Optimal feeder ship size in Northeast Asia : a ship operator's perspective

Thesis submitted as a partial fulfillment to obtain the degree of
M.Sc. in Transport and Maritime Management

Academic year 2008-2009

Promoter : Prof. Dr. Wout Dullaert

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DECLARATION ON PLAGIARISM – Academic year 2008-2009

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DATE: 24th April 2009

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ABSTRACT

Key words : Optimal, Feeder ship size, Hub-and-spoke, Northeast Asia, Operation costs

The growth of the global economy, driven by the strong performance of Asian countries, especially China, has given rise to an increase of the world container volume. Major container shipping liners have ordered large container vessels to minimize unit shipping cost through economies of scale. In the era of global financial/economic crisis, however, shipping companies face difficulties to deploy proper-sized vessels due to demand fluctuations. They intended to replace existing container vessels with bigger vessels before the crisis. Currently however, they adjust shipping schedules and re-deploy their existing vessels to cope with demand decreases.

The aim of this thesis is to address the issue of the optimal feeder ship size in Northeast Asia, a topic which has been overlooked in the academic literature. It is, however, worthwhile to analyze feeder ship size in a hub port feeder network, because relatively few studies have been devoted to an analytic, detailed examination of feeder container liner services. This study analyzes the optimal feeder ship size for Pusan port, a hub port in Northeast Asia, dominated by transshipment, from a feeder ship operator's perspective. Factual information such container liner schedules, chartering rate and nautical distance between ports has been collected by the author and a number of model assumptions are made to construct an analytical model for analyzing optimal feeder ship size inspired by Ng and Kee (2008).

The analysis shows that the optimal ship size for the Qingdao, Dalian, Shanghai and Tianjin ports are 744 TEU, 963 TEU, 655 TEU and 655 TEU respectively, while the currently deployed average ship size for the Qingdao, Dalian, Shanghai and Tianjin ports are 615 TEU, 611 TEU, 756 TEU and 703 TEU respectively. For Hakata, Osaka, Yokohama and Tokyo feeder ship sizes of 342 TEU, 702 TEU, 700 TEU and 588 TEU seem more appropriate. The current average ship size for the Hakata, Osaka, Yokohama and Tokyo are 329 TEU, 387 TEU, 449 TEU and 523 TEU respectively. Finally, the findings of this paper confirm that every port has its own optimal size of feeder ships and ship capacity differences remains between currently deployed vessels and optimally sized ships. It seems that ship operators need to consider a vessel fleet replacement with large vessels to operate at the lowest possible unit cost.

Table of Contents

Table List

Figure List

LIST OF ABBREVIATIONS

CHB : CHIBA
DLC : DALIAN
HKT : HAKATA
KAN : KWANGYANG
KWS : KAWASAKI
LKU : LONGKOU
LYG : LIANYUNGANG
MAS : MASAN
MIZ : MIZUSHIMA
MOJ : MOJI
NGB : NINGBO
NGO : NAGOYA
OSK : OSAKA
PUS : PUSAN
SHA : SHANGHAI
SHD : SHIDAO
TAK : TAKAMATSU
TAO : QINGDAO
TXG : TIANJIN
TYO : TOKYO
UKB : KOBE
USN : ULSAN
YOK : YOKOHAMA
YTN : YANTAI

1. Introduction

The growth of global economy, driven by the strong performance of Asian countries, has given rise to an increase of the world container volume. Major container shipping liners have ordered large container vessels to minimize unit shipping cost through economies of scale. The concept of container vessel over 18,000 TEU, with a Length Over All (LOA), breadth and draft of 400 meters, 60 meters and 21 meters respectively exists. In practice, Vessels with 11,000 TEU capacity, 397 meters length, 56 meters breadth and 15.5 meters draft, such as Emma Maersk are already for a while in operation.

Even though the size of these large container vessels is restricted by port facilities limitations, shipping liners prefer to deploy them in certain services in order to exploit economies of scale. Such large ships resulted in inevitable selective port calling to minimize turnaround time of vessels and had influence on a maritime hub-and-spoke container network.

Deploying a right-sized vessel and establishing cost minimizing fleets in a container liner service route is very important for shipping companies. Many stakeholders are involved in achieving a better utilization at a lower cost per TEU with vessels; not only shipping companies and terminal operators but also government agencies and port authorities are involved. Accordingly, many studies related to hub ports have been published on topics such as optimal size of large containerships, the hub port location problem and routing container vessels. On the contrast, topics related to the optimal feeder ship and feeder networks have been overlooked even though feeder service is of a comparable significance in a maritime hub-and-spoke network.

Due to the recent global financial/economic crisis, shipping companies are also facing difficulties in balancing supply with demand. As is well known, supply of shipping capacity is affected by new building and scrapping of ships during the same period. Besides, vessel speed such as slow steaming also impacts supply. According to AXS-Alphaliner liner shipping database (accessed February 2009) 1,100,000 TEU are currently believed idle. Idle ships in the 1,000 TEU ~ 2,000 TEU range amount to 104 ships, for the 500 TEU~1,000 TEU range amounts 88 ships, in the 3,000 TEU~5,000 TEU range 78 ships are idle, 61 ships in the 2,000~3,000 TEU range, in the 5,000TEU~7,500 TEU range 42 ships and finally in 7,500 TEU~10,000 TEU range 19 ships were idle in February 2009. According to AXS-Alphaliner, these idle figures are worst figures recorded since the start of liner shipping services.

Especially feeder service operators, which are often small to medium sized companies, have more difficulties in securing demands and in deploying right sized vessels compared to the major shipping liners operating on trunk routes. Feeder service operators are more risk averse, in part because of their weaker financial position. To overcome the recent recession, they are not only considering shipping schedule adjustments but also lay-up, sell-off and demolition of their ships.

The aim of this thesis is to suggest the optimal feeder ship size for shipping services in Northeast Asia. Data on the shipping schedules is collected both from AXS-Alphaliner, which is based on annual service, and from the Schedulebank database, which consigners are using in practice.

As we shall see later, it is worthwhile to analyze the optimal feeder ship size because relatively few studies have been devoted to an analytic, detailed examination of feeder container liner service and feeder services influences on a hub-and-spoke system as well as being affected by a hub port.

