Asian Container Cargo Transportation Model including Multi-Layer Transportation Network and Economy of Scale

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Abstract: A container cargo transportation model taking into account multi-layer transportation network and scale economy is constructed. The model has been confirmed its accuracy through several case studies. Solution algorithm of the model has been suggested. An incremental assignment procedure is modified to solve this nonconvex problem. Effects of increase in container vessel size and soaring marine fuel price are estimated by numerical simulation applied to the Asian transportation network. Both two likely simulation results show the same direction that is increase of transshipment and further concentration at hubs.

Keywords: Multi-layer Network, Transshipment, Economy of Scale, Container Cargo

1. INTRODUCTION

Intra-Asia container cargo transportation market has been tightening competition and mainly three types of services exist in the market, that is, direct transportation by small sized vessels, hub and spokes type transportation by middle or small sized vessels, and direct or transshipped transportation by large sized vessels which is enrolled in long distance trunk line. Various type of network and various sizes of vessels are represented in this area. Each transportation type has drawback and advantage. Shippers take on different transportation type based on their priority of factors in transportation conditions. As the result, each transportation type has gained particular share. This paper formulates intra-Asia container cargo transportation network model which demonstrates those various services. A main contribution of the model is to formulate a hierarchical configuration in transportation network and economy of scale at transshipment terminals simultaneously. And the model is applied to analyze impacts of increase in vessel size and fuel price rising.

Authors has already developed a multi-layer transportation network model and applied it to surface transportation network. The model represents two types of scale economy. It is assumed that several sizes of vehicles are operated in each link of network. Unit transport costs vary depending on the size of vehicle. Transshipment terminals also enjoy economy of scale by assuming the fixed cost which does not depend on cargo volume. Unit handling costs vary depending on total transshipment volume at the terminal. The model is modified especially in a formulation of transshipment in order to be fit to maritime transportation network in this paper.

The paper is inspired by a model suggested by Ieda *et al.* (1999) which formulates a transshipment terminal as a combination of links, not as a simple node.

There are many transportation models considering transshipment in the field of surface transportation. Cooper (1963) suggested a location allocation model which was the first contribution to decide a location of transshipment terminals and to estimate their handling volume. Taniguchi *et al.* (1999) developed a model to decide location and size of distribution center in an inter-regional transportation network. Ieda *et al.* (1993) formulated a location of consolidation terminal and an activity of pickup and delivery. Tokunaga *et al.* (1995) modeled a location of consolidation terminal and transportation route of home delivery service.

In the field of seaborne transportation, Shibasaki *et al.* (2005) improve the model suggested by Ieda *et al.* (1999). The model includes both surface and seaborne transportation systems and represents modal split between them. Song *et al.* (2005) assigns international container cargo flow to fixed container vessel network. Leachman (2008) analyzes a transportation cost elasticity and a service quality elasticity of import container cargo transportation.

Transshipment terminal has been focused by many researchers; however an economy of scale of the terminal and a hierarchical configuration in transportation network has never been formulated in those works.

2. CONTAINER CARGO TRANSPORTATION NETWORK

2.1 Hierarchical configuration in transportation network

2.1.1 Container port

Container ports are classified by its roles in a transportation network. We assume following three types of ports. Inter-national hub ports often handle quite huge inter-national transshipment container cargoes and many trunk lines call the ports. Every size of vessels including a post-panamax vessel gathers at the ports. Regional hub ports take a role of distribution center of neighboring countries. Trunk lines do not call the port so many; however certain numbers of transshipment container cargoes are handled. Local ports never handle transshipment container cargoes. Only inbound and outbound cargoes from/to hinterland of the port are handled there. (Figure 1)

