How International Cargo Flow will Change by Expansion of Panama Canal?
-An Approach using the World Model for International Cargo Simulation-

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Abstract: In this paper, the authors expand the Model for International Cargo Simulation (MICS) to include worldwide international maritime shipping network as well as land transport network in North America, in order to simulate an impact of the Panama Canal expansion, which will be planned to open in 2014. The expansion of the Panama Canal will greatly affect to the worlds' international maritime shipping market, especially for container shipping, because the size of some container ship have been restricted in order to pass through the Canal and the optimal choice behavior of ship size are distorted due to the Canal. Using the developed model, change of transportation pattern of international container cargo such cargo handling volume and a decreased amount of shipping cost due to the Canal expansion are predicted and calculated.

Key Words: *international cargo flow modeling, policy simulation, Panama Canal expansion, world model*

1. INTRODUCTION

The Panama Canal (hereafter, the Canal) is a canal approximately 80km in total length with 3 levels of locks on the Pacific Ocean and Atlantic Ocean (Caribbean Ocean) sides, respectively. As described in Shibasaki and Watanabe (2007b), following the return of the Canal to Republic of Panama from the United States at the end of 1999, the government of Panama (Panama Canal Authority, hereafter ACP) prepared a canal expansion plan featuring the construction of a third lock. The sizes of the existing locks and the third lock planned for the future are shown in Figure 1. Although a load capacity of maximum size of containership that can currently pass through the Canal (called "Panamax" ships) is around 4,200TEU, when the third lock is completed, almost all containerships existing (except for the largest mega-containership such as "Emma-Maersk") can pass through the Canal.

In this canal expansion project, a total construction cost was estimated at approximately 5.25 billion US dollar. An implementation of the project was formally approved in a national referendum on October 2006, and now construction continues targeting completion in 2014. The cost of maritime shipping via the Canal will be reduced by using large-scale vessels, although this will depend on how much tolls are set. In addition, particularly for containership, because the current ship size distribution worldwide is regulated by the size of the Panama Canal, this project is expected to have a very large impact for mid-term on the world international maritime container transport market as a whole. Looking at the regions of origin and destination of container cargos which pass through the Canal, East Asian countries including China, Japan, and Korea account for large shares, next to the United States and other Central and South American countries. Therefore, the need to predict the changes in global international container cargo flows when the Canal expansion is completed is considered high.

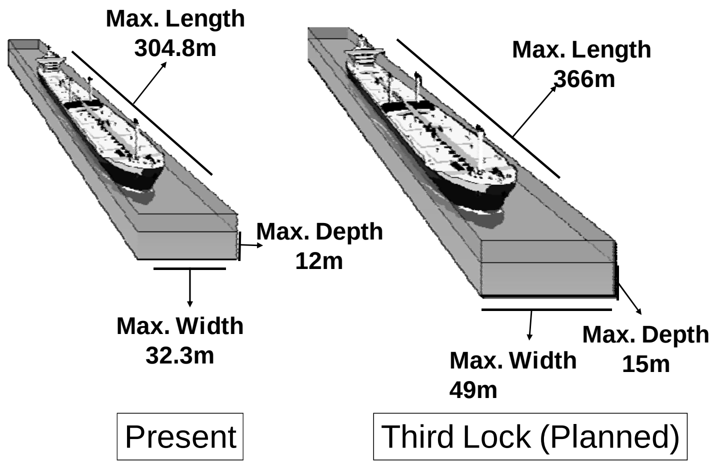


Figure 1. Size of existing Panama Canal locks and planned third lock (Panama Canal Authority, 2006)

Until now, the authors had developed a Model for International Cargo Simulation (MICS) which can simulate a movement of cargo with the volume of OD container cargo as a given input, especially focused in East and Southeast Asian region (e.g. Shibasaki et al. 2005, 2007a, and 2009), in order to measure impacts of various international freight transport policies. This model, for example, had already applied to simulate impacts on international cargo flow pattern in Eastern Asia as well as ASEAN countries, of investment for ASEAN Logistics Infrastructure Projects formulated by ASEAN Secretariat as prioritized projects.

In this paper, the authors expand this model to include worldwide international maritime shipping network in order to simulate such a big project as the Canal expansion, which will impact on the world international cargo flow over a wide range. In particular, because an alternative route for transportation between East Asia and central and east part of North America is using intermodal transportation (land bridge service) from west coast ports of North America such as Los Angeles, Long Beach, and Oakland across the land of the United States, mainly by railways. Therefore, the model expanded in this paper also includes a land transport network of North America (the U.S. and Canada), in order to predict the volume of cargoes which will shift from using the land transportation to passing through the Canal after the expansion.

Several researches on predicting future demand of the Canal had implemented by ACP itself before publication of a master plan. These research reports (which are listed in Reference) are available through Internet (http://www.acp.gob.pa/eng/plan/temas/) as well as the master plan. Some of them tried to calculate the volume of container cargo to shift from an intermodal transport route after the expansion, by the respectively developed model. Estimating from rough description in the reports because detail of these models are not available, an applied methodology for route allocation seems to be very simple such as a shortest path search, econometric model like multiple linear regression analysis, or stochastic model like logit model, although parameter settings for model input were elaborated and other type of cargo than container were also considered. In other words, this paper tries to depict internally in the model how the transportation pattern of international container cargo is changed due to the Canal expansion, considering both behavior of shippers (to select mode and port for export/import) and ocean-going carriers (to select vessel size and transshipped port).

Below, in chapter 2, a structure of the model is introduced; in chapter 3, input data for the expanded model are shown; in chapter 4, prediction of the model and simulation results of the expansion are examined; and in chapter 5, a conclusion is stated.

2. MODEL STRUCTURE

2.1. General Outline

The model outputs transportation patterns of container cargo on maritime and land network, given a regional cargo transport demand (OD cargo volume), service level of each port such as the number of berths by water depth or port charges, and information related to the transportation network (transportation costs and time etc.). The outputs are tabulated for each port to calculate the handling volume and transshipment cargo volume by port.

The model focuses on the behavior of "shippers" and "ocean-going shipping companies" who are the principal actors in the international container cargo shipping market. A "shipper" makes reference to the freight and shipping time by route indicated by each ocean-going carrier group, and selects a carrier group for maritime transport, ports used for import/export, and land transport route and mode for each cargo. Here, the selection for the shipper is determined to minimize the "recognized generalized costs" including not only the shipping cost and time, but also factors which cannot be observed by the model developer. Also, the selection is divided into two steps in the model; choice of carrier group and the others including ports, land route and mode.

On the other hand, the "ocean-going shipping company", which cargo transport demand is given as an input, assumingly behaves to maximize profit for each alliance (ocean-going carrier group). Each group determines a freight and vessel size by port pair (combination of port for export and import) and maritime transportation route such as ports of call and transshipment ports, so that the profit (= income – costs) of their own group is maximized with taking into account the behavior of other groups' freights and shipping time. Herein, carrier groups assumingly behave within a shortsighted scope, although they consider shipper's behavior as far as they can. Concretely, an ocean-going carrier behaves to maximize its own profit in short term, considering shipper's behavior to select a carrier; however, the carrier cannot predict a midterm behavior of shipper such as selection or change of port used for export and import. In other words, each carrier group is assumed to have only short-term strategy to compete with other carrier groups and deprive them of their cargo, not any midterm strategy to encourage changing port for export and import for shippers. This assumption reflects the actual situation of an international maritime container shipping market in which change of freights or an entry and exit of carrier frequently occur and which carrier often determines shipping routes through trial and error.

Summarizing the above discussion, in this research the authors develop two models as described below; namely, a short-term model in which cargo shipping demands by port pair are assumingly not changed, so that each carrier group determines freights by port pair to maximize its own profit, reflecting behavior of other carrier groups and shipper's choice of carrier group. The other is a midterm model in which shipping demands by port pair can be changed due to shipper's unrestricted choice of port used for export/import but shipping demands by regional pair (i.e. a demand from a ‘true’ origin to a ‘true’ destination) are fixed. In the midterm model, shippers and carrier groups are countervailed each other and neither of them has no power to control the international maritime container shipping market. Therefore, the authors assume a Nash equilibrium to reach in which all shippers and all ocean-going shipping companies cannot improve their own objective function when the behavior of the other party is not changed.

The following sections explain a profit maximization model (short-term model) of ocean-going carriers reflecting shippers’ choice of carrier groups and an equilibrium model (midterm model) between ocean-going carriers and shippers including shippers’ choice of port used for export/import separately.

2.2. Short-term Model – Profit Maximization Model of Ocean-going Carriers reflecting Shippers’ Carrier Group Choice

2.2.1. Formulation

Ocean-going carriers determine freights by route in order to maximize their own profit, under the condition that cargo transport demands by route are given. Herein, the authors assume that each carrier group determines their freight with taking into account the freights and other factors on the level of service of the route for the other groups. In order to reflect the fact that various elements other than the freight can be included in supplied transportation services, it is assumed that all transport demand are not assigned to the group with the lowest freight on a given route but rather some of them are assigned to groups with relatively high freights. In other words, the model is a Bertrand equilibrium (price competition) model in an oligopolistic market with product differentiation as an extraneous element to freights.

The profit maximization behavior by each carrier group is formulated as

$$\max_{p,x} \pi_g , \quad \forall g \in G , \tag{1}$$

$$s.t. \quad \pi_g = \sum_{a \in A} \left\{ \left(p_{ag} - c_{ag} \right) \cdot q_{ag} \left(p_{a1}, \cdots, p_{ag}, \cdots, p_{aG} \right) \right\}. \tag{2}$$

The constraint condition (2) means that profit π_g for each carrier group g is defined as the total revenue minus total shipping cost of the group. Herein, p_{ag}: the freights (JPY/TEU) indicated by a carrier group g on a maritime OD pair (combination of port used for import and export, hereafter calling “port pair”) a, c_{ag}: the shipping cost (JPY/TEU) of carrier group g on port pair a, q_{ag}: shipping volume of carrier group g on port pair a, A: set of port pairs, and G: set of carrier groups. Each carrier group g determines freights p_{ag} on a port pair a to maximize profit making reference to the freights $p_{ag'}$ of other groups g' ($\forall g' \in G, g' \neq g$) on the same port pair and carrier group selection behavior of shippers, given total demand d_a for each port pair. The shipping volume q_{ag} of carrier group g on port pair a is assumingly formulated as the following stochastic choice behavior of shippers, taking into account the factors which cannot be observed by the model developer

$$q_{ag} = d_a \cdot prob_{ag} , \tag{3}$$

$$s.t. \; prob_{ag} = \frac{\exp\left(-\theta \cdot GM_{ag}\right)}{\sum_{g \in G} \exp\left(-\theta \cdot GM_{ag}\right)} , \tag{4}$$

wherein $prob_{ag}$: probability of carrier group g selection on a port pair a, θ: variance parameter, and GM_{ag}: generalized cost of maritime shipping when using a carrier group g on a port pair a. The shipper makes a selection based on service levels provided by each group (freights, frequency, shipping time, etc.) and is not concerned with the shipping details such as the actual path and vessel size used which are determined by the carrier groups. The generalized cost of maritime shipping GM_{ag} is formulated as

$$GM_{ag} = p_{ag} + vt_{shpr} \cdot TM_{ag} \ , \tag{5}$$

wherein vt_{shpr}: value of time for shipper (JPY/TEU/hour), and TM_{ag} : total time of maritime shipping (also including waiting time etc.) for carrier group g on a port pair a (hour).