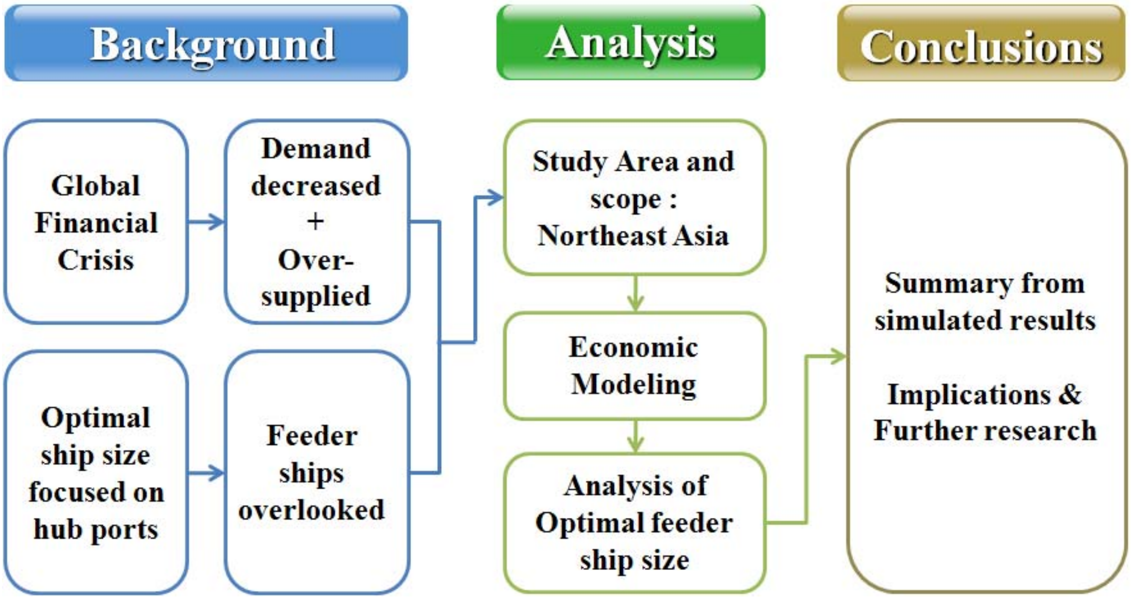

Figure 1. Structure of the study

Source : own representation

This paper begins by presenting a brief literature review on optimal ship size. Section 3 defines the scope of this research consisting of feeder services in Northeast Asia focusing on China, Korea and Japan. Section 4 analyzes the optimal feeder ship size for Pusan port, a hub port in Northeast Asia, dominated by transshipment, from a feeder ship operator's perspective. In this section, factual information such as container liner schedule, chartering rate and nautical distance between ports will be examined and some assumptions are made to facilitate model construction. The modeling framework applied in this paper is based on the model of Ng and Kee (2008). Finally, section 5 presents conclusions, managerial implications and direction for further research.

2. Literature review

Optimization problems deal with minimizing or maximizing an objective function subject to side constraints such as time, costs, resources and etc.

Applying this methodology to container vessels, optimal ship size could be determined, according to general economic theory: , exploiting economies of scale, a lower average unit cost achieved by deploying ships with a large carrying capacity (Ng and Kee, 2008).

There have been many studies in optimal ship sizes and most of them were aim at finding the lowest unit cost in terms of ship operation costs. For instance, McConville (1999) demonstrates the cost structure of a hypothetical ship, which consists of fixed and variable costs depends on whether the item concerned varied with operational period. In the short run, the operational costs consist of repairs, maintenance and daily running costs, which are partially fixed and of additional crew expenses, which is classified as partially variable costs. Note that, however, according to general economic theory, in the long term, fixed costs would become variable costs and the limitation of timeframe was crucial in determining which costs should (not) be categorized as fixed costs within a certain time period (Ng and Kee, 2008).

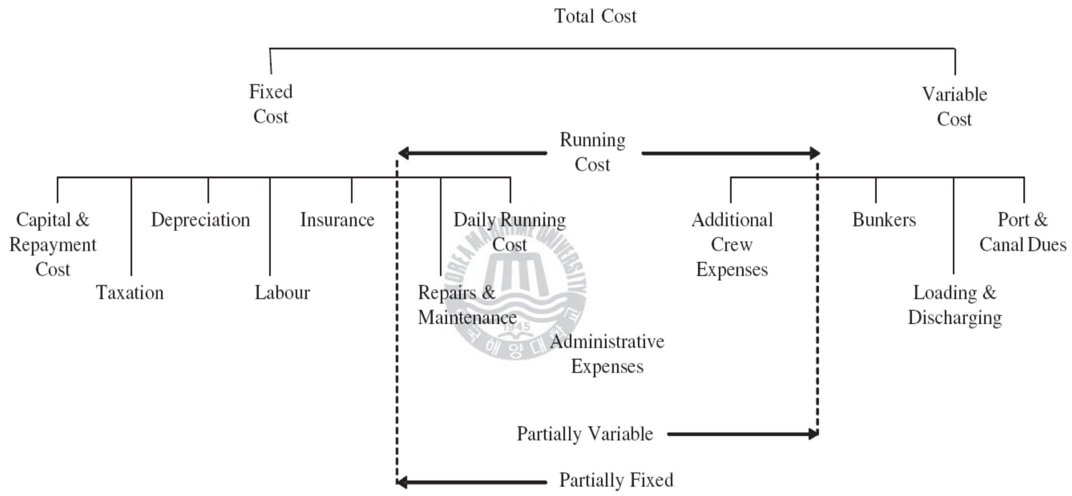

Figure 2. The cost structure of a hypothetical ship
Source : McConville (1999)