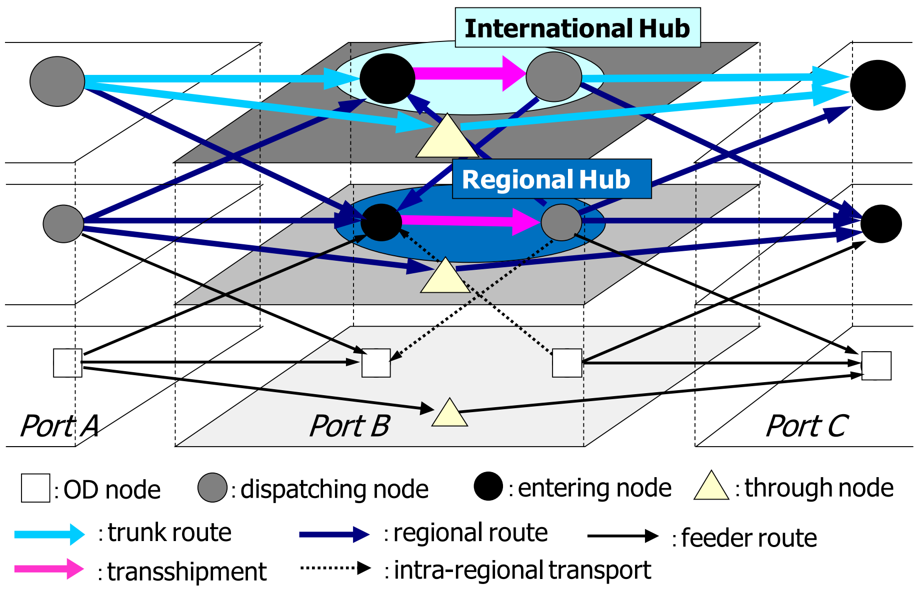

Figure1 Multi-layer transportation network

Container cargoes are assumed to be generated and attracted at the port. We do not pay attention to inland transport. Every cargo is loaded at the point of generation at first and unloaded at the point of attraction finally as well. Not all cargoes are transported directly. Certain share of them is transshipped at an International hub port and/or a Regional hub port, although distance of the transportation is longer than the direct connection. All cargoes will be transported through minimum cost path respectively.

2.1.2 Maritime transportation network

Maritime transportation network consists of links which connect neighboring ports and is classified by its roles as well as above container ports. We assume the following three types of maritime transportation network. Trunk route network connects only international hub ports and large size vessels are operated on the network. Regional route network connects not only regional hub ports but also international hub ports. Medium size vessels are operated on the network. Feeder network connects all type of ports within same region and small size vessels are operated on the network. Feeder network does not connect different region therefore trunk route or regional route are selected in case of inter-regional container cargo such as Asia-North America and Asia-Europe. Unit cost of transportation is different by the type of network. The cost is the lowest in trunk line network and highest in feeder network.

2.2 Economy of scale

2.2.1 Shipping Cost

Shipping cost is composed of fixed cost and variable cost. Depreciation cost of asset and labor cost at headquarter are typical examples of the fixed cost. Fixed cost is not depending on cargo volume. Larger handling volume brings in lower average cost. Container terminals require huge area and facility, a lot of cargo handling equipment and advanced management systems, therefore its fixed cost is quite large and significant economy of scale is expected.

2.2.2 Economy of scale at Container Terminal

Cargo demand has considerable seasonal and weekly variation. A size of an ordinary container terminal is beyond peak demand in order to meet various customer demands. An average utilization rate of the terminal is generally not so high. There is redundant capacity. There is room for further cargo to enjoy further economy of scale. Terminal aggregation and cooperative consolidation make the utilization higher and provide lower shipping cost.

3. MODEL

3.1 Assumption

3.1.1 Carrier

Only one shipping company exists and provides transportation services for all given demand. We do not have a concern with competition among carriers.

3.1.2 Cargo

We do not consider characteristics of cargo such as value and commodity type. Only a number of containers (TEU) are given as a transportation demand.