2.2.2. Solution

As shown in Equation (3)-(5), the shipping volume q_{ag} does not depend on the freights $p_{a'g}$ of any other port pairs a' ($\forall a' \in A, a' \neq a$) than that in the question and the shipping cost c_{ag} is assumingly fixed in the short-term model. Therefore, Equation (1) and (2) are rewritten as the following profit maximization *by port pair*

$$\max\lfloor \hat{p}_{ag} - c_{ag}, 0 \rfloor, \quad \forall a \in A, \forall g \in G \ , \tag{6}$$

$$s.t. \ \ \hat{p}_{ag} = \arg\max_{p} \left\{ \left(p_{ag} - c_{ag} \right) \cdot q_{ag}\left(p_{a1}, \cdots, p_{ag}, \cdots, p_{aG} \right) \right\}, \tag{7}$$

wherein a function "max[x, y]" in Equation (6) means choosing larger one from x and y, and a function "$\arg\max_{p} f(p)$" means choosing p to maximize $f(p)$. These equations stand that the freight $\hat{p}_{ag}$ is determined in order to maximize the profit for each port pair but if $\hat{p}_{ag}$ is lower than the shipping cost c_{ag}, it is defined as the same amount as c_{ag} supposing non-negative profit.

Since the shipping cost c_{ag} does not depend on neither the shipping volume q_{ag} nor freights p_{ag}, when the freights of other groups are fixed ($\overline{p}_{ag'}, \forall g' \neq g$), the first-order condition of Equation (7) for each group g is written as

$$\frac{\partial \left\{ p_{ag} \cdot q_{ag}\left(\overline{p}_{a1}, \cdots, p_{ag}, \cdots, \overline{p}_{aG} \right) \right\}}{\partial p_{ag}} = 0 \ . \tag{8}$$

Therefore, when inputting Equation (3)-(5) into this, if $prob_{ag} \neq 0$, it is acquired

$$prob_{ag} + \frac{1}{\theta \cdot p_{ag}} - 1 = 0 \cdot \tag{9}$$

Equation (9) can be solved by using a quasi-Newton method.

2.3. Midterm Model – Equilibrium Model of Ocean-going Carriers and Shippers considering Shippers' Port Choice

2.3.1. Outline

In this model, given regional cargo transport demand, both ocean-going carriers and shippers behave optimally each other according to respectively different objective functions in the context of a relationship of freights and shipping time by port pair and transport demand. They are assumed to reach Nash equilibrium conditions that when the other actor's behavior is given, a party cannot optimize their own objective function anymore.

Concretely, each shipper chooses a optimal shipping route including ports used for import/export, making reference to the generalized cost GM_{ag} shown in Equation (5) indicated by each ocean-going carrier group and other factors. On the other hand, each ocean-going carrier group determines the freights for each port pair and transportation pattern, given the shipping volume q_{ag} of carrier group g on port pair a acquired from the results of shippers' behavior as shown in the following sections.

2.3.2. Carrier Model: Formulation and Solution

In this midterm model, the profit maximization behavior for each carrier group is formulated as

$$\max_{p,x} \pi_g , \quad \forall g \in G , \tag{10}$$

$$s.t. \quad \pi_g = \sum_{a \in A} p_{ag} \cdot q_{ag}\left(p_{a1}, \cdots, p_{ag}, \cdots, p_{aG}\right) - \sum_{v \in V} x_{vg} \cdot t_{vg}\left(x_{11}, \cdots, x_{vg}, \cdots, x_{VG}\right), \tag{11}$$

$$q_{ag} = \sum_{k \in K_{ag}} h_{akg} , \quad \forall a \in A , \quad \text{and} \tag{12}$$

$$x_{vg} = \sum_{a \in A} \sum_{k \in K_{ag}} \delta^{v}_{akg} h_{akg} , \tag{13}$$

wherein x_{vg}: container flow of link v (in the carriers' cost minimization model) for carrier group g, $t_{vg}\left(x_{,1}, \cdots, x_{vg}, \cdots, x_{VG}\right)$: shipping cost of link v for carrier group g per container (TEU), V: set of links, h_{akg}: shipping volume of containers on a path k in shipping demand q_{ag} of group g on a port pair a, δ^{v}_{akg} : Kronecker delta (δ^{v}_{akg} =1; when a link v is included in the path k: δ^{v}_{akg} = 0; when not included), and K_{ag}: path choice set of shipping demand q_{ag}.

The different point from the short-term model shown in Equation (1) and (2) is that each shipping cost t_{vg} depends on container flow x_{vg} in the constraint condition (11). Note that the cost t_{vg} is defined as generalized cost including shipping time; in other words, by considering shipping time, notion of shippers is indirectly reflected in the cost minimization model of carriers. The other constraint condition (12) and (13) on cargo shipping demand q_{ag} and shipping amount x_{vg} guarantee that all of cargo are transported.

Since Equation (10) cannot be solved by $\delta\pi_g/\delta x = 0$ and $\delta\pi_g/\delta p = 0$ due to difficulty of differentiation, the above problem is solved by a following stepwise procedure; first, focusing in minimization of total shipping costs expressed by the second term; and second, profit maximization as shown in 2.2 when shipping cost in each port pair is fixed. Namely,

Step 0. $n = 0$; initial shipping demand $\left\{q^{(0)}_{ag}\right\}$ by port pair for each carrier group is given, estimated by shipping demand by region pair (which is expressed as $\left\{Q_{rs}\right\}$ in next section) and the share by ports of maritime container flow for each carrier group.

Step 1. $n = n + 1$.

Step 2. The cost minimization problem is solved under fixing shipping demand $\{q_{ag}^{(n-1)}\}$ for a previous period as below

$$\min_x \left\{ \sum_{v \in V} x_{vg}^{(n)} \cdot t_{vg}^{(n)} \left(x_{11}^{(n)}, \cdots, x_{vg}^{(n)}, \cdots, x_{VG}^{(n)} \right) \right\}, \qquad \forall g \in G .$$

Step 3. The profit maximization problem is solved according to the solution described in section 2.2.2 when shipping cost $\{c_{ag}^{(n)}\}$ in each port pair is fixed, by calculating from the link costs $\{t_{vg}^{(n)}\}$ and cargo flow $\{x_{vg}^{(n)}\}$ determined in Step 2 as below

$$\max_p \sum_{a \in A} \left\{ \left(p_{ag}^{(n)} - \bar{c}_{ag}^{(n)} \right) \cdot q_{ag}^{(n)} \left(p_{a1}^{(n)}, \cdots, p_{ag}^{(n)}, \cdots, p_{aG}^{(n)} \right) \right\}, \quad \forall g \in G .$$

Note that when n = 1, the freights $\{p_{ag}^{(n-1)}\}$ in the previous iteration which are used in the above calculation is substituted by the sum of monetary costs on the lowest-cost route using each link cost $\{t_{vg}^{(1)}\}$ which is obtained in Step 2.

Step 4. If the demand $\{q_{ag}^{(n-1)}\}$ for a previous period is converged comparing with the cargo demand $\{q_{ag}^{(n)}\}$ from Step 3 to confirm convergence, or the repeat count n reaches an upper limit, the calculation is over. If not, return to Step 1.

In the above calculation procedure, the cost minimization problem stated in Step 2 is described as a problem to determine a cargo flow of each link on international maritime container shipping network as shown in Figure 1.

$$\min_x \left\{ \sum_{v \in V} x_{vg} \cdot t_{vg} \left(x_{11}, \cdots, x_{vg}, \cdots, x_{VG} \right) \right\}, \quad \forall g \in G . \tag{14}$$

$$s.t.\ (12),\ (13)$$

As shown in Figure 2, in this model, as links are set by vessel size, the decision problem of each link flow includes the problem to determine, not only the handling volume for each port, but also the vessel size transported. Equation (14) corresponds to a system optimum in a traffic network equilibrium assignment methodology. Since the cost function t_{vg} for each link depend not only on flow x_{vg} for a given link but also on the flow $x_{v'g}, \forall v' \in V$ of other links in the same carrier group and the links $x_{vg'}, \forall g' \in G$ of other carrier groups, in this network equilibrium assignment problem, interference from the flow of other links needs to be incorporated. For detail, please refer to Shibasaki et al (2005).

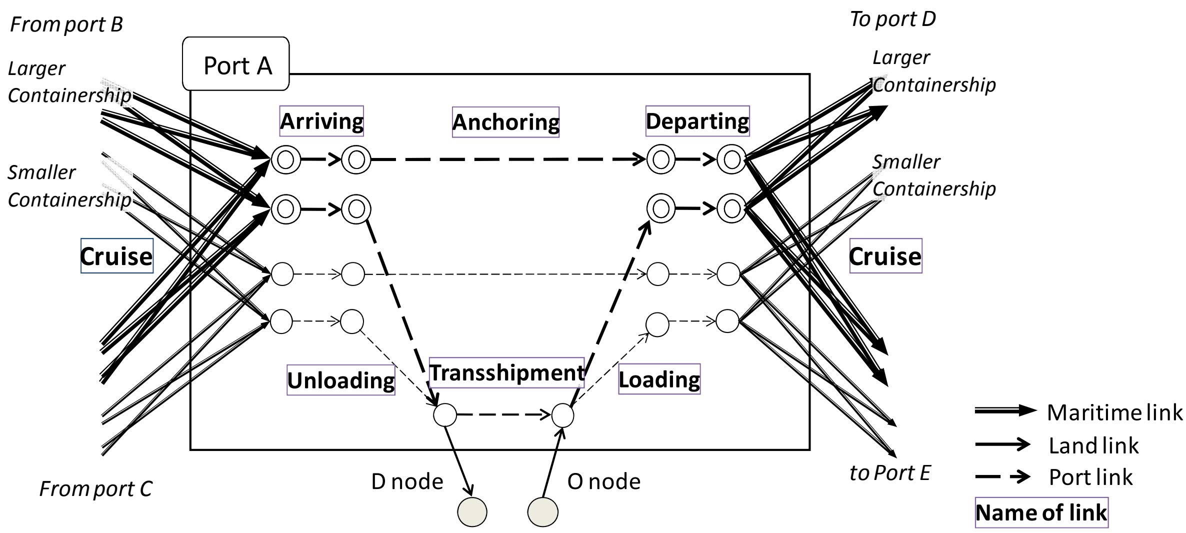


Figure 2. Network structure of carrier's cost minimization model.