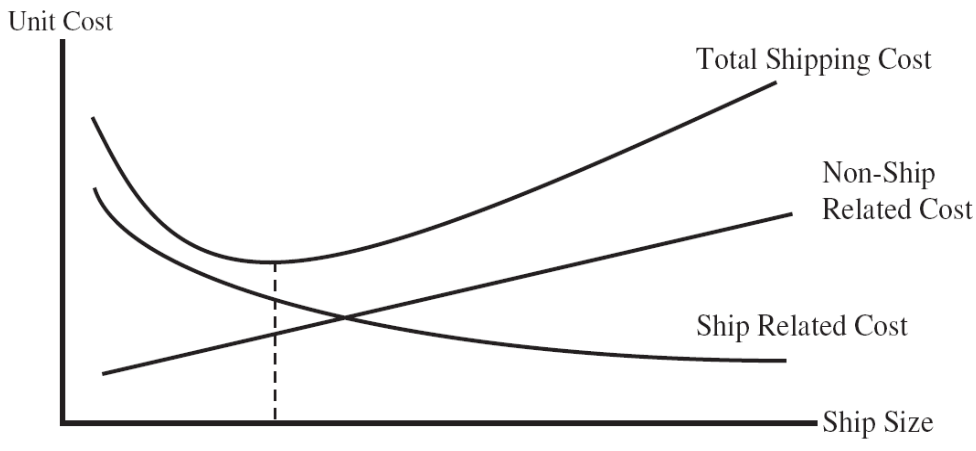

Figure 3. The total shipping cost including ship and non-ship related components
Source : Kendall (1972)

For determining the optimal ship size, all ship related costs (i.e. total shipping costs) should be considered, consisting of ship operating costs, and non-ship related costs indicating port dues, handling costs in the ports and inventory holding costs. As shown in Figure 3. the large ship can carry more shipments at lower unit costs to the ship operators because of economies of scale. For shippers, on the other hand, when reducing the frequency of the sailings and deploying the large ship, it will increase inventory costs since large ship carries more transit cargoes. This paper will focus on analyzing optimal feeder ship size from the perspective of the ship operator only.

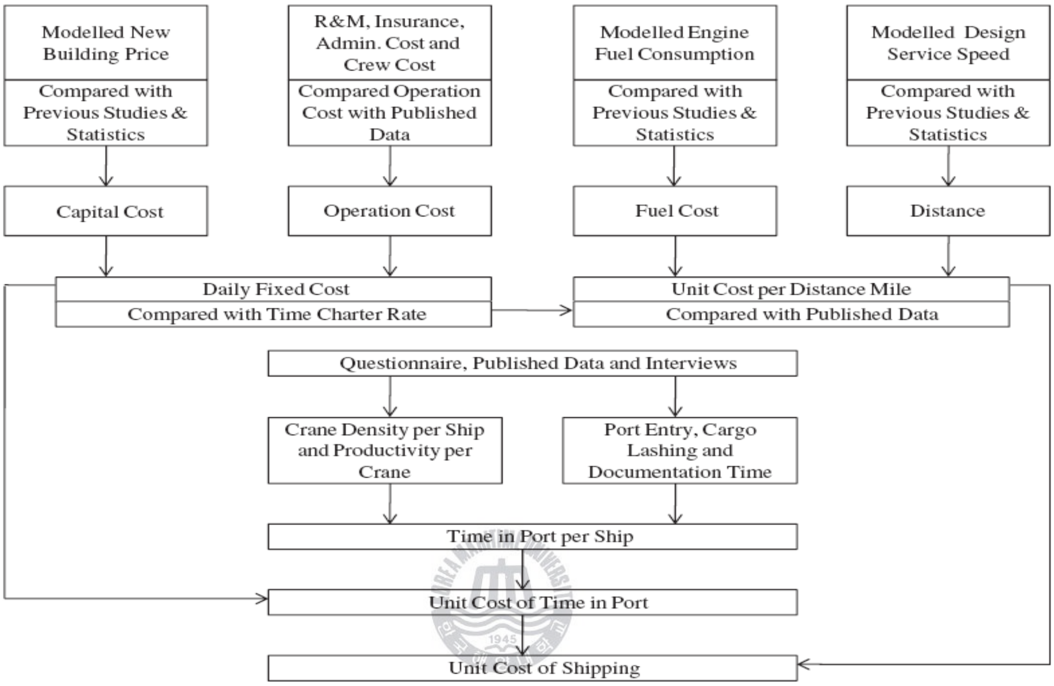

Figure 4. The Cullinane and Khanna model in calculating shipping cost
Source : Cullinane and Khanna (2000)

Cullinane and Khanna (2000) provide a model for calculating shipping costs detailed in Figure 4. This model comprises of daily fixed cost and operational unit cost. Especially, operational unit cost was investigated how cost varied in relation to voyage distance. This model has received much academic attention since the authors also attempted to include non-ship related costs generated in ports area in their model.

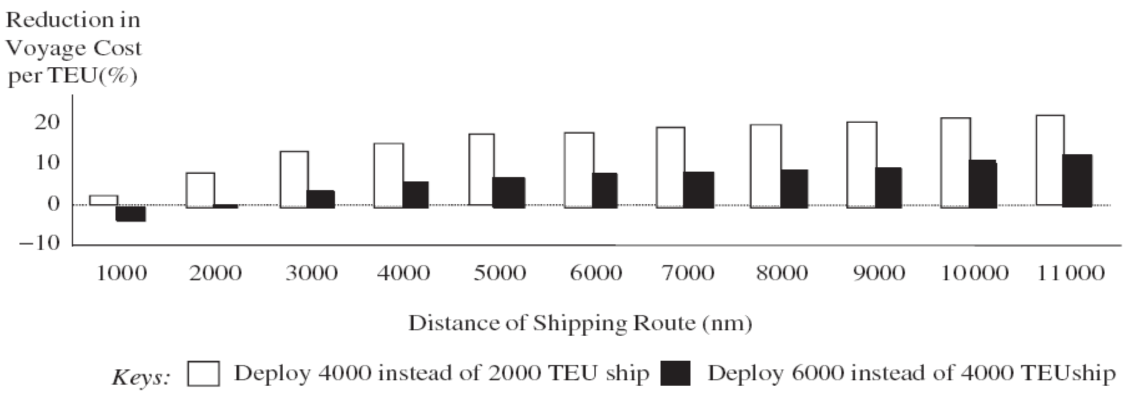

Figure 5. The relations between ship sizes, distances of shipping route and voyage costs
Source : Cullinane and Khanna (2000)

In spite of such improvement, they focused on analysis on long haul nature. Given that distances in a hub-and-spoke network are less than the minimum distance 1,000 nm considered in Cullinane and Khanna (2000), it appears appropriate to also study feeder ships operating in short haul of less than 1000 nm.