3.1.3 Unit Cost of Transportation

Unit cost of transportation is given with respect to each network type that is trunk route network, regional route network and feeder network. This assumption means three types of vessels are operated on maritime transportation network.

3.1.4 Port

Each port has a possibility to be an international hub port, a regional hub port, and a feeder port. The type of port can be discussed after we get a result of an application. If a result shows that transshipment volume between trunk route network and another network at a port is positive, we can conclude the port has a function of an international hub port. If not, but in case that transshipment volume between regional route network and feeder network at a port is positive, we can conclude the port has a function of a regional hub port as well. If no transshipment cargo is forecasted at a port, the port is regarded as a local port.

3.1.5 Transshipment Cost

Transshipment cost of each port is changed depending on handled volume. Increasing volume brings in decreasing transshipment cost. We do not consider a diseconomy of scale such as congestion. It is assumed that terminal facilities are expanded when a port faces short of capacity.

3.2 Transportation Network

The model is applied to international trade among East and South-East Asia and Europe. The distinctive treatments on representation of network in this model are following three points. 1) Each port on respective transportation network is not represented as a single node but as two nodes and one link, that is, an entering node, a dispatching node and transshipment link connecting those two nodes. 2) Each port has through nodes. In case that a cargo remains loaded on a vessel although the vessel calls at a port, the cargo is represented to pass through corresponding “through node.” 3) Asia and Europe are connected by trunk route network and regional route network.

Each port has three through nodes on all three layer of networks, two entering nodes and two dispatching nodes on trunk route network and regional route network, an origin node and a destination node. The above nodes are connected by link appropriately.

An origin node is connected to entering nodes on trunk route network and regional route network at same port by directed link. Dispatching nodes on trunk route network and regional route network are connected to a destination node at same port by directed link as well. Beside, an origin node is connected to destination node, through node and entering node on trunk route network and regional route network at neighboring ports. Transshipment is represented by transshipment link which does not have a distance but a handling cost. Handling cost is changed depending on transshipment volume at the port.

3.3 Cost Function

3.3.1 Transshipment

Transshipment cost is expressed as a summation of fixed cost and variable cost. as Eq.1. Average unit handling cost is obtained by dividing both sides of Eq.1 by handled volume as Eq.2. Increasing the handled volume brings in unit cost reduction. In case the ratio of fixed cost is larger, the economy of scale works stronger.

$$C = CF + CV \times q \tag{1}$$

$$\frac{C}{q} = \frac{CF}{q} + CV \tag{2}$$

where,

C: Transshipment cost,
CF: Fixed cost,
CV: Variable cost,
q: Handled volume.

Not surprisingly, larger terminal requires large fixed cost. Fixed cost should be expressed by function of scale of a terminal facility. On the other hand, small terminal requires certain costs. For example an administration office and information systems are needed even where little demands are. Reflecting above consideration, fixed cost is formulated by function of diminishing marginal cost as Eq.3 and Eq.4. Also we assume minimum requirement scale of the terminal. Even when handled volume is less than q1, fixed cost does not decrease into under CF1. (Eq.5)

$$CF(x) = \int \delta_1^{x-q_1} \cdot CF_1 \, dx \quad (x > q_1) \tag{3}$$

$$= \frac{CF_1}{\delta_1^{q_1} \cdot \log \delta_1} \cdot \left(\delta_1^{x} - 1\right) \quad (x > q_1) \tag{4}$$

$$CF(x) = CF_1 \quad (x < q_1) \tag{5}$$

where,

x: Scale of terminal facility,
CF_1: Standard fixed cost,
q_1: Minimum required volume,
δ_1: Degression parameter (<1).

