentrated in particular links pursuing economies of scale.

Figure 3 shows the whole handled amount of containers by port (import /export /transshipment), and the amount of transshipment by port. The whole handled amounts are rather stable irrespective of assignment hypotheses, since the amount of import and export, which takes major part of the whole amount, are given. Nevertheless, all assignment hypotheses provide significant and consistent over-estimation in the amount of transshipment at Hongkong and Busan.

Model analysis on the characteristics of Asian ports

Figure 4 shows the inter-port container flows (both directions, total of all vessel size) of the present situation and the results derived by the model under GSO hypothesis. The general situation of flow pattern is well reproduced by the model. However, there are small differences. For example, link flows connecting Busan-Kaoshiung, Keelung-Hongkong, Kobe-North America, Port Kelang-Europe, and flows in-between Japanese large ports are less concentrated in the model-output than in the present situation.

Figure 5 shows the microscopic movement of containers in the port of Yokohama and Singapore which were reproduced by the model under GSO hypothesis (these microscopic output can be brought only by the simulation). The characteristics of ports are clearly presented. In Yokohama, the amount of transshipment and the passing containers take 29% and 56% of the whole handled amount, and 27% and 53% of the average of total arrival flows and total departure flow respectively. On the other hand in Singapore, these figures become 74% and 44%, 79% and 47% respectively. These characteristics of ports; transshipment rate (transshipment / handled containers) and passing rate (passing containers / (handled containers + passing containers)) calculated by the model are roughly shown in Figure 6. In Asian large ports, transshipment rates are significantly higher, and passing rates are little lower. These ports are clearly functioning as hub ports. On the contrary, in Japanese ports, handled amount is comparatively limited due to low transshipment rates, though large vessels make many calls as shown in high passing rates. This present structure means that Japanese ports have to be ready for calls of large vessels (otherwise they would become secondary ports).

Distribution of vessel use by size category is shown in Figure 7 for the whole transport. All assignment hypotheses tend to emphasize the use of larger vessels, though GSO rule provides the best fitness to the actual distribution of vessel use among three. It implies that either further cost oriented management or stronger competition may bring more concentration of the use of larger vessels in the future, and those port which cannot physically catch up with this trend will be left behind. Figure 8 also shows the distribution for several typical ports which have different level of facilities. The results of the model suggest that Singapore and Yokohama still have potential for increasing number of calls of large vessels for the future, and that the function of Shanghai and Moji

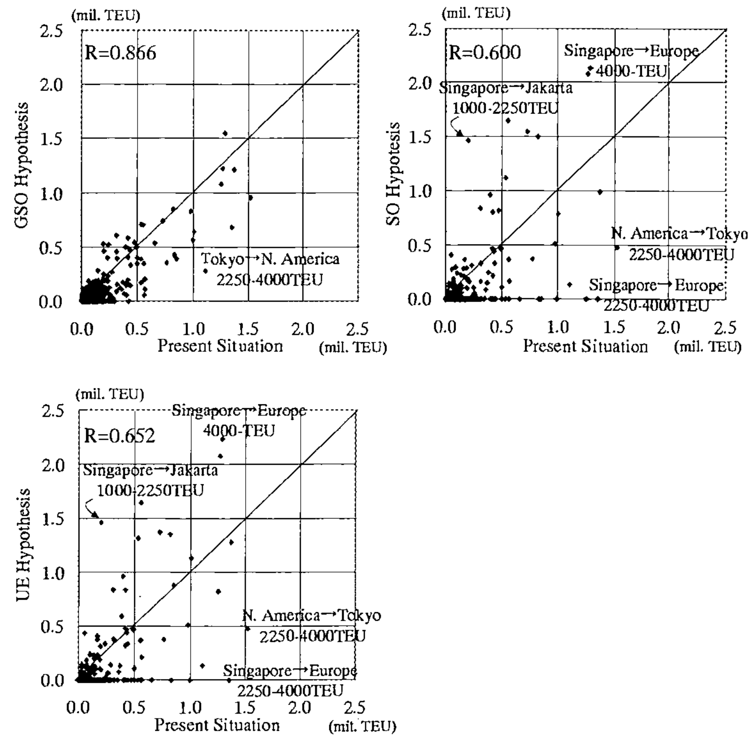

Figure 2 - Comparison of cruise-link flows between the present situation and the results of the model under different assignment hypotheses