2.3.3. Shipper Model: Formulation and Solution

In this model, cargoes are assigned on a network as shown in Figure 3. The maritime transportation link is herein defined as the direct linkage between an export ports and an import ports irrespective of the actual maritime transportation route and the shipping company used which are considered in the carrier model. A stochastic (but not equilibrium) network assignment model is also applied in this model taking into account factors which cannot be observed by the model developer. Widely, a logit model is applied for this type of problem; however, the authors do not apply due to the computational difficulties associated with the large number of choices in the logit model which requires enumeration of transportation routes in advance in a large-scale network like this model or the expanded model discussed below.

A shipper chooses a route (including mode of hinterland transport and port used for export/import) to minimize expected generalized shipping costs, given freights for maritime and land transport, the shipping time, etc. Herein, when K_{rs} is path choice set of regional cargo transport demand on a regional OD pair (hereafter calling "regional pair") rs ($rs \in \Omega$; Ω is set of regional pair), a cargo m chooses a path k to maximize utility U_{rskm} including error term ε_{rskm}, that is,

$$U_{rskm} > U_{rsk'm}, \quad \forall k \in K_{rs}, \forall k' \in K_{rs}, k \neq k', \forall rs \in \Omega, \tag{15}$$

$$s.t. U_{rskm} = -G_{rsk} + \varepsilon_{rskm}, \tag{16}$$

wherein G_{rsk}: shipping cost (JPY/TEU) of path k on a regional pair rs. If error term ε_{rskm} follows Gumbel distribution, a choice of shipper is formulated as

$$f_{rsk} = Q_{rs} \cdot \frac{\exp(-\theta \cdot G_{rsk})}{\sum_{k \in K_{rs}} \exp(-\theta \cdot G_{rsk})}, \tag{17}$$

wherein f_{rsk}: cargo volume on a path k between regional pair rs, and Q_{rs}: shipping demand (TEU) between regional pair rs. The shipping cost G_{rsk} for each path is expressed by the equation below.

$$G_{rsk} = \sum_{a \in k} \Lambda_a + \sum_{b \in k} GL_b + \sum_{i \in k} \left(GPX_i + GPM_i + GPT_i \right), \tag{18}$$

wherein Λ_a: the minimum expected cost (composite cost) for maritime links a including a path k, which is a log-sum variable reflecting the selection result of carrier group as shown in Equation (3)-(5) in section 2.2. More precisely,

$$\Lambda_a = -\frac{1}{\theta} \cdot \ln \sum_{g \in G} \exp\left(-\theta \cdot GM_{ag} \right) + \zeta, \tag{19}$$

wherein ζ: adjustment parameter to avoid the log-sum variable to be negative. GL_b in Equation (18) is the generalized shipping cost on land links b including the path k, expressed as

$$GL_b = CL_b + vt_{shpr} \cdot TL_b, \tag{20}$$

wherein CL_b : freight on land link b (JPY/TEU), and TL_b : shipping time (hours) on land link b. Additionally, GPX_i, GPM_i, GPT_i in Equation (18) are the cost of a port link i including the path k. Figure 4 shows the network structure in each port which is omitted from Figure 3. As shown in Figure 4, a receipt (of export cargo) and a dispatch (of import cargo) link are respectively set to take account of the lead time in each port. In addition, an inter-carrier transshipment link is also considered for each port taking into account the transshipment determined by the shipper. These link costs are defined as

$$GPX_i = vt_{shpr} \cdot TPX_i \ , \tag{21}$$

$$GPM_i = vt_{shpr} \cdot TPM_i, \text{ and} \tag{22}$$

$$GPT_i = CPT_i + vt_{shpr} \cdot TPT_i, \tag{23}$$

wherein, TPX_i: lead time when export in port i (hours), TPM_i: lead time when import in port i (hours), CPT_i: freight when transshipped between carrier groups (JPY/TEU), and TPT_i: shipping time when transshipped between carrier groups (hours).

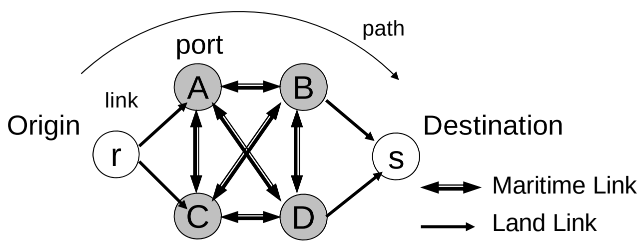


Figure 3. Schematic view of network structure of shipper model

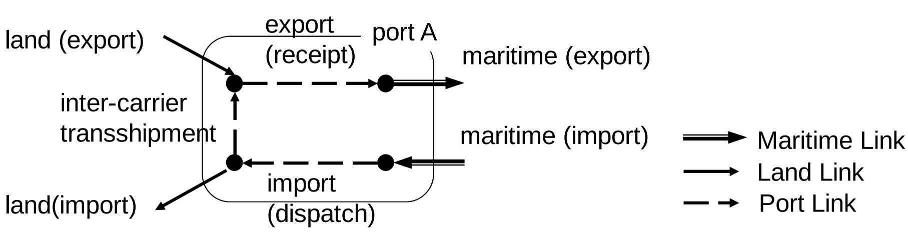


Figure 4. Network structure in port of shipper model

Also, a relationship between the path flow f_{rsk} and the shipping demand d_a for each port pair is expressed as

$$d_a = \sum_{rs \in \Omega} \sum_{k \in K_{rs}} \delta'^{a}_{rsk} \cdot f_{rsk} \ , \forall a \in A \ , \tag{24}$$

wherein δ'^{a}_{rsk} : Kronecker delta (δ'^{a}_{rsk} =1; when a link a is included in the path k on the regional pair rs: δ'^{a}_{rsk} = 0; when not included).

As shown above, a stochastic network assignment model without any flow-independent link is applied in this model. The cargo flow for each link is calculated using the Dial algorithm.

2.3.4. Procedure of Calculation to Acquire Nash Equilibrium Solution

Using initial conditions as a starting point and alternately repeating both shipper and carrier model calculations, a local optimum solution is obtained according to following steps.

Step 0. [Setting initial condition] N = 0 and an initial calculation of profit maximization problem of carrier groups is performed inputting initial values $\{q_{ag}^{(0)}\}$ for shipping demand and initial link cost $\{t_{vg}^{(0)}\}$ with respect to initial flow $\{x_{vg}^{(0)}\}$ by carrier group and using the solution method described in section 2.3.2. In this manner, the shipping time $\{TM_{ag}^{(0)}\}$ and freights $\{p_{ag}^{(0)}\}$ by port pair for each carrier group are calculated.

Step 1. $N = N + 1$.

Step 2. [Shipper model calculation] Based on the shipping time $\{TM_{ag}^{(N-1)}\}$ and freights $\{p_{ag}^{(N-1)}\}$ by port pair for carrier group calculated in the last step, calculation of the route choice model for shipper as shown in 2.3.3 is performed. In this manner, shipping demand $\{d_{a}^{(N)}\}$ by port pair for the overall carrier group is calculated.

Step 3. [Calculation of cargo shipping demand by carrier group] Cargo shipping demand $\{q_{ag}^{(N)}\}$ for each carrier group is calculated according to the short-term model shown in section 2.2, using freights $\{p_{ag}^{(N-1)}\}$ calculated in the previous iteration and total shipping demand $\{d_{a}^{(N)}\}$ by port pair acquired in the previous step as initial values.

Step 4. [Carrier model calculation] Carrier model is calculated according to the solution method described in section 2.3.2, using freights $\{p_{ag}^{(N-1)}\}$ calculated in the previous iteration and shipping demand $\{q_{ag}^{(N)}\}$ by port pair for each carrier group calculated in Step 3 as initial values. In this manner, the shipping time $\{TM_{ag}^{(N)}\}$ and the freights $\{p_{ag}^{(N)}\}$ by port pair for each carrier group, and the link flow $\{x_{vg}^{(N)}\}$ in the network of the cost minimization model for carrier group can be obtained.

Step 5. [Convergence test] The sum $\{XC_{ijsg}^{(N)}\}$ of the four types of cruising link flow in the network of the cost minimization model for carrier group calculated in Step 4 is compared with the sum $\{XC_{ijsg}^{(N-1)}\}$ of the previously existing link flow and checked for convergence. If it is converged or the repeat count N approaches an upper limit, the process is terminated, if not, return to Step 1.

3. MODEL EXPANSION AND DATA PREPARATION

3.1 Maritime Network

The existing model mainly focused in East and Southeast Asia. However, since the model expanded in this paper targets worldwide international cargo flow, container ports dealt in the model are re-selected as shown in Figure 5. The total number of port is 95 including almost all important ports of the world for international maritime cargo movement, such as port of Singapore, Shanghai, Hong Kong, Shenzhen, Rotterdam, and Los Angeles. The name of ports and settings input into the model for each port are shown in Table A1 for the carrier model input and Table A2 for the shipper model input in Appendix. As shown in Table A1, the number of vessel size in the carrier model is categorized to six. Settings for each vessel size such as unit of shipping cost are shown in Table 1. Among vessel sizes shown in Table 1, only containerships that belong to less than category three (i.e. capacity is less than 4,000 TEU) can assumingly pass through the Canal before the expansion, while all containerships can pass through after the expansion.