Labor cost might represent a large proportion of variable cost. When handled volume increase, it is getting easier to make more streamlined and efficient in operation. Therefore, economy of scale can be considered in variable cost. We assume that increasing handled volume brings in lower variable cost and converges into minimum variable cost. Variable cost is formulated as Eq.6. We also assume maximum requirement variable cost as Eq.7.

$$CV(x) = \delta_2^{x-q_1} \cdot CV_a + CV_b \quad (x > q_1) \tag{6}$$

$$CV(x) = CV_1 (= CV_a + CV_b) \quad (x < q_1) \tag{7}$$

where,

CV_1: Standard variable cost,
CV_a: Degressive variable cost,
CV_b: Minimum required variable cost,
δ_2: Degression parameter (<1).

When we assume that every terminal is constructed appropriately in terms of its scale (x=q), cost function can be expressed as Eq.8 and Eq.9. Eq.8 implies an envelope curve of cost functions of each terminal scale. Average unit handling cost is obtained by dividing both sides of Eq.8 and Eq.9 by handled volume. (Eq.10, Eq.11 and Eq.12)

$$C = CF(q) + CV(q) \cdot q \quad (q > q_1) \tag{8}$$

$$C = CF_1 + CV_1 \cdot q \quad (q < q_1) \tag{9}$$

$$\frac{C}{q} = \frac{CF(q)}{q} + CV(q) \quad (q > q_1) \tag{10}$$

$$= \frac{CF_1 \left(\delta_1^{q} - 1\right)}{\delta_1^{q_1} \cdot q \cdot \log \delta_1} + \delta_2^{q-q_1} \cdot CV_a + CV_b \quad (q > q_1) \tag{11}$$

$$\frac{C}{q} = \frac{CF_1}{q} + CV_1 \quad (q < q_1) \tag{12}$$

Since international hub port is more capital intensive than regional hub port, parameters of above function are given in respect to type of port. (Eq.13)

$$LC_{k_m} = \frac{CF_{m1} \left(\delta_{m1}^{q^{k_m}} - 1\right)}{\delta_{m1}^{q_{m1}} \cdot q^{k_m} \cdot \log \delta_{m1}} + \delta_{m2}^{q^{k_m} - q_{m1}} \cdot CV_{ma} + CV_{mb} \tag{13}$$

where,

LC_{km}: Cost of link type k at port type m,
m: International hub (m=1), Regional hub (m=2).

3.3.2 Transportation

Transportation cost is simply formulated. It is assumed as proportional to a distance. Only network type is considered. (Eq.14)

$$LC_{ij} = \beta_h \times d_{ij} \tag{14}$$

where,

LC_{ij}: Transportation cost from node i to node j,
β_h: Unit transportation cost
(Trunk route (h=1), Regional route (h=2), Feeder route (h=3)),

d_{ij}: Distance from node i to node j (nautical mile: M).

4. DATA, PARAMETERS AND SOLUTION PROCEDURE

4.1 Data and Parameters

Traded container volumes between each country pair are estimated by using two published data that is World Trade Service by IHS Global Insight and Investigation on General Export/Import Container Cargo Distribution Channel by Ministry of Land, Infrastructure, Transport and Tourism in Japan. We use both data in 2008, because the latest version of the latter data is in 2008, although the former data of more recent version is available.

Parameters are obtained by tuning so that the model represents higher reproducibility. It is referred that Cooper showed the ratio of fixed cost and unit variable cost is approximately 500:1. It is also referred a result of interview survey to several container terminal companies conducted by authors. Parameters are given as follows.

- Transshipment Cost
  - International hub port
    - Standard fixed cost : CF_{11}=8,273,700 (JPY/day)
    - Standard variable cost : CV_1=16,545 (JPY/TEU/day)
    - Depressive variable cost : CV_{1a}=15,095 (JPY/day)
    - Minimum required variable cost : CV_{1b}=1,450 (JPY/TEU/day)
    - Depression parameter : δ_{11}=0.9998, δ_{12}=0.995
  - Regional hub port
    - Standard fixed cost : CF_{21}=1,654,740 (JPY/day)
    - Standard variable cost : CV_2=6,206 (JPY/TEU/day)
    - Depressive variable cost : CV_{2a}=406 (JPY/day)
    - Minimum required variable cost : CV_{2b}=2,900 (JPY/TEU/day)
    - Depression parameter : δ_{21}=0.9998, δ_{22}=0.995
- Transportation Cost
  - Trunk route unit cost : β_1=10 (JPY/TEU/M)
  - Regional route unit cost : β_2=20 (JPY/TEU/M)
  - Feeder route unit cost : β_3=40 (JPY/TEU/M)