Optimal ship size is decided by not only the operational costs of the ship on certain service routes but also by the infra/ superstructure of ports, i.e. water draught, berth length, quay crane's reach and etc. In other words, it is impossible to get economic benefits from deploying container vessels with large carrying capacities without improving physical facilities of ports or terminals.

Table 1
The dimensions of containerships with different container carrying capacities

Ship carrying Capacity (TEUs)	LOA (m)	Beam (m)	Maximum water Draught (m)
1100	155.0	25.3	-9.5
1750	190.5	27.8	-10.6
2200	198.6	30.2	-11.0
2840	216.8	32.2	-12.3
4300	292.0	32.2	-13.5
6000	318.2	42.8	-14.5

Source : Almec corporation (2002)

Finally, Ng and Kee (2008) address the optimal ship sizes of container liner feeder services in Southeast Asia from a ship operator's perspective. A well-developed ship size modeling is used to the minimize unit FIO (Free In, Free Out) cost per TEU of current feeder container ships. FIO cost means that the freight cost for transporting cargo between two ports excludes any cargo handling charges incurred in both ports. This paper focused on the demands to sustain liner service. As already mentioned in introduction section, the global economic crisis has created serious imbalance between supply and demand, and this demand decrease should inevitably be considered when determine the optimal ship size.

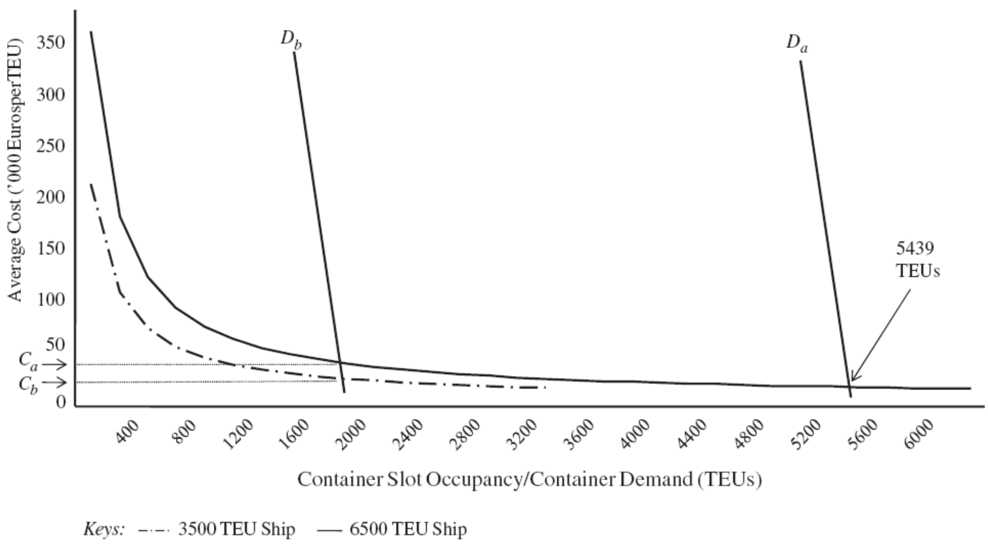

Figure 6. An example illustrating the relations between demands and optimal ship sizes
Source : Ng and Kee (2008)

As shown in Figure 5, Ng and Kee (2008) articulate that a containership with a carrying capacity of 6500 TEUs needed to achieve a load factor of at least 84% (about 5,439 TEUs) in order to equal the unit cost of a fully loaded containership with only a carrying capacity of 3500 TEUs, i.e. the threshold of which the benefits of economies of scale could be realized. Any quantity demand smaller than that, say, 2000 TEUs, would result in the unit cost of operating a bigger containership with low load factor (C_a) being less economical than using a smaller one but with higher load factor (C_b).

Many literature reviews focused on shipping costs when determine the optimal ship size, especially deep-sea large ship and long haul service. In the changing from direct service to hub-and-spoke system, it is true that the studies on feeder service have been largely ignored. In this paper, the optimal feeder ship sizes in Northeast Asia that have not been examined to date will be examined by the economic model of Ng and Kee (2008).

Table 2

Summary of literature review

Title	Author	Features
A theory of optimum ship size	Kendall (1972)	Optimal ship size is determined by both non-ship related cost and ship related cost.
Economics of Maritime Transport : Theory and practice	McConville (1999)	The cost structure of a hypothetical ship is divided into fixed cost and variable cost.
Economies of scale in large containerships : optimal size and geographical implication	Cullinane and Khanna (2000)	Shipping costs consist of daily fixed unit cost, operational unit cost and time cost in relation to voyage distance.
The optimal ship sizes of container liner feeder services in Southeast Asia : a ship operator's perspective	Ng and Kee (2008)	Optimal ship size is restricted by port facilities, adequate demands.

Source : own representation

3. Study area and scope

Huge sea-born trade volumes have been generated from / to China since China has joined the WTO in 2001. China influenced neighboring countries to develop port infra/ superstructures due to the deficiency of Chinese port facilities. As a consequence, the transpacific route between Far East and North America has the biggest container volumes, which recorded about 20 million TEUs in 2007 according to Drewry.