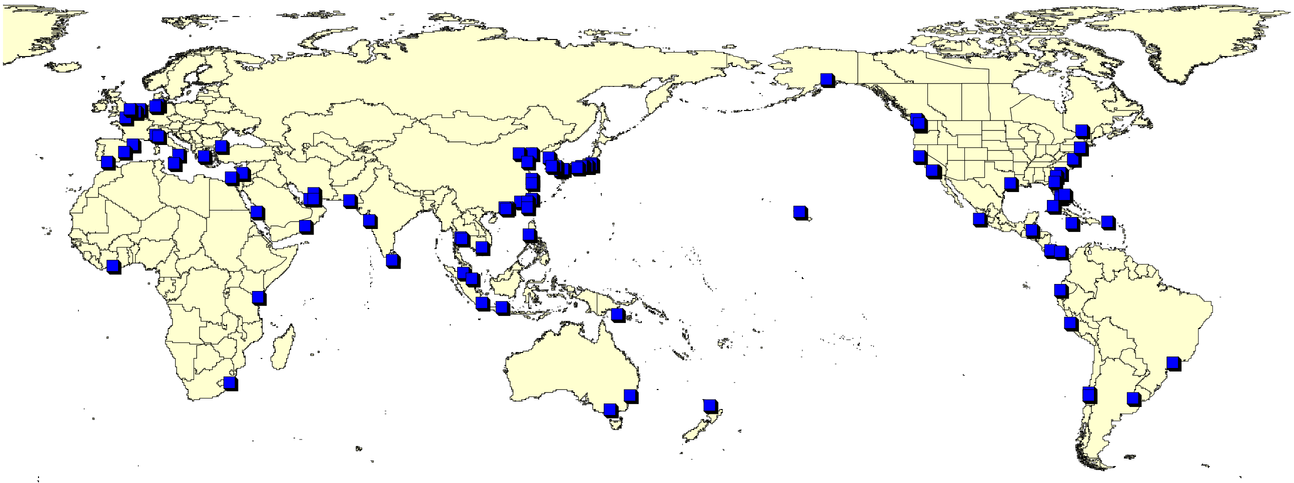


Figure 5. Ports dealt in the expanded model

Table 1. Settings by containership size in the carrier model

- containership size

category	range of TEU capacity (TEU)	average of TEU capacity (TEU)	berth size category that containership can enter	maritime shipping cost (JPY/TEU/hour)		vessel speed (knot)
				when vessel is sailing**	when vessel is anchoring**	
1	- 1000	500	all 1-6	3,293	3,040	16.5
2	1000 - 2500	1750	2,3,4,5,6	2,094	1,780	20.3
3	2500 - 4000	3250	3,4,5,6	1,695	1,346	22.5
4*	4000 - 6000	5000	4,5,6	1,455	1,080	24.2
5*	6000 - 8000	7000	5,6	1,286	888	25.6
6*	8000 -	9000	6	1,167	752	26.7

- berth size

category	depth (m)
1	under 11.0
2	11.0 - 13.0
3	13.0 - 14.0
4	14.0 - 15.0
5	15.0 - 16.0
6	over 16.0

*impossible to pass through the Panama Canal before expansion (possible after expansion)

**exemplified figures if load factor is assumed to be 80%

3.2. Land Network

In this expanded model, a land transport network including road and railways in North America should be added. The authors utilized a database acquired from ADC WorldMap™, as well as when Asian land network was incorporated; however, this database is very dense and if the network is directly incorporated into the maritime shipping network, the problem on independence from irrelevant alternatives cannot neglect because a stochastic assignment methodology is applied in the model as described in the previous chapter. Therefore, a shortest path search between origin/destination points (set for each U.S. and Canadian state) and ports for import/export in North America continent was conducted only on the land transport network. The land network used in the shortest path search and the routes selected as a result are shown in Figure 6. In almost all inter-state transport including cross border transport, railways were selected, while roads were limited to usage in the short distance transport such as access to railways from ports and intra-state transport. These calculation results are also corresponding to the authors' interview survey results that railways were often used for the transport with more than 500 km distance.

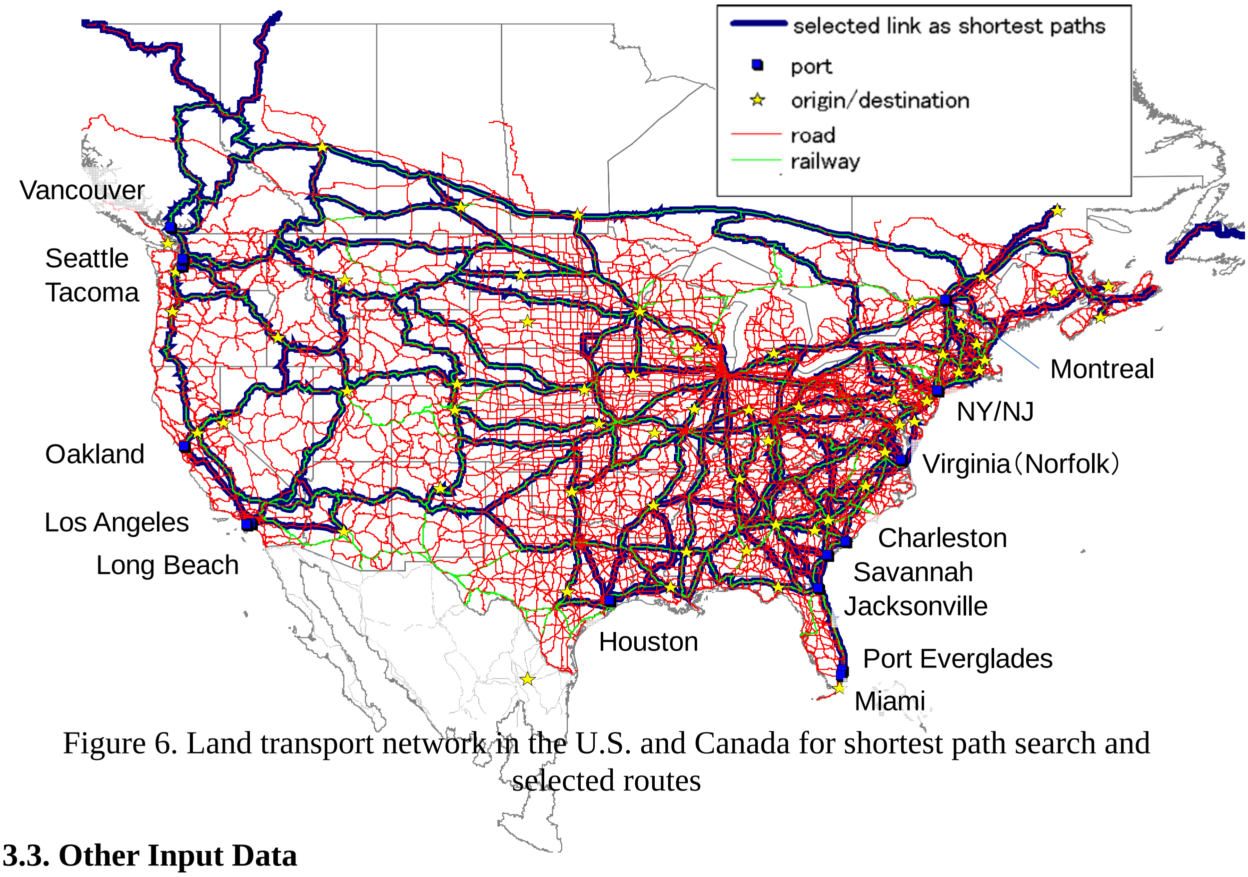


Figure 6. Land transport network in the U.S. and Canada for shortest path search and selected routes

3.3. Other Input Data

Other main input data in this model are cargo shipping demand and initial input such as link flow between ports by ship size and by carrier group. The database is renewed in year-2008 data instead of year-2003 data, although methodologies for estimation are almost the same. In particular, cargo shipping demands are assumed as following steps; first, information on bilateral trade amount about all countries of the world are gathered through GTAP Database and Global Insight Database and trade matrix is made; second, these figures are converted into the volume of maritime containerized cargo between each countries, by multiplying unit price per tonnage, modal share for maritime transport, containerized ratio, and conversion rate from tonnage-basis to TEU-basis data; third, cargo shipping demand between each countries are divided into regional-basis or port-basis data, using the shares for the region or port of the country. For the first simulation (Simulation 1) in next chapter, since in this case maritime shipping on the maritime network and cargo flow in each port including inter-carrier and intra-carrier transshipment are only considered, a worldwide matrix on the cargo shipping demand between ports is made. For the second simulation (Sim. 2), since land transport network in North America is added to the network of Simulation 1, a matrix on the cargo shipping demand is made on a regional-basis for North America and made on a port-basis for other regions of the world.

4. SIMULATION RESULTS AND DISCUSSIONS

In order to confirm performances of the expanded model, two cases for model calculation are prepared as follows. The first simulation (Sim.1) is a calculation in which maritime shipping on the maritime network and cargo flow within each port are only considered. In other words, ports used for export/import assume to be unchanged for shippers; shippers can only select carrier group and ports for inter-carrier transshipment. The second simulation (Sim.2) is a calculation in which land transport network in North America is also considered, in addition to the above maritime and intra-port network. In other words, shippers in North America can change the ports used for export/import, while shippers in other regions cannot change as well as in Sim.1.

4.1. Simulation 1: Results using the Model Only Considering Maritime Shipping

4.1.1. Confirmation of Model Accuracy

By the calculation results using the model with restriction on passing through the Canal (before the canal expansion), an accuracy of the model expanded can be confirmed. Figure 7 shows the annual transshipment container cargo volume estimated for each port, comparing with the actual amount. As shown in the model, the volumes in a few ports such as Singapore and Rotterdam are overestimated, while those in most of other ports are underestimated. Also, the total volume of transshipped containers is underestimated by 19%, compared with the actual volume. Judging from these results, underestimation in most of ports is considered causing mainly from the following two reasons; too much concentration of containers to the largest hub port of the region such as Singapore and Rotterdam mainly due to the structure and parameter settings of the model; and the underestimation of the total volume in transshipment mainly due to omission for local ports to be transported by feeder ship. However, as a whole, the estimation result of the model seems to reproduce a general tendency of the actual selection of transshipment ports for shippers and carriers.