4.2 Solution Procedure

An incremental assignment method is applied to solve the problem. The incremental assignment method is widely applied to traffic assignment problem which involves congestion of each link. Congestion is a kind of diseconomy of scale. Since this model involves economy of scale, conventional incremental assignment method is modified to get a reasonable solution. A conventional method may reach a solution which does not contain transshipment so much and is obviously high total transportation cost because initial cost of each transshipment link is pretty high. Cargoes is hardly been assigned to transshipment link by a conventional method.

Conventional method does not require iteration; however we suggest a following modified method with iteration. Step 1) Standard fixed cost of transshipment at each port (CFm1) is initially given pretty low and all demand is assigned by incremental assignment method. Fixed cost and variable cost is updated corresponding to assigned volume in every time that cargoes are newly assigned. Quite many cargoes are expected to be transshipped at the first iteration. Step 2) And then standard fixed cost of transshipment at each port is given again as certain times (>1) of that of the latest iteration. Assigned volumes at the latest iteration are substituted into transshipment cost function of each port and gained transshipment cost is assumed as the upper limit of transshipment cost at the port. Transshipment cost of each port might be updated to larger number than those of latest iteration. All demand is assigned by incremental assignment method again. Slightly fewer cargoes are expected to be transshipped at the new iteration than the latest iteration. Above step 2 is repeated until standard fixed cost reaches certain value. And then iteration is continued without updating standard fixed cost until assigned volume is converged. In following applications, we set the standard fixed cost at the first iteration as 2^{10th} part of a given value and it is doubled every iterations. The given value of the standard fixed cost is used after the 11th iteration.

5. APPLICATIONS AND DISCUSSIONS

5.1 Reproducibility

Estimated value and observed value of handled volume of several countries are shown in Figure 2. The value in China, Hong Kong and Singapore are over estimated, while that in Japan, Korea and Taiwan are under estimated. Parameter of economy of scale seems quite effective in the model. Although the model has such a problem, overall trend and magnitude relation are reproduced. These estimated values are regarded as a benchmark set and each simulation result are compared with the benchmark in order to discuss on an impact of transportation environment change in following applications.