(Unit : `000 TEUs)

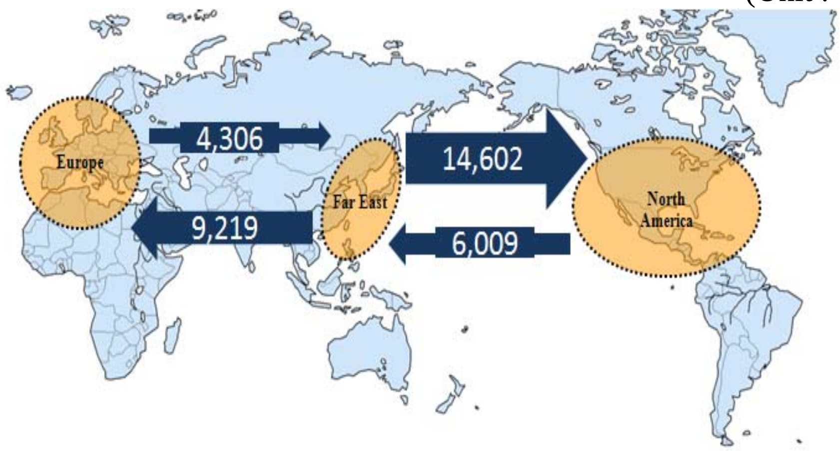

Figure 7. Estimated container trade comparison by route

Source : Drewry (2007)

The study area in this paper is Northeast Asia that focuses on North Chinese ports and Japanese ports, which have plenty of contribution to Pusan port of South Korea, transshipment dominated port in Northeast Asia. For that reason, this study will focus on feeder ships serving the routes between North Chinese ports from / to Pusan port and Japanese ports from / to Pusan port. Accordingly, the chosen ports for this area consist of Qingdao, Tianjin, Shanghai and Dalian (North China) and of Hakata, Osaka, Yokohama, Tokyo (Japan).

Table 3

Total container volumes with Pusan port (2007)

Region	Port	Volume (TEUs)
North China	Qingdao	678,000
	Tianjin	571,000
	Shanghai	564,000
	Dalian	353,000
Japan	Hakata	245,017
	Osaka	174,473
	Yokohama	163,559
	Tokyo	134,693

Source : Busan Port Authority (2008), Korea customs office (2008)

Figure 8. Chosen ports in Northeast Asia

According to Yellow Sea Liners Committee of Korea, container volume from China to Korea recorded 1.51 million TEUs in 2008. It was decreased by 7.2% comparing to year of 2007 due to global economic crisis and exchange rate increase. The volume from Korea to China recorded 0.92 million TEUs in 2008. This figure was a little decreased by 1.8% comparing to year of 2007.

Shipping liners serving Chinese routes have heavily suffered from demand decreases especially from Korea and Japan to China. Due to demand decreases, freight rate of east bound which had kept about 150 USD per TEU almost reached to zero. Korean shipping liners are struggling to keep the freight rates at about 50 USD per TEU. On the other hand, Chinese shipping liners that relatively have more difficulties to attract cargoes than Korean companies even cannot charge 50 USD to shippers. Therefore there are lively discussions on reducing shipping capacities and adjusting shipping schedules on the long-term basis. Shipping liners are simultaneously reducing their capacities by themselves.

Container volume between Korea and Japan recorded 1.35 million TEUs. It was decreased by 2.7% comparing to year of 2007. Volumes from Korea to Japan and from Japan to Korea were 0.76 million TEUs by 1.4% decrease and 0.59 million TUEs by 4.2% decrease respectively. The freight rate of Korea – Japan routes is stable because of the Ceiling Institution, which is a treaty between feeder shipping liners to keep reasonable freight rate to cope with the situation against demand decrease. Accordingly, freight rate of east bound, from Pusan to Japan, is approximately 300~350 USD per TEU as of February 2009 and actual freight rate is anticipated higher than informed rate since shipping liners are charging separately BAF (Bunker Adjustment Factor) to shippers. Relatively, decreasing rate of west bound volume from Japan to Pusan was steep and freight rate recorded about 200 USD per TEU.

Feedering is either carried out by common feedering, which is independent carriers, the common or third party feeder operators and dedicated feedering, which are the mainline carriers themselves. The common feeder carrier does not operate a container fleet. Feeder operators diversifying into the carriage of local cargoes usually start off by using their principal's to be repositioned empty containers and/or transporting shippers owned containers. Dedicated feeder operations usually achieve a higher efficiency, as they only have to deal with the own cargo of the mainline operators (Dynamar B.V., 2007).

As indicated in Table 5, the average age, TEU capacity and speed of common feeder ships in Northeast Asia are 13.2 years, 700 TEUs and 16 knots respectively. The average specifications of dedicated feeder ships are 14.9 age, 1,360 TEUs and 18.2 knots.

Table 4
Specifications of Feeder ship in Northeast Asia

	Carriers	Ships	Age	TEU	DWT	Speed
Common feeders [1)]	34	142	13.2	700	11,100	16.0
Dedicated feeders [2)]	13	53	14.9	1,360	20,500	18.2

Note : 1) Independent carriers, the common or third party feeder operators
2) The mainline carriers themselves
Source : Dynamar B.V. (2007)

(Unit : `000TEUs)

Figure 9. Container volumes in Northeast Asia (2008)
Source : Shipping Conference And General Administration, Yellow Sea Liners Committee

As indicated in Figure 8., The route between China and Japan had the biggest volumes, which recorded about 3 million TEUs in 2008 and the route between Korea-China and Korea-Japan recorded 2.4 million TEUs and 1.3 million TEUs respectively. In this regards, it is anticipated that the feeder ship sizes and service frequencies between China and Japan are bigger and more frequent than other routes in Northeast Asia.

The reasons for choosing Northeast Asia as feeder service area are as follows. First, as discussed above, China is influencing on neighboring countries and in a maritime hub-and-spoke system. Second, Pusan port is transshipment dominated port in Northeast Asia and the container shipping liners still rely on Pusan port as a hub port in this area because of the reliable and efficient service. More than 30 feedering service companies are calling at Pusan port to offer services from / to Pusan port in Northeast Asia.

Table 5
Feeder connections of transshipment hub ports

Port	Dedicated feeders	Common feeders
Hong Kong	16	23
Kaohsiung	13	12
Pusan	8	24

Source : Dynamar B.V. (2007)