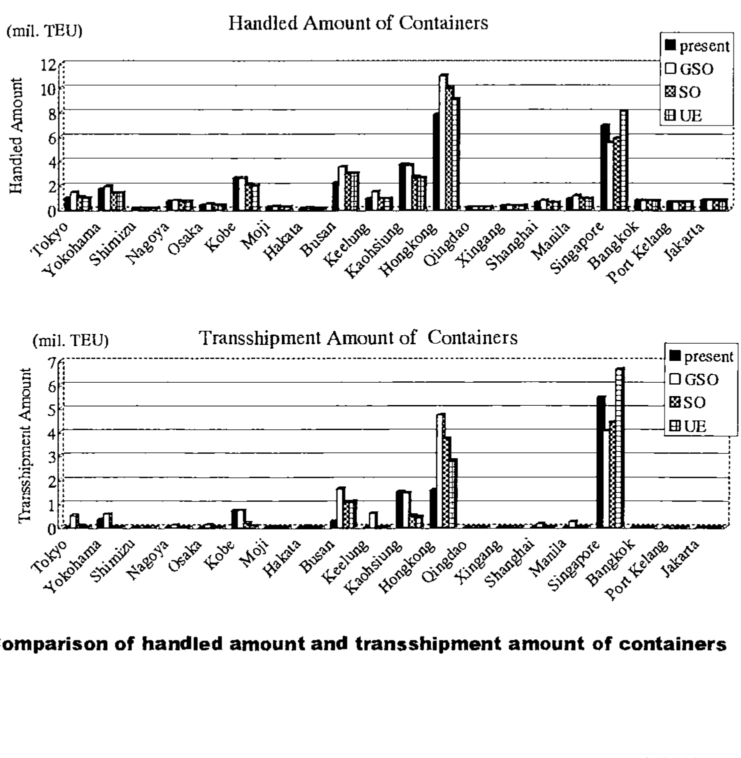

Figure 3 - Comparison of handled amount and transshipment amount of containers

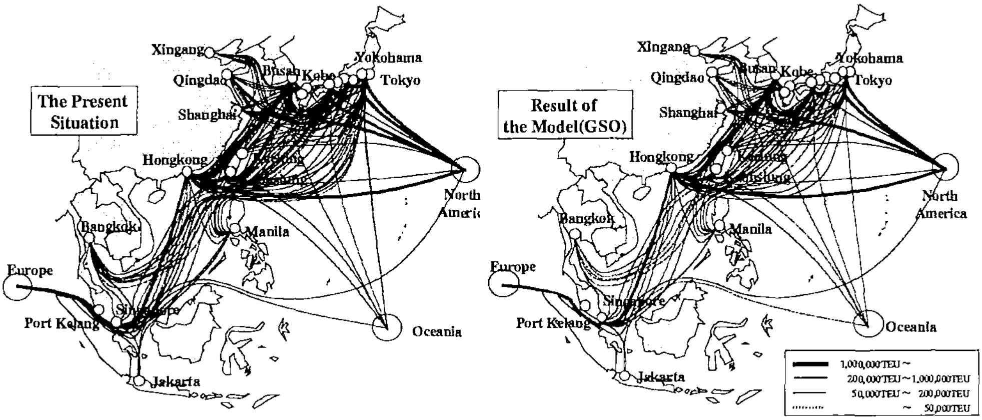

Figure 4 - Inter-port flows of the present situation and the model result of GSO

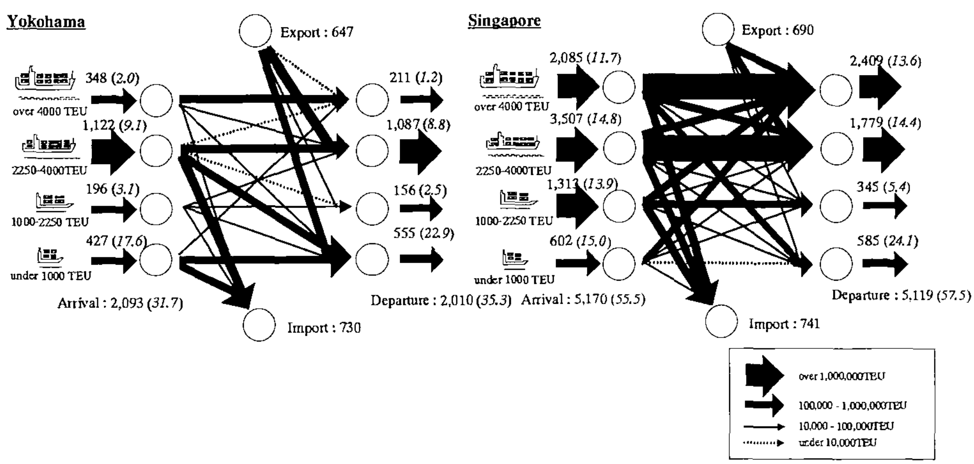