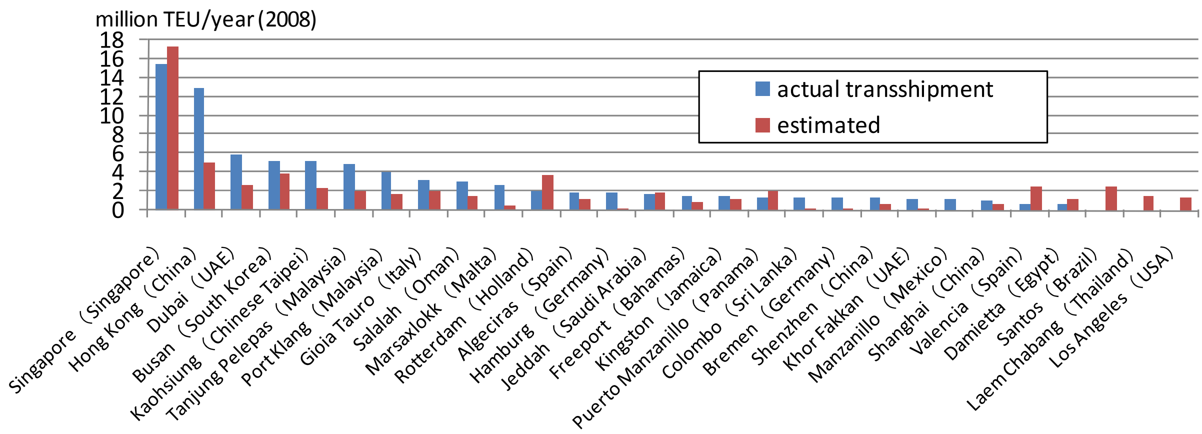
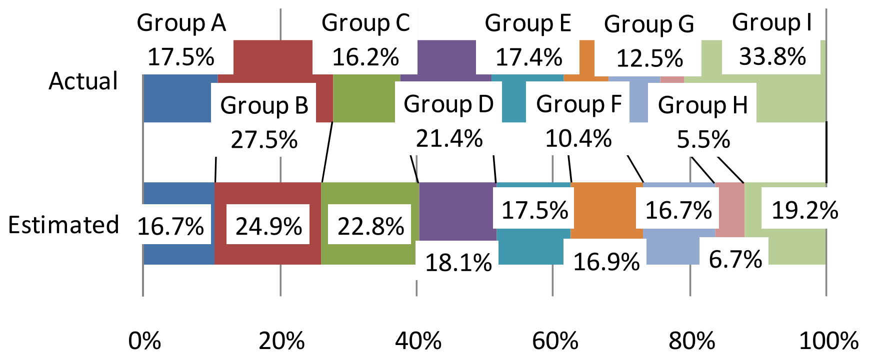


Figure 7. Estimated and actual transshipment container cargo volume for each port (in which the estimated or actual volume is more than 1 million TEU per year)

Figure 8 shows the estimated and actual share for each ocean-going carrier group on a TEU basis of cargo flow transported. Comparing the estimated share with the actual, the estimated share for each carrier group is more equalized (i.e. in groups for which the actual share is relatively larger, the estimated share become smaller, while in groups for which the actual share is smaller, the estimated share become larger) and thus competition among groups estimates to be severer. Figure 9 also shows the estimated and actual share for containership size on a TEU basis of cargo flow transported. The estimated share for under 1000 TEU and 6000-8000 TEU are underestimated compared with the actual share, while the estimated share for 2500-4000 TEU is overestimated.



Group A: New World (APL, Hyundai, MOL), Group B: Grand Alliance (Hapag-Lloyd, MISC, NYK, OOCL), Group C: CKYH (Cosco, K-Line, Yang Ming, Hanjin), Group D: Maersk, Group E: MSC, Group F: CMA-CGM, Group G: Evergreen, Group H: China Shipping (CSCL), Group I: Other carriers

Figure 8. Estimated and actual share for ocean-going carrier group
(on a TEU basis of cargo flow transported)

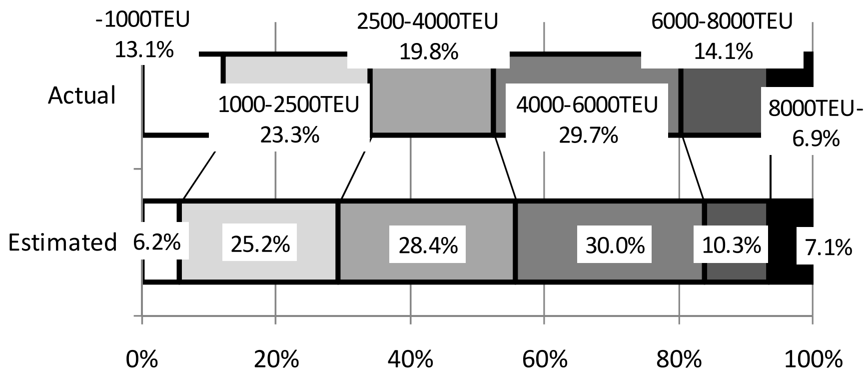


Figure 9. Estimated and actual share for containership size
(on a TEU basis of cargo flow transported)

4.1.2. Simulation of the Canal expansion

The authors prepare two scenarios on the Canal expansion; in Scenario 1 (S1), a simple expansion of the Canal is assumed so that larger containership (with more than category four) can pass through it; on the other hand, in Scenario 2 (S2), in addition to the Canal expansion, construction of new container terminal (namely, four berths with 16.0m depth) in port of Puerto Manzanillo (Panama), which is closely located to the Canal, is assumed.

Table 2 shows the estimation results in transshipped container cargo volume, comparing the case before the Canal expansion with the two scenarios after the expansion. As shown in the table, in Scenario 1, the estimated total volume of transshipment container of the world decreases by 0.6% compared with the case before expansion, although an increasing rate in each port varies and significant tendency is not observed. Meanwhile, in Scenario 2, the transshipment containers in port of Puerto Manzanillo increase by about 150%; in other words, it is found that the effect of investment for new terminal is highly expected.

The synergistic effect of a canal expansion and terminal construction can be also found in terms of the saved amount of shipping cost. Table 3 shows the estimated shipping cost for each case by country/region that container cargoes are originated from or destined into. As shown in the table, in Scenario 1, the total annual shipping cost is estimated to be saved by 24.9 billion JPY (Japanese Yen) which is equal to 0.03% of the total shipping cost. Comparing with the investment cost (5.25 billion US$), the saved amount is almost equal to one-twentieth. Herein, note that the estimated saved amount of the model is only considered in container cargo shipping and that any effect of the expansion in reducing congestion for waiting when passing through the Canal are not considered. Looking at by country/region, the effect of the expansion is not uniform and even among countries/regions. The significant effects are expected for the cargo of the U.S. and East Asian countries, while even negative effects are expected for those in most of other countries/regions. On the other hand, in Scenario 2, the saved amount of the total annual shipping cost is estimated 315.9 billion JPY, which is more than ten times compared with that in Scenario 1. Also, the effect of the expansion spreads broadly to the world. In particular, for the cargo that are originated from/destined into Central and South America, in which the Panama Canal is located, the saved amount of shipping cost is estimated to be most significant.

Figure 10 also shows comparison of the share for each containership size on a TEU basis of cargo flow transported. By comparing the results before and after expansion, it is found that the shares for containership size which capacity is more than 4000 TEU (i.e. post-panamax class) is predicted to increase by 5.0% for Scenario1, and 7.2% for Scenario 2. In particular, the share for containership which capacity is 4000 to 6000 TEU increases, instead that the share for containership which capacity is 2500 to 4000 TEU decreases.

Table 2. Estimated volume of transshipment containers in 2008 and its comparison between before and after expansion (Sim.1)

Rank	port	Before Expansion	(S1) After Expansion		(S2) After Expansion + New Terminal	
		mil. TEU	mil. TEU	%*	mil. TEU	%*
1	Singapore (Singapore)	17.38	16.83	−3.1%	16.65	−4.2%
2	Hong Kong (China)	5.04	5.24	4.0%	5.20	3.0%
3	Busan (South Korea)	3.94	3.97	0.8%	3.96	0.5%
4	Rotterdam (Holland)	3.74	3.71	−0.8%	3.71	−0.8%
5	Dubai (UAE)	2.69	2.67	−0.8%	2.67	−0.6%
6	Santos (Brazil)	2.53	2.57	1.6%	2.57	1.3%
7	Valencia (Spain)	2.45	2.40	−2.1%	2.37	−3.3%
8	Kaohsiung (Chinese Taipei)	2.39	2.40	0.4%	2.43	1.9%
9	Puerto Manzanillo (Panama)	1.99	2.03	1.6%	4.99	150.4%
10	Tanjung Pelepas (Malaysia)	1.97	1.88	−4.5%	1.83	−6.9%
11	Gioia Tauro (Italy)	1.96	1.99	1.3%	1.96	−0.1%
12	Jeddah (Saudi Arabia)	1.78	1.73	−2.8%	1.76	−1.2%
13	Port Klang (Malaysia)	1.63	1.66	1.7%	1.59	−2.3%
14	Laem Chabang (Thailand)	1.57	1.53	−2.1%	1.53	−1.9%
15	Salalah (Oman)	1.55	1.50	−3.2%	1.49	−3.6%
16	Los Angeles (USA)	1.36	1.34	−1.4%	1.32	−3.1%
17	Algeciras (Spain)	1.26	1.14	−9.0%	1.09	−13.4%
18	Damietta (Egypt)	1.22	1.25	1.7%	1.29	5.2%
19	Kingston (Jamaica)	1.13	1.01	−10.4%	0.76	−33.2%
20	Piraeus (Greece)	0.94	1.18	25.8%	1.13	20.1%
	World Total	73.22	72.76	−0.6%	74.03	1.1%

*increasing rate against the figures before expansion

Table 3. Estimated annual shipping cost (in 2008) and its comparison between before and after expansion (Sim.1)

country/region	conainer volume (million TEU)	before expansion	(S1) After Expansion			(S2) After Expansion + New Terminal		
		bil. JPY	bil. JPY	dif.	%	bil. JPY	dif.	%
USA	28.5	29,722	29,646	−75.8	−0.26%	29,495	−226.8	−0.76%
Canada	3.4	3,786	3,828	42.1	1.11%	3,774	−12.1	−0.32%
Japan	11.9	9,195	9,186	−9.6	−0.10%	9,175	−20.7	−0.23%
China (incl. Hong Kong)	39.7	32,963	32,847	−115.9	−0.35%	32,850	−113.0	−0.34%
Korea and Chinese Taipei	16.4	11,882	11,849	−33.3	−0.28%	11,853	−29.1	−0.24%
ASEAN	21.5	16,598	16,598	0.1	0.00%	16,598	0.0	0.00%
South Asia	3.9	3,736	3,740	4.0	0.11%	3,745	8.3	0.22%
Central and South America	15.6	18,255	18,322	67.0	0.37%	18,067	−187.9	−1.03%
Middle East	18.8	18,190	18,193	2.4	0.01%	18,185	−5.3	−0.03%
Europe	25.9	26,999	27,050	50.5	0.19%	26,940	−58.7	−0.22%
Africa	5.6	7,380	7,377	−3.4	−0.05%	7,377	−2.8	−0.04%
Oceania	3.1	3,548	3,570	21.8	0.62%	3,564	16.3	0.46%
World Total	194.3	91,128	91,103	−24.9	−0.03%	90,812	−315.9	−0.35%

Note: 1) figures for each country/region are total of export and import, while figure on the "world total" is based on the sum of the export *or* import amount for all countries/regions.
2) "dif." and "%" stands for a difference and increasing rate with the case before expansion respectively.