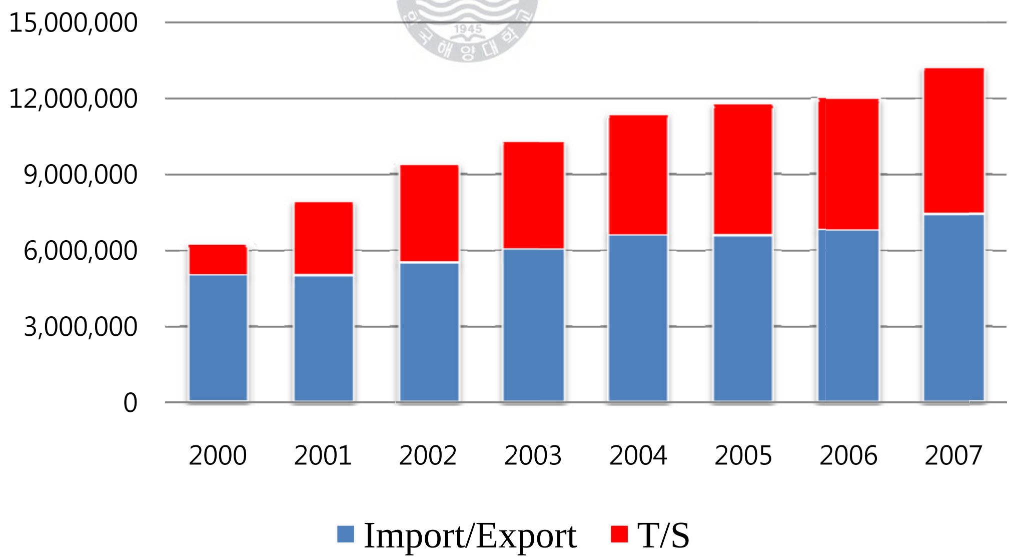

Figure 10. Annual container volume of Pusan port
Source : Busan Port Authority

Transshipment amount of Pusan port occupied about 40 % of whole container volume from 2003. Busan Port Authority and Korean government have been struggling to generate local cargoes and transshipment cargoes by developing hinterland and giving incentives to shipping liners. It is true, however, that China government has been enormously investing in port infra/superstructures to meet plenty of container volumes. Consequently, transshipment cargoes had moved from Pusan port to North Chinese ports because deep sea container liners decided to directly call at North Chinese ports rather than spending on time and costs for feedering service in Pusan port. As is well known, nonetheless, transshipment cargo is not only footloose but also volatile. According to the announcement of Ministry of Land, Transport and Maritime Affairs of South Korea, New world Alliance (APL, MOL) and Grand Alliance (NYK, Hapag-Lloyd, OOCL) are coming back to Pusan port because of reliable service. Finally, topics on optimal feeder ship size in Northeast Asia have received relatively little attention in comparison with such fields of large container vessels of deep sea container lines. Given the glaring lack of studies on feeder ship, this study can be seen as the first in Northeast Asia.

4. Optimal feeder ship size

This section introduces parameters for modeling and accordingly displays the simulated optimal feeder ship size in Northeast Asia by country. Simulated feeder services in North east Asia include only intra-Northeast Asia services, which are Northern part of Chinese ports including Shanghai and Ningbo and all Japanese ports. The feeder services calling at Southeast Asia such as Singapore, Hong kong and Bangkok are not included.

The economic modeling introduced by Ng and Kee (2008) is slightly adjusted to classify fuels at sea and port since every vessel does not use same fuel at sea and at port. This model is developed to analyze the optimal feeder ship size in Northeast Asia from a ship's operator's perspective. Every expense such as port dues, bunker price, etc. except cargo handling charges at ports is used. This modeling enables to rather easily analyze the optimal feeder ship size with variety components. The objective consists of searching for the lowest shipping cost per TEU, including both ship and non-ship components, i.e. the lowest point of the U-shaped curve, as shown in Figure 3. To facilitate model construction, it is assumed that sailing frequency of the feeder service would be 365 services per year. In this modeling, the assumptions are as follows;

(a) Container vessels are on time charter basis and ship operators have complete freedom to choose the best available ships in the market for deployment. The reason of using time charters as a basis is that it is difficult to get the costs of shipbuilding and operation due to confidentiality matters. Besides, the market charter rate gives a good reflection of the current market conditions
(b) Ship operators have no interests in other activities other than container vessel operation.
(c) The operational cost of ships would be expressed cost per TEU (in US$) incurred during a round voyage. Any cargo handling charges occurred at both transshipment and feeder ports are excluded.
(d) Inventory cost is not considered because ship operators were not same as the cargo owners in container transport. Besides, crew expenses, maintenance and repairs are not included because time charters are used.
(e) The voyage distance is indicated in nautical mile (nm) and ship's service speed (in knots) is applied according to the vessel's actual speed, which is obtained from AXS-Alphaliner. The time to berth and approach the terminal, which is controlled by the Port Authority pilot is negligible. Besides, ship's fuel consumption at sea is applied in accordance with data from AXS-Alphaliner and fuel consumption at port is ignored as it is relatively small and very difficult to obtain.

$$\text{Min}\overline{\text{Q}} = \frac{\text{N}_{\wp}\left\{\begin{array}{c}\text{P}_c\left(\sum_{m=1}^{\text{M}} \text{T}_m + \sum_{\text{s}=1}^{\text{S}} \text{T}_\text{s} + \sum_{\wp=1}^{\text{P}} \text{T}_\wp\right) \\ + \text{P}_{\text{b}1}\left(\text{F}_m \sum_{\wp=1}^{\text{P}} \text{T}_m\right) + \text{P}_{\text{b}2}\left(\text{F}_\wp \sum_{\wp=1}^{\text{P}} \text{T}_\wp\right) + \text{P}_e + \sum_{\wp=1}^{\text{P}} \text{P}_\wp\end{array}\right\}}{2\text{GN}_\text{t}}$$

s.t.

$$\text{F, G, N, P, T} > 0$$

Where $\text{N}_\wp$ is the nautical distance between hub and feeder port (in nm); N_t is the turnaround voyage distance (in nm); G is the indicated ship capacity, with effective capacity at 14mt per TUE (in TEUs); P_c is daily charter rate (in US$ per day); F_m and $\text{F}_\wp$ are the fuel consumption rates at sea and port respectively (in tones per hour); T_m is the time navigating on the sea ($N_{\wp}$/speed) (in hours), T_s is the time berthing in port (in hours), $T_{\wp}$ is the time navigation within the port regions (in hours); P_e is all other ship operation expenses throughout the turnaround journey (in US$); P_{b1} is the unit bunker price at sea (in US$ per tonne), P_{b2} is the unit bunker price at port (in US$ per tonne). Cargo handling cost occurred to load and unload containers is excluded.