Figure 5 - Microscopic movement of containers in Yokohama and Singapore derived by the model (GSO) 1,000 TEU/year (*vessels/week*)

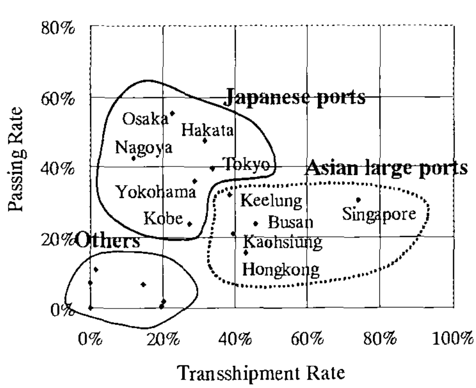

Figure 6 Transshipment rates and passing rates derived by the model (GSO)

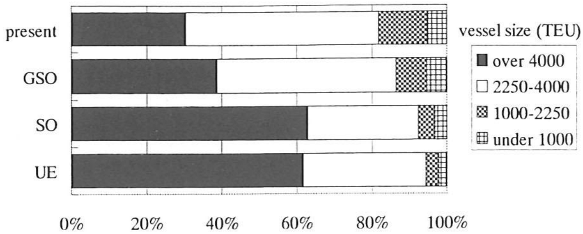

Figure 7 - Distribution of vessel use by size-category (NM·TEU base for all cruise links)