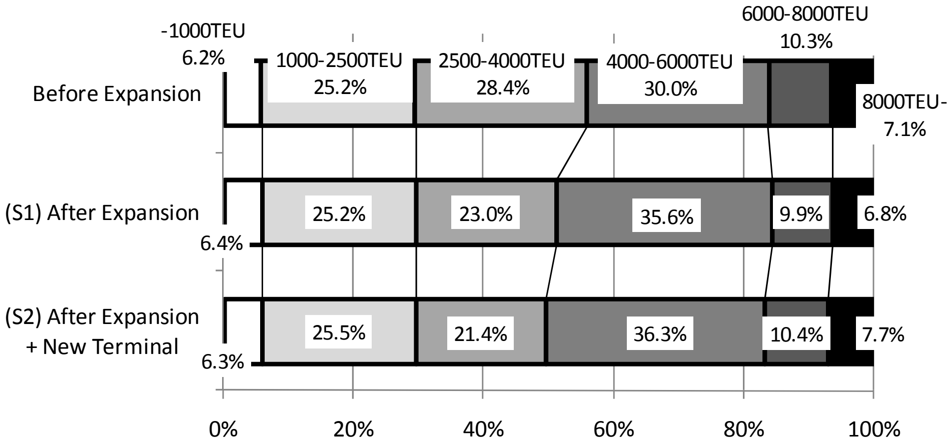


Figure 10. Estimated share for containership size and its comparison between before and after expansion (Sim.1)

4.2. Simulation 2: Results using the Model Incorporated Land Transport in North America

4.2.1. Confirmation of Model Accuracy

As well as Simulation 1, by the results using the model with restriction on passing through the Canal (the case before expansion), an accuracy of the model is confirmed. Figure 11 shows the annual local (i.e. sum of export and import) container cargo volume estimated for each the U.S. and Canadian port, comparing with the actual amount. The share of cargo volume for west coast ports (from Anchorage to Long Beach as shown in Figure 11) is estimated to be 51%, while that in the actual was 56%. For the west coast ports, there are trade-offs on the cargo volume between geographically closer ports or between ports in the same state, for example, between port of Vancouver and Seattle, and between port of Oakland and Long Beach. The differences in between the actual and estimated volume in these ports may be partly reduced if zones used in the calculation are finely divided further. For the east coast ports, in ports located in south or along a river including port of Houston, Miami, Port Everglades and Montreal, the cargo volume is underestimated, while in ports located in north including port of Savannah, Charleston, Virginia, and NY/NJ, it is overestimated. In other words, in the ports located closer to the Metropolitan Area of the U.S. that most of cargo is originated from and destined into, cargo are estimated to concentrate more, compared with the actual. This may be caused from a quantity of relatively higher setting on the land transport cost rather than the maritime shipping cost.

For the model precision from the other viewpoints such as transshipment cargo volume for each port, share for each carrier group, and share for each ship size, there is not big difference, compared with the estimation results which are shown in Sim.1.

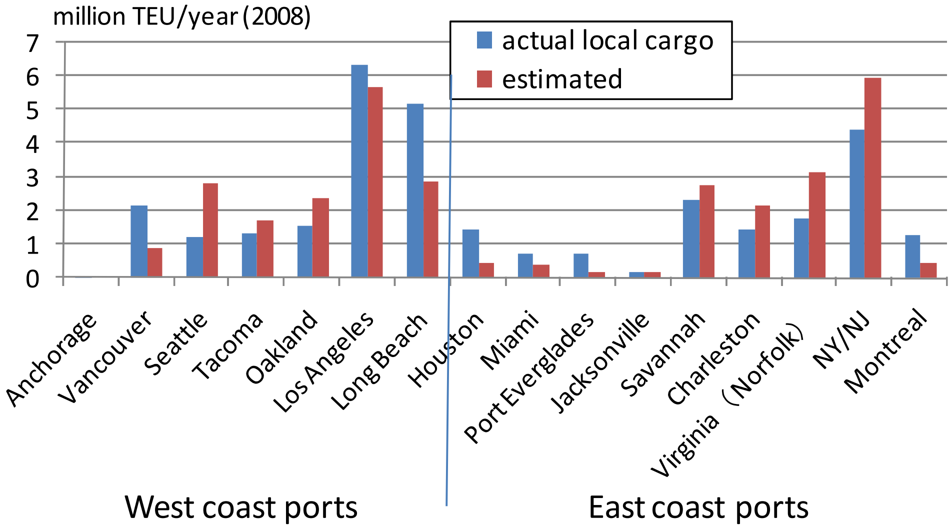


Figure 11. Estimated and actual local (sum of export and import) container cargo volume for each the U.S. and Canadian port

4.2.2. Simulation of the Canal expansion

As well as Sim.1, two scenarios on the Canal expansion are prepared. Figure 12 shows a comparison in the estimated volume of local container cargo for the U.S. and Canadian port between before and after expansion. From the figure, there are not significant differences due to the Canal expansion, except for the tradeoffs in the volume between in port of Los Angeles and Long Beach, and between in port of Savannah and Charleston.

Table 4 shows the estimated shipping cost by country/region that container cargoes are originated from or destined into, as well as shown in Table 3. As shown in the table, in Scenario 1, the total annual shipping cost is estimated to be saved by 50.0 billion JPY, which is almost twice as that estimated in Sim.1, although the share for the saved amount (0.03%) in the total shipping cost is the same as in Sim.1 because land transport cost in North America is included in the calculation of Sim.2. On the other hand, in Scenario 2 (canal expansion plus terminal construction), the total saved cost is estimated 229.2 billion JPY, which is almost two-thirds as that estimated in Sim.1. In terms of geographical distribution of the effect, the overall trend in both scenarios is similar to Sim.1; however, the increased shipping costs in Scenario 1 in Central and South America are quite different between two simulations (67.0 million JPY in Sim.1, while 0.4 million JPY in Sim.2).

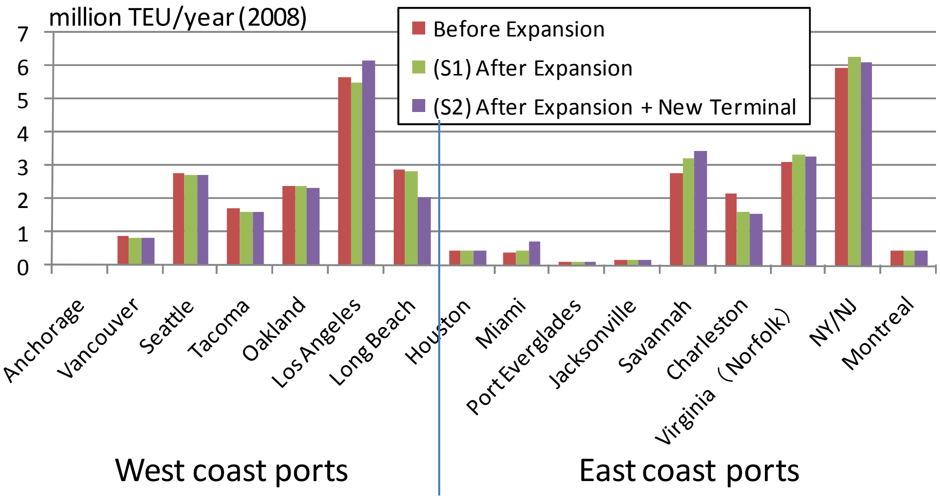


Figure 12. Estimated local container cargo volume for each the U.S. and Canadian port and its comparison between before and after expansion (Sim.2)

Table 4. Estimated annual shipping cost (in 2008) and its comparison between before and after expansion (Sim.2)

country/region	conainer volume (million TEU)	before expansion	(S1) After Expansion			(S2) After Expansion + New Terminal		
		bil. JPY	bil. JPY	dif.	%	bil. JPY	dif.	%
USA	28.5	48,460	48,402	−58.0	−0.12%	48,337	−123.4	−0.25%
Canada	3.4	6,162	6,161	−0.1	0.00%	6,156	−5.8	−0.09%
Japan	11.9	19,177	19,168	−9.0	−0.05%	19,158	−18.8	−0.10%
China (incl. Hong Kong)	39.7	74,628	74,547	−80.7	−0.11%	74,548	−79.8	−0.11%
Korea and Chinese Taipei	16.4	25,665	25,652	−13.0	−0.05%	25,647	−17.8	−0.07%
ASEAN	21.5	38,264	38,266	1.7	0.00%	38,263	−0.5	0.00%
South Asia	3.9	7,601	7,607	6.2	0.08%	7,606	4.8	0.06%
Central and South America	15.6	32,312	32,312	0.4	0.00%	32,120	−192.1	−0.59%
Middle East	18.8	35,946	35,966	19.4	0.05%	35,939	−7.5	−0.02%
Europe	25.9	48,448	48,477	29.0	0.06%	48,434	−14.1	−0.03%
Africa	5.6	13,828	13,826	−2.1	−0.02%	13,826	−1.6	−0.01%
Oceania	3.1	6,297	6,303	6.1	0.10%	6,295	−1.8	−0.03%
World Total	194.3	178,394	178,344	−50.0	−0.03%	178,165	−229.2	−0.13%

Note: same as stated in Table 3.

4.3 Discussion

For both model in which maritime shipping is only considered as described in 4.1 (Sim.1) and in which land transport in North America is also incorporated as described in 4.2 (Sim.2), the model accuracy was found to be generally fine, in terms of container cargo volume handled in each port and shares for carrier group and containership size. In addition, when some shocks such as the expansion of the Canal and the construction of container terminal were given, the direction of the change for the above outputs seemed to be quite reasonable. It is also found that the amount of the change is not significant.

As stated in the previous sections, a shipping cost for each cargo and its change due to the shocks were also estimated in the model. Sometimes were they calculated by countries or regions that cargo are originated from and destined into. With the view in mind that the shipping cost calculated is very liable to change compared with other outputs stated in this paper, distinctly depending on the settings of the cost function in the model and the variation in order to reflect the investment policy, and thus the results shown in this paper are possibly altered after future modification of the model, some implication are derived from the results shown in the previous sections as below.

First, the synergistic effect of a canal expansion and terminal construction was observed. In Sim.1, from the authors' estimation in the same manner stated in 4.1, the saved amount of shipping cost for a sole project of container terminal construction in port of Puerto Manzanillo is calculated to be 127.7 billion JPY. Therefore, the saved amount (315.9 billion JPY) when two projects are simultaneously implemented (i.e. Scenario 2) was beyond the sum of the saved amount (24.9 + 127.7 = 152.6 billion JPY) when each project assumes to be independently implemented. This synergy effect means that even if only container terminal is constructed, there is small chance to use for larger containership which cannot pass through the Canal, and that even if only the Canal is expanded, use of larger containership does not prevail because there are few ports around the Canal in which the larger containership can enter.