Shipping schedules applied into modeling are from both AXS-Alphaliner and Schedulebank data (accessed in March 2009) to compensate the deficiencies of the information. Ship's specifications such as gross tonnage, net tonnage, nominal TEU capacity, effective capacity (14mt per TEU), fuel consumption, speed and etc. are obtained from AXS-Alphaliner website (accessed in March 2009). Charter rate and port expenses such as tonnage due, port due, pilotage and tuggage are based on the information from a shipping company in Korea. The bunker price is obtained from www.bunkerworld.com (accessed in March 2009) and nautical distance between ports comes from Dataloy system www.dataloy.com (accessed in March 2009).

4.1 North Chinese ports

The simulated results of Pusan-Qingdao, Pusan-Tianjin, Pusan-Shanghai and Pusan-Dalian cases are described in this section. Those ports were chosen because of their large share in the container volumes in Pusan port. Tianjin port is the farthest located from Pusan port and Shanghai port is the most close to Pusan port and recorded the busiest port in the world in 2008.

Navigation hours in Table 6 are calculated based on average service speed, which has been mentioned as 17 knots/ hour in Northeast Asia on Dynamar B.V. (2007) and each different speed of vessels is applied in accordance with real-life data in modeling.

Table 6
Port Distance between Pusan and North Chinese ports

	Qingdao		Tianjin		Shanghai		Dalian	
	nm	hours	nm	hours	nm	hours	nm	hours
Pusan	514	30.24	745	43.82	501	29.47	591	34.76
Qingdao			434	25.53	445	26.18	280	16.47
Tianjin	-				730	42.94	208	12.24
Shanghai			-				576	33.88
Dalian					-		-	

Source : Dataloy
Note : nm – Nautical Mile , Service Speed – 17 knot

4.1.1 Pusan – Qingdao

As displayed in Table 7, a total of 21 container vessels was deployed in March 2009 between Pusan and Qingdao and the average ship capacity (14mt per TEU) for Qingdao was 615 TEUs. The nearest average size is 600TEUs, with $\overline{Q}$ equal to USD 128 as shown in Table 8. The largest deployed vessel is 963 TEUs (effective carrying capacity at 14 metric tonnes per TEU). The range of deployed ship size varies from 350 TEUs to 963 TEUs. Due to the data's confidential nature, vessel names are denoted by Roman numerals.

Table 7
The deployed feeder container vessels between Pusan and Qingdao

Vessel Name	Service Route	Effective carrying capacity (in TEUs)
I	pus/txg/dlc/tao/ngb/sha	350
II	pus/tao	350
III	pus/txg/dlc/tao/ngb/sha	370
IV	pus/lyg/tao	410
V	pus/kan/dlc/tao/	436
VI	pus/kan/tao	491
VII	pus/tao	492
VIII	pus/txg/dlc/tao/ngb/sha	504
IX	pus/tao	515
X	pus/lyg/tao/shd	600
XI	pus/tao/lyg	646
XII	pus/kan/tao	655
XIII	pus/kan/tao	655
XIV	pus/txg/dlc/tao/ngb/sha	710
XV	pus/txg/dlc/tao/ngb/sha	725
XVI	pus/tao	742
XVII	pus/usn/tao	744
XVIII	pus/ynt/tao	762
XIX	pus/tao	870
XX	pus/txg/dlc/tao/ngb/sha	933
XXI	pus/tao	963
Average size		615

Source : AXS-Alphaliner and Schedulebank website (Accessed March 2009)

As shown in the economic modeling formulation, shipping operation cost per TEU is not simply affected by ship's capacity but also by the routes serviced, nautical distance, ship speed and fuel consumption between ports. For this reason, we can find the point of diseconomy of scale in ship capacities. The cost per TEU shows the decreasing by the certain ship capacities and then the cost increases again due to the diseconomy of scales as displayed in Figure 11.

As shown by Table 8 and Figure 11, $\overline{Q}$ for Pusan – Qingdao for existing shipping service is USD 69, which means that 744 TEUs at 14 metric tonnes per TEU is optimal ship size for Pusan-Qingdao in terms of lowest operation costs. The modeled result seems to indicate that ship operators for Pusan – Qingdao can deploy slightly larger container vessels since average ship size is less than optimal ship size.

Table 8
Operation cost per TEU for existing shipping service for Qingdao

Vessel Name	Service Route	Effective carrying capacity (in TEUs)	Cost per TEU (US$)
VI	pus/txg/dlc/tao/ngb/sha	491	84
X	pus/lyg/tao/shd	600	128
XII	pus/tao	655	89
XIII	pus/txg/dlc/tao/ngb/sha	655	89
XVII	pus/lyg/tao	744	69

Source : AXS-Alphaliner, Own calculation

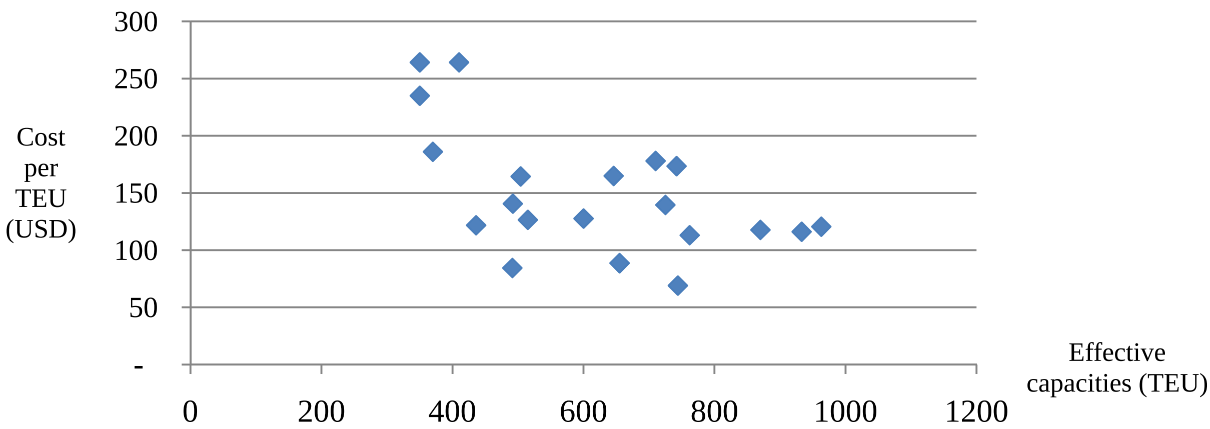

Figure 110. Pusan-Qingdao Cost per TEU with equal to ships effective capacity

4.1.2 Pusan – Dalian

As displayed in Table 9, a total of 24 container vessels was deployed in March 2009 for Pusan - Dalian and the average ship capacity (14mt per TEU) for feeder container vessels calling Dalian was 611 TEUs. The nearest average size is 609 TEUs, with $\bar{Q}$ equal to USD 177 as shown in Table 10. The largest deployed vessel is 1210 TEUs (effective carrying capacity at 14 metric tonnes per TEU). Due to the data's confidential nature, vessel names are denoted by Roman numerals.