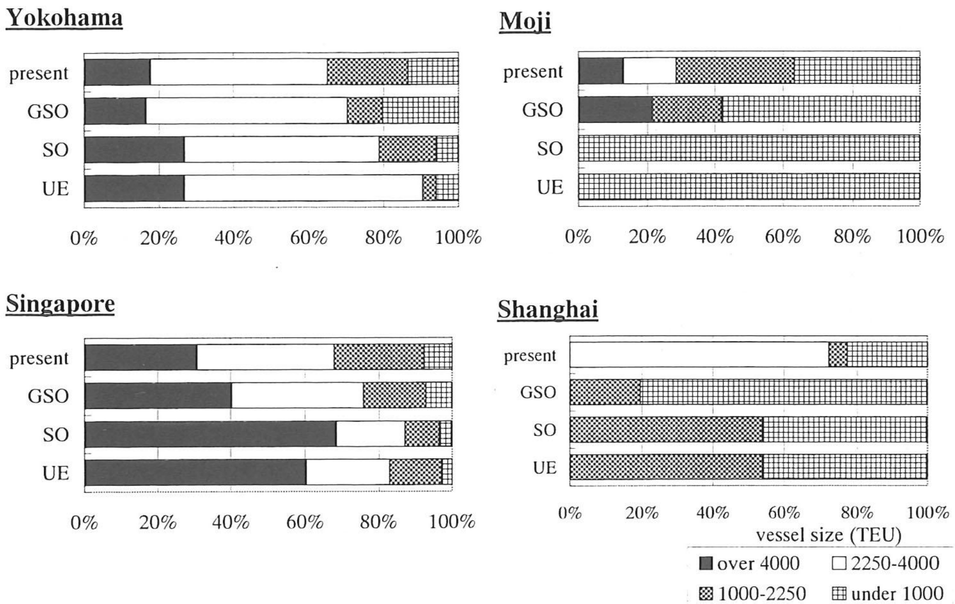

Figure 8 Distribution of vessel use by size-category
(TEU base for arriving and departing cruise links by port)

(Japan) would on the contrary be specialized for the secondary feeder-services using smaller vessels under the present level of port facilities.

An example of simulation of port improvement scenario

In order to assess the impact of port improvement, we prepared a hypothetical scenario for trial with a set of improvement options for eight major Japanese ports: the number of berth which can serve for larger vessels are increased by 50%, port charges and load/unload charges are reduced by 30% (They are currently more expensive by 50% or 100% than those in the other Asian large ports), and the 24 hour operation is fully realized (Japanese large ports including Tokyo port and Yokohama port are rather behind at this point). Providing these new conditions to the model under GSO assignment rule, we compared the model results under the new conditions of ports with those calculated under the present conditions (GSO rule). Table 2 shows the rates of change in handled amount and transshipment amount in each port. Although all inter-port OD flows are fixed, port activities are significantly augmented under the hypothetical set of port improvement. It is also clear that the proportional improvement in the scenario (with the same improvement rates) may cause the concentration of sea traffic flows to the Tokyo area. The total cost spent in the whole world network was reduced by 1.1% after the hypothetical scenario.

Table 2 - Impact of the hypothetical scenario of port improvement (rate of change, %)

Port	Tokyo	Yoko-Hama	Nagoya	Osaka	Kobe	Busan	Keelung	Hong-kong	Shang-hai
handled amount	26.4	0.9	0.6	3.1	4.1	2.0	-2.2	-0.5	2.6
transshipment amount	78.3	3.2	4.9	13.5	15.0	4.4	-5.7	-1.2	12.8

CONCLUSIONS

(1) We proposed an Asian-range model for international container movement based on a framework of comprehensive network analysis, which is capable for the use in the assessment of the present situation as well as for the estimation of the impact of port-improvement options. It must be noted that the scale merit in the use of vessels and transshipment of containers, the congestion effect in ports, various factors in port performance, and the global alliances of shipping companies are specially considered in the model formulation.
(2) Three different hypotheses in traffic assignment rule were applied, on which the situation of the container market was implicitly reflected, and GSO hypothesis (by-group system optimum) among the three provided the best fitness of the model-output to the actual situation as well as the practically acceptable reproduction.
(3) The model focused on the different characteristics of Asian large ports and Japanese ports, specially in terms of transshipment and vessel use. It was also implied that the use and the function of ports might be more specialized in hub-ports or secondary ports, under the cost-oriented management and the more competition in the future. We showed that port improvement will possibly bring change in the wide range flow-pattern such as an increase in transshipment as well as the sea-traffic concentration.
(4) We also proposed a way to estimate the inter-port TEU based OD flows by shipping company group and the cruise link flows by vessel size under the limited availability of data on container transport.
(5) Issues for further study: to examine the statistical error and the stability of the parameters of the model, to combine with a model of inland-transport of containers including domestic port choice mechanism, and so forth.