Second implication that can be acquired from the shipping cost estimation was the difference in the saved amount among both simulations. Generally, the changed amount due to the project becomes milder when more alternatives can be chosen. Since more alternatives for shipping route are included in Sim.2 which land transport network across the North American Continent is incorporated, the changed amount for each country/region (including both positive and negative) in Sim.2 is expected to be smaller than that in Sim.1. The results shown in Table 3 and Table 4 were endorsed the above expectation; for example, for the cargo in Canada, Central/South America, Europe and Oceania the increased cost were larger in Sim.1, while for those in the U.S. and East Asia including Japan, China, Korea and Chinese Taipei, the decreased cost were larger in Sim.1.

5. CONCLUSION

In this paper, in order to simulate the impact for the expansion of the Panama Canal, the authors expanded the model that the authors had developed, for including the worldwide international maritime shipping network as well as land transport network in North America. The expanded model can simulate the impact for such a big project on the world international cargo flow. After the model accuracy was confirmed to be good at least in term of the container cargo throughput predicted for each port, etc., two scenarios on the Canal expansion were examined for two simulation model. The change direction and amount of various outputs due to the expansion were also found reasonable, there still remains to be reviewed on the estimation of shipping cost for container cargo.

The developed and expanded model has still some challenges to be improved from both theoretical and practical aspects, as well as the input data such as cargo shipping demand on a regional basis should be revised. In addition to the above tasks, the authors would like to apply this expanded model for further simulation on the Canal expansion; namely, a simulation inputting future cargo shipping demand and considering emergence of mega-containership which capacity is more than 10000 TEU.

ACKNOWLEDGEMENTS

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APPENDIX

Table A1 Settings for each port in the carrier model

No.	Port Name		Handl-ing Charge (thousand JPY/	Port Charge** (million JPY/vessel)						Terminal Charge (billion JPY/year/berth)**	Handling Time of Trans-shipped Cargo (hours)**	Number of berth***					
				< 1000 TEU	1000 – 2500 TEU	2500 – 4000 TEU	4000 – 6000 TEU	6000 – 8000 TEU	8000 TEU <			> -11 m	-11 – -13 m	-13 – -14 m	-14 – -15 m	-15 – -16 m	-16 m >
1	Japan	Tokyo	20	1.76	2.05	2.49	3.08	3.66	4.25	1.08	48	2	2	0	2	8	0
2	Japan	Yokohama	20	1.76	2.05	2.49	3.08	3.66	4.25	1.08	48	0	4	9	1	4	2
3	Japan	Shimizu	20	1.76	2.05	2.49	3.08	3.66	4.25	1.08	48	0	3	0	0	1	0
4	Japan	Nagoya	20	1.76	2.05	2.49	3.08	3.66	4.25	1.08	48	3	5	0	2	2	2
5	Japan	Yokkaichi	20	1.76	2.05	2.49	3.08	3.66	4.25	1.08	48	0	0	1	1	0	0
6	Japan	Osaka	20	1.76	2.05	2.49	3.08	3.66	4.25	1.08	48	2	4	5	1	2	0
7	Japan	Kobe	20	1.76	2.05	2.49	3.08	3.66	4.25	1.08	48	2	4	2	4	6	0
8	Japan	Hakata	20	1.76	2.05	2.49	3.08	3.66	4.25	1.08	48	0	1	2	1	1	0
9	Japan	Kitakyushu	20	1.76	2.05	2.49	3.08	3.66	4.25	1.08	48	3	2	0	0	2	0
10	South Korea	Busan	22	0.65	0.94	1.38	1.97	2.55	3.13	0.69	24	0	2	2	2	15	6
11	South Korea	Kwangyang	22	0.65	0.94	1.38	1.97	2.55	3.13	0.69	24	0	2	0	0	3	11
12	South Korea	Incheon	22	0.65	0.94	1.38	1.97	2.55	3.13	0.69	48	0	4	0	2	0	0
13	China	Dalian	8	0.68	0.97	1.41	1.99	2.57	3.16	0.50	72	0	2	3	8	2	2
14	China	Tianjin	8	0.68	0.97	1.41	1.99	2.57	3.16	0.50	72	0	1	0	4	7	4
15	China	Qingdao	8	0.68	0.97	1.41	1.99	2.57	3.16	0.50	72	0	0	1	5	3	3
16	China	Shanghai	8	0.68	0.97	1.41	1.99	2.57	3.16	0.50	72	9	12	6	4	0	9
17	China	Ningbo	8	0.68	0.97	1.41	1.99	2.57	3.16	0.50	72	0	0	6	0	4	4
18	China	Xiamen	8	0.68	0.97	1.41	1.99	2.57	3.16	0.50	72	0	8	7	0	0	3
19	China	Shenzhen	8	0.68	0.97	1.41	1.99	2.57	3.16	0.50	72	0	2	0	3	15	12
20	China	Guangzhou	8	0.68	0.97	1.41	1.99	2.57	3.16	0.50	72	0	9	0	10	0	0
21	China (Hong Kong)	Hong Kong	30	1.58	1.87	2.31	2.89	3.48	4.06	4.53	12	0	0	0	1	23	0
22	Chinese Taipei	Keelung	19	1.24	1.53	1.97	2.55	3.14	3.72	0.87	48	2	6	5	0	0	0
23	Chinese Taipei	Taichung	19	1.24	1.53	1.97	2.55	3.14	3.72	0.87	48	0	0	0	6	0	0
24	Chinese Taipei	Kaohsiung	19	1.24	1.53	1.97	2.55	3.14	3.72	0.87	24	4	4	1	15	3	0
25	Philippines	Manila	24	0.65	0.95	1.39	1.97	2.55	3.14	0.50	72	29	7	2	1	0	0
26	Vietnam	Ho Chi Minh City	46	0.65	0.94	1.38	1.96	2.55	3.13	0.50	72	10	6	2	1	0	0
27	Thailand	Laem Chabang	14	0.73	1.02	1.46	2.05	2.63	3.22	0.16	48	0	0	0	8	0	5
28	Thailand	Bangkok	14	0.73	1.02	1.46	2.05	2.63	3.22	0.16	72	21	0	0	0	0	0
29	Malaysia	Tanjung Pelepas	15	0.97	1.26	1.70	2.28	2.87	3.45	0.50	12	0	0	0	0	6	0
30	Malaysia	Port Klang	15	0.97	1.26	1.70	2.28	2.87	3.45	0.50	24	0	0	0	6	13	0
31	Singapore	Singapore	20	1.01	1.30	1.74	2.32	2.91	3.49	0.62	12	6	15	4	4	11	20
32	Indonesia	Surabaya (Tj Perak)	18	0.77	1.07	1.50	2.09	2.67	3.26	0.50	72	11	0	0	0	0	0
33	Indonesia	Jakarta (Tj Priok)	18	0.77	1.07	1.50	2.09	2.67	3.26	0.50	72	2	4	0	6	0	0
34	India	Jawaharlal Nehru	21	0.75	1.04	1.48	2.06	2.65	3.23	0.35	72	3	5	2	0	0	0
35	Sri Lanka	Colombo	16	0.75	1.04	1.48	2.06	2.65	3.23	0.50	24	4	2	1	0	5	0
36	Pakistan	Karachi	14	0.75	1.04	1.48	2.06	2.65	3.23	0.50	72	4	0	2	0	0	0
37	USA	Anchorage	26	1.65	1.94	2.38	2.97	3.55	4.13	3.00	48	3	0	0	0	0	0
38	Canada	Vancouver	64	1.65	1.94	2.38	2.97	3.55	4.13	1.50	48	0	1	0	0	8	1
39	USA	Seattle	26	1.65	1.94	2.38	2.97	3.55	4.13	3.00	48	0	0	0	0	11	0
40	USA	Tacoma	26	1.65	1.94	2.38	2.97	3.55	4.13	3.00	48	0	0	0	0	10	0
41	USA	Oakland	26	1.65	1.94	2.38	2.97	3.55	4.13	3.00	48	0	20	0	0	5	0
42	USA	Los Angeles	26	1.65	1.94	2.38	2.97	3.55	4.13	3.00	48	2	5	10	1	4	7
43	USA	Long Beach	26	1.65	1.94	2.38	2.97	3.55	4.13	3.00	48	0	3	7	5	14	1
44	USA	Honolulu	26	1.65	1.94	2.38	2.97	3.55	4.13	3.00	48	0	5	0	0	0	0
45	Mexico	Manzanillo	27	0.75	1.04	1.48	2.06	2.65	3.23	0.50	72	0	9	0	3	0	0
46	Panama	Puerto Manzanillo	27	0.75	1.04	1.48	2.06	2.65	3.23	0.50	24	0	0	4	1	0	0
47	Costa Rica	Limon	29	0.75	1.04	1.48	2.06	2.65	3.23	0.50	72	2#	0	0	0	0	0
48	Puerto Rico	San Juan	50	0.75	1.04	1.48	2.06	2.65	3.23	0.50	72	9	0	0	0	0	0
49	Jamaica	Kingston	39.2	0.75	1.04	1.48	2.06	2.65	3.23	0.50	24	7	2	3	0	0	0
50	Cuba	Havana	69	0.75	1.04	1.48	2.06	2.65	3.23	0.50	72	1	0	0	0	0	0
51	Bahamas	Freeport	49	0.75	1.04	1.48	2.06	2.65	3.23	0.50	24	0	0	0	0	0	3
52	USA	Houston	25.9	1.65	1.94	2.38	2.97	3.55	4.13	3.00	48	0	5	0	7	0	0
53	USA	Miami	26	1.65	1.94	2.38	2.97	3.55	4.13	3.00	48	0	4	0	0	5	0
54	USA	Port Everglades	26	1.65	1.94	2.38	2.97	3.55	4.13	3.00	48	1	6	4	0	0	0
55	USA	Jacksonville	26	1.65	1.94	2.38	2.97	3.55	4.13	3.00	48	0	18	0	0	0	0
56	USA	Savannah	26	1.65	1.94	2.38	2.97	3.55	4.13	3.00	48	0	14	0	4	0	0
57	USA	Charleston	26	1.65	1.94	2.38	2.97	3.55	4.13	3.00	48	0	6	7	0	0	0
58	USA	Virginia (Norfolk)	26	1.65	1.94	2.38	2.97	3.55	4.13	3.00	48	5	4	2	0	4	0
59	USA	NY/NJ	26	1.65	1.94	2.38	2.97	3.55	4.13	3.00	48	1	12	4	15	4	0
60	Canada	Montreal	64	1.65	1.94	2.38	2.97	3.55	4.13	1.50	48	16	0	0	0	0	0
61	Ecuador	Guayaquil	28	0.75	1.04	1.48	2.06	2.65	3.23	0.50	72	3	0	0	0	0	0
62	Peru	Callao	28	0.75	1.04	1.48	2.06	2.65	3.23	0.50	72	0	18	0	0	0	0
63	Chile	Valparaiso	22	0.75	1.04	1.48	2.06	2.65	3.23	0.50	72	2	3	0	0	0	0
64	Chile	San Antonio	22	0.75	1.04	1.48	2.06	2.65	3.23	0.50	72	2	3	0	0	0	0
65	Brazil	Santos	21	0.75	1.04	1.48	2.06	2.65	3.23	0.50	72	2	5	9	0	0	0
66	Argentina	Buenos Aires	57	0.75	1.04	1.48	2.06	2.65	3.23	0.50	72	21	0	0	0	0	0