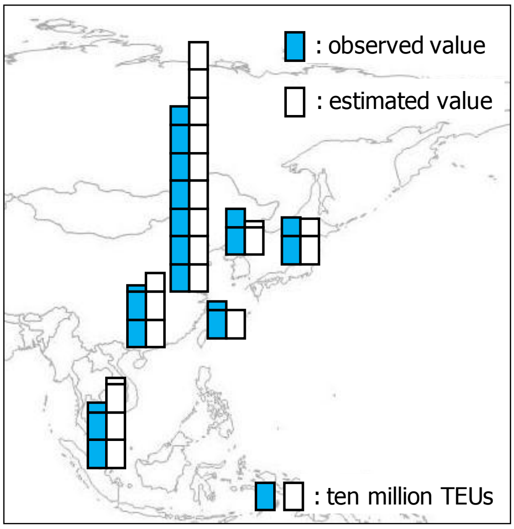

Figure 2 Reproducibility of the model

5.2 Increases in Vessel Size on Trunk and Regional Route

Container vessel has been enlarged rapidly and continuously after appearance of post panamax vessel. Main physical restriction after the Panama Canal will be width and depth of the Malacca-Singapore Strait in actual trunk route. Next focused size, as it is called Malacca-max, is approximately 18,000 TEU. Panama Canal will be expanded in near future and it will drive vessel size growth. This is why increase in vessel size continues for a while. Increase in vessel size brings in transportation cost reduction. We assume that average vessel sizes are doubled and transportation costs are reduced 20% on trunk and regional route while nothing change in feeder route. The result and benchmark are shown in Figure 3. When transportation cost on trunk route and regional route are reduced, volume of directly transported cargo decrease and transshipment volume increase. Although traded container volumes between each country pair are given and fixed, total handled volume increase corresponding to the increase of transshipment volume. Quite many cargoes are transshipped in China due to its high economy of scale. China seems to be growing stronger than ever in this region. Transshipped volume in Japan also increases due to geographical advantage in Asia-North America trade. Singapore gains a little more transshipment cargo as well.

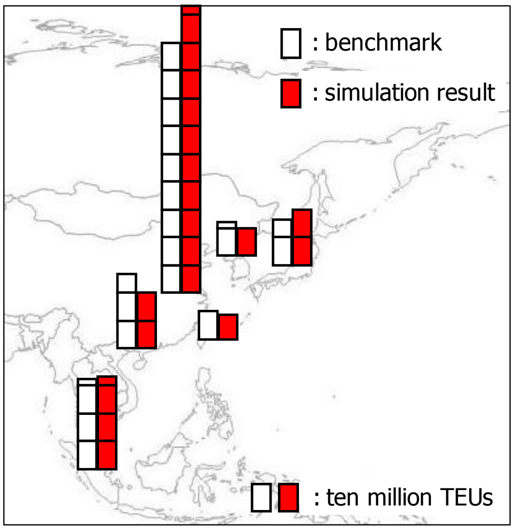

Figure 3 Simulation result (increase in vessel size)

5.3 Rises in Fuel Prices

Crude oil price soared to more than triple in the first decade in this century. We assume that fuel cost is tripled and it causes that transportation costs are increased 50% on all route. The result and benchmark are shown in Figure 4. Entire trend of impact is similar to previous example. Fixed rate overall transport cost rising widens the gap between the cost of larger vessel and small vessel. It works to larger vessel's advantage. Therefore volume of directly transported cargo decrease and transshipment volume increase.

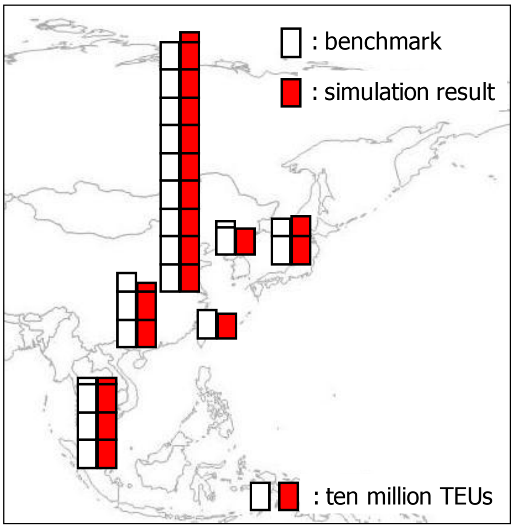

Figure 4 Simulation result (rise of fuel price)

6. CONCLUSION

This paper developed Asian container cargo transportation model including multi-layer transportation network and economy of scale. The solution procedure is suggested and validated. Since the suggested procedure is a simple searching algorithm, we can hardly to obtain a global optimum but one of local optimum. However, comparably reasonable solutions are obtained in the applications. Current actual situation may be regarded as reasonable and not deflected.

Both two likely simulation results show same direction that is increase of transshipment and further concentration at hubs. It is meaningful and considerable result for a discussion not only on port policy and maritime policy but also on strategy of carriers and shippers.

Followings are remained as future study. Parameters should be given by using more reliable data to improve reproducibility of the model. Solution procedure should be reconsidered and improved if needed in order to apply to other regions or other fields.

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