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APPENDIX

Estimation of inter-state container OD flows

OD flows are available for port-pairs to/from Japanese ports in intra-Asia routes and in trans-pacific routes both on tonnage base[1] and on TEU base[2][3] (OD pairs A). Since just tonnage based OD flows are provided, for port-pairs on other sea-routes (OD pairs B), we converted their tonnage based OD flows into TEU based flows, using the simple average of ratios of TEUs and tons in OD flows on intra-Asia and trans-pacific routes. TEU based inter-state OD flows vs. Japan are easily calculated (OD matrix a).

Since there's no sufficient OD container flow data for other state pairs (OD pairs C) either on TEU base or on tonnage base, we estimated them based on inter-state monetary based import/ export statistics[4][5] by the following procedure. 1) The amount of transshipment at the ports of Yokohama, Nagoya, Kobe[6], Busan[7], Kaohsiung[8] and so on, were gathered except at Hongkong and Singapore. Those at Hongkong and Singapore were estimated using the whole handled amounts at these ports and the estimated rate of transshipment which was studied in a committee report[9]. 2) Import flows and export flows to/from ports in the region were calculated from the TEU based statistics of landed amount (the sum of unloaded flows and transshipped flows) and shipped amount (the sum of loaded flows and transshipped flows) of containers at each port[10] by subtracting transshipment amount acquired in the above. Then, state based import/ export flows of containers are easily calculated from them. 3) We converted the inter-state monetary based import/ export data for those state-pairs into TEU based flows by multiplying the average of the ratio of monetary import flows and container import flows, and the ratio in export by state (OD matrix b).

We combined these TEU based inter-state OD matrices (matrix a and b) into one (OD matrix c), and modified it through the procedure of Fratar method, using the state based import/ export flows of containers calculated in 2) as control values.

Estimation of inter-port container OD flows

For OD pairs A, TEU based inter-port flows are already given (OD matrix d). For OD pairs B, each member of the inter-state flows (OD matrix c) was divided into TEU based inter-port flows (OD matrix e) according to the share of the tonnage based inter-port flows among the particular state pair. For OD pairs C, we divided each member of the inter-state flows (OD matrix c), firstly onto ports in the destination state according to the share of each port among all ports in the state in terms of handled amount (loading/ unloading/ transshipment) of containers[10], secondly onto ports in the origin state similarly using the handled amount data in the origin state.

Regarding these divided values for origin ports and for destination ports, together with generation amounts and concentration amounts of each port calculated in OD matrices d and e, as the control values in the whole OD matrix, we estimated inter-port flows of all inter-port pairs by Fratar method

(OD matrix f).

Estimation of inter-port container OD flows by shipping company group

We estimated TEU based inter-port OD flows by shipping company group from the OD matrix f, using the information of the activity level of shipping company groups at each port. Firstly, we assumed the loading factors of cruise links as mentioned previously, being based on the interview survey, and calculated the flows on cruise links between ports by vessel size and by shipping company group[11]. Secondly, the whole flows carried by all size of vessels between each pair of ports are summed up by group. Thirdly, the whole arrival flows ($F_{in}{}^{i}{}_{k}$) and the whole departure flows ($F_{out}{}^{i}{}_{k}$) to/from each port were calculated by company group. These two factors: $F_{in}{}^{i}{}_{k}$ and $F_{out}{}^{i}{}_{k}$ represent the activity level of group k at port i in terms of import and export activities respectively.

The total concentration flow onto port i in the inter-port OD matrix f, was divided to each shipping company group, according to the share of $F_{in}{}^{i}{}_{k}$ in the sum of $F_{in}{}^{i}{}_{k}$ by k, and the total generation flow from port i was also divided to each group according to $F_{out}{}^{i}{}_{k}$ similarly. Finally, the inter-port OD matrix f was modified into inter-port flows for each group (OD matrices g) by Fratar method again, regarding these divided concentration and generation flows of each group as control values of the matrices.

Sources of Materials

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