Table A1 (continued)

No.	Port Name		Handl-ing Charge (thousand JPY/	Port Charge** (million JPY/vessel) < 1000 TEU	1000 – 2500 TEU	2500 – 4000 TEU	4000 – 6000 TEU	6000 – 8000 TEU	8000 TEU <	Terminal Charge (billion JPY/ year/ berth)**	Handling Time of Trans-shipped Cargo (hours)**	Number of berth*** > -11 m	-11 – -13 m	-13 – -14 m	-14 – -15 m	-15 – -16 m	-16 m >
67	Iran	Bandar Abbas	24	0.75	1.04	1.48	2.06	2.65	3.23	0.50	72	0	5	0	0	0	0
68	UAE	Dubai	15.4	0.75	1.04	1.48	2.06	2.65	3.23	0.50	24	0	5	5	3	3	11
69	UAE	Khor Fakkan	15	0.75	1.04	1.48	2.06	2.65	3.23	0.50	72	0	2	0	0	0	3
70	Oman	Salalah	22	0.75	1.04	1.48	2.06	2.65	3.23	0.50	24	0	0	0	0	0	6
71	Saudi Arabia	Jeddah	11	0.75	1.04	1.48	2.06	2.65	3.23	0.50	24	0	1	0	0	4	14#
72	Israel	Haifa	28.6	1.31	1.60	2.04	2.62	3.21	3.79	0.50	48	4	2	0	2	0	0
73	Turkey	Ambarli (Istanbul)	23	1.31	1.60	2.04	2.62	3.21	3.79	1.00	72	6	4	3	7	0	0
74	Greece	Piraeus	34	1.31	1.60	2.04	2.62	3.21	3.79	1.00	24	0	2	2	2	1	2
75	Malta	Marsaxlokk	36	1.31	1.60	2.04	2.62	3.21	3.79	1.00	24	0	0	0	0	6	1
76	Italy	Gioia Tauro	37	1.31	1.60	2.04	2.62	3.21	3.79	1.00	24	0	0	5	0	5	0
77	Italy	La Spezia	37	1.31	1.60	2.04	2.62	3.21	3.79	1.00	24	0	0	1	3	0	0
78	Italy	Genoa	37	1.31	1.60	2.04	2.62	3.21	3.79	1.00	24	3	6	2	2	5	0
79	Spain	Barcelona	22	1.31	1.60	2.04	2.62	3.21	3.79	1.00	24	6	4	0	3	0	2
80	Spain	Valencia	22	1.31	1.60	2.04	2.62	3.21	3.79	1.00	24	0	2	0	0	2	8
81	Spain	Algeciras	22	1.31	1.60	2.04	2.62	3.21	3.79	1.00	24	4	0	0	2	0	3
82	Egypt	Damietta	21	1.31	1.60	2.04	2.62	3.21	3.79	1.00	24	0	0	0	4	0	0
83	UK	Felixstowe	20	1.31	1.60	2.04	2.62	3.21	3.79	1.00	48	1	2	2	2	2	0
84	France	Le Havre	28	1.31	1.60	2.04	2.62	3.21	3.79	1.00	48	2	4	8	10	0	0
85	Belgium	Antwerp	32	1.31	1.60	2.04	2.62	3.21	3.79	1.00	48	0	0	9	4	15	4
86	Holland	Rotterdam	22	1.31	1.60	2.04	2.62	3.21	3.79	1.00	24	5	17	4	8	0	20
87	Germany	Bremen	25	1.31	1.60	2.04	2.62	3.21	3.79	1.00	48	2	3	0	10	0	0
88	Germany	Hamburg	25	1.31	1.60	2.04	2.62	3.21	3.79	1.00	48	1	9	5	3	9	7
89	Cote	Abidjan	105	0.65	0.94	1.38	2.62	3.21	3.79	0.50	72	0	5	0	0	0	0
90	South Africa	Durban	37	0.65	0.94	1.38	2.62	3.21	3.79	0.50	72	0	9	0	0	0	0
91	Kenya	Mombasa	44	0.65	0.94	1.38	2.62	3.21	3.79	0.50	72	0	5	0	0	0	0
92	Australia	Sydney	30	0.93	1.22	1.66	1.96	2.55	3.13	1.00	48	0	0	1	6	0	0
93	Australia	Melbourne	30	0.93	1.22	1.66	1.96	2.55	3.13	1.00	48	4	2	8	0	0	0
94	New Zealand	Auckland	26	0.93	1.22	1.66	1.96	2.55	3.13	1.00	48	0	4	0	0	0	0
95	Papua New Guinea	Port Moresby	22	0.93	1.22	1.66	1.96	2.55	3.13	1.00	72	3	0	0	0	0	0

Source: * World Bank: Doing Business. ** authors' estimation. *** Containerisation International Yearbook etc.

Note: In berth categories gray-colored, containerships with correspondting size cannot enter.
The number of container berths with # is increased to meet the actual needs for container cargo shipping.

Table A2 Settings for each port in the shipper model (shown by country)

country/region	monetary cost (JPY/TEU) export A	export B	import A	import B	time (hours) export A	export B	export C	import A	import B	import C	country/region	monetary cost (JPY/TEU) export A	export B	import A	import B	time (hours) export A	export B	export C	import A	import B	import C
Japan	31.0	7.0	37.9	13.9	144	48	48	168	48	48	Ecuador	65.4	20.4	63.8	20.4	336	96	48	552	96	96
South Korea	11.0	3.6	11.0	3.6	72	24	72	96	24	48	Argentina	87.6	14.4	97.2	18.0	192	48	48	264	72	72
China	38.4	8.4	39.6	8.4	384	48	48	456	96	48	Brazil	60.0	12.0	48.0	18.0	192	48	72	264	72	72
China (Hong Kong)	13.2	4.8	14.2	4.8	72	24	48	72	24	24	Iran	39.1	18.0	59.5	24.0	336	48	96	600	48	120
Chinese Taipei	36.4	14.0	37.8	7.2	216	48	48	192	24	48	UAE	33.7	12.0	32.0	12.0	144	24	24	168	24	24
Philippines	45.1	22.4	44.9	22.4	264	48	72	264	72	96	Saudi Arabia	34.3	22.7	33.5	21.8	216	72	96	288	144	96
Vietnam	24.8	12.0	19.1	10.7	384	96	72	384	96	96	Oman	46.9	22.3	72.8	45.2	408	72	72	360	24	96
Thailand	38.4	6.0	45.0	9.0	216	24	72	240	48	48	Israel	28.8	7.2	21.6	7.2	144	24	72	144	24	72
Malaysia	18.0	7.8	18.0	7.8	288	48	72	240	24	48	Turkey	50.4	24.0	57.6	24.0	216	72	72	264	72	72
Singapore	16.3	3.7	14.3	3.7	48	24	24	48	24	24	Greece	55.8	27.6	48.6	31.8	384	48	48	432	144	120
Indonesia	45.5	20.3	40.2	15.0	384	48	48	456	96	144	Italy	44.5	18.4	44.5	18.4	312	72	72	288	48	72
India	56.4	14.4	61.2	14.4	240	48	72	288	96	144	Spain	48.0	18.0	48.0	18.0	120	24	48	144	48	48
Sri Lanka	53.4	34.2	57.0	34.2	360	72	72	360	72	72	Egypt	32.0	21.8	32.8	10.8	240	24	48	288	24	24
Pakistan	35.5	24.0	39.6	24.0	336	72	96	312	48	72	Malta	31.8	7.8	53.4	7.8	72	24	48	72	24	24
USA	30.0	7.2	35.4	10.8	72	24	48	72	24	24	Belgium	74.3	30.0	72.0	30.0	96	24	24	168	48	24
Canada	31.2	4.2	31.2	9.0	96	24	24	120	24	48	France	16.2	3.6	36.6	18.0	96	24	72	144	24	72
Mexico	48.0	18.0	96.0	60.0	216	48	48	288	48	72	Germany	20.6	3.6	28.4	6.6	96	24	48	96	24	24
Costa Rica	54.0	24.0	54.0	24.0	192	48	72	264	72	48	UK	33.6	16.8	43.2	16.8	120	24	48	120	24	24
Panama	24.0	6.0	42.0	24.0	120	24	24	168	24	24	Holland	26.4	10.8	37.4	10.8	96	24	24	96	24	24
Puerto Rico	63.0	33.0	63.0	33.0	240	96	72	264	48	72	Cote d'Ivoire	45.6	9.7	69.2	29.3	480	120	72	624	168	192
Bahamas	51.6	15.6	51.6	15.6	240	72	96	240	72	48	Kenya	93.6	45.0	96.0	51.6	408	120	144	336	72	168
Jamaica	126.0	30.0	86.4	18.0	336	96	72	432	96	48	South Africa	41.6	9.0	56.6	9.0	456	96	216	432	96	336
Cuba	129.0	33.0	128.4	60.0	336	96	96	432	96	72	Australia	39.6	5.4	46.7	14.4	144	24	24	120	48	48
Peru	31.8	12.0	34.2	12.0	408	120	72	408	120	120	New Zealand	32.2	6.0	30.0	6.0	144	24	48	144	24	24
Chile	22.2	6.0	28.2	6.0	312	48	96	360	72	96	Papua New Guinea	33.1	7.0	33.0	6.8	408	96	72	552	96	96

Note A: document preparation and custom clearance, B: inter-carrier transshipment, C: lead time for port handling. These parameters are estimated based on Doing Business database provided by World Bank. For parameters on B, they are substituted by cost and time on "custom clearance" for each country/region.