Table 9
The deployed feeder container vessels between Pusan and Dalian

Vessel Name	Service Route	Effective carrying capacity (in TEUs)
I	pus/dlc	237
II	pus/dlc	239
III	pus/txg/dlc /tao/ngb/sha	350
IV	pus/dlc	350
V	pus/txg/dlc /tao/ngb/sha	350
VI	pus/txg/dlc /tao/ngb/sha	370
VII	pus/kan/dlc/tao	436
VIII	pus/txg/dlc /tao/ngb/sha	504
IX	pus/dlc	590

X	pus/dlc	609
XI	pus/kan/txg/dlc	623
XII	pus/lku/txg/dlc	655
XIII	pus/dlc	655
XIV	pus/dlc	655
XV	pus/dlc	655
XVI	pus/txg/dlc	701
XVII	pus/txg/dlc	701
XVIII	pus/txg/dlc	701
XIX	pus/ytn/dlc	710
XX	pus/dlc	725
XXI	pus/usn/dlc	744
XXII	pus/txg/dlc/tao/ngb/sha	933
XXIII	pus/usn/kan/dlc	963
XXIV	pus/txg/dlc	1210
Average size		611

Source : AXS-Alphaliner and Schedulebank website (Accessed March 2009)

By applying model, $\overline{Q}$ for Pusan – Dalian for existing shipping service is USD 56, which means that 963 TEUs at 14 metric tonnes per TEU is optimal ship size for Pusan – Dalian in terms of lowest operation costs. The model outputs seem to indicate that ship operators who have plan to adjust vessel deployment for Pusan – Dalian can deploy larger container vessels since average ship size is less than optimal ship size.

Table 10

Operation cost per TEU for existing shipping service for Dalian

Vessel Name	Service Route	Effective carrying capacity (in TEUs)	Cost per TEU (US$)
VII	pus/kan/dlc/tao	436	124
X	pus/dlc	609	177
XXI	pus/usn/dlc	744	79
XXIII	pus/usn/kan/dlc	963	56
XXIV	pus/txg/dlc	1210	150

Source : AXS-Alphaliner, Own calculation

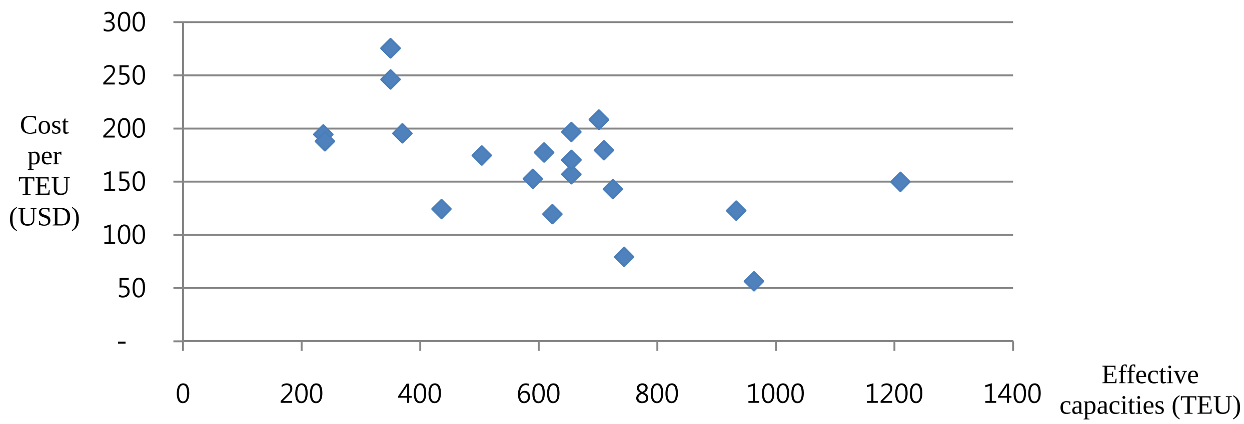

Figure 12. Pusan-Dalian Cost per TEU with equal to ships effective capacity

4.1.3 Pusan – Shanghai

As shown in Table 11, a total of 34 container vessels was deployed in March 2009 for Pusan - Shanghai and the average ship capacity (14mt per TEU) for Shanghai was 756 TEUs. The average feeder size of Shanghai is larger than other ports. It seems that ship size is affected by port volume of Shanghai, the world busiest port. The nearest average size is 762 TEUs, with $\overline{Q}$ equal to USD 86 as shown in Table 12. The largest deployed vessel is 2,031 TEUs effective carrying capacity at 14 metric tonnes per TEU. Due to the data's confidential nature, vessel names are denoted by Roman numerals.

Table 11
The deployed feeder container vessels between Pusan and Shanghai

Vessel Name	Service Route	Effective carrying capacity (in TEUs)
I	pus/sha	305
II	pus/txg/dlc/tao/ngb/sha	350
III	pus/txg/dlc/tao/ngb/sha	350
IV	pus/txg/dlc/tao/ngb/sha	370
V	pus/sha	379
VI	pus/kan/sha	396
VII	pus/sha	401
VIII	pus/sha	412
IX	pus/usn/kan/ngb/sha	450
X	pus/usn/kan/ngb/sha	450
XI	pus/txg/dlc/tao/ngb/sha	504
XII	pus/kan/sha	515
XIII	pus/usn/sha	614
XIV	pus/kan/sha	618
XV	pus/sha	620
XVI	pus/sha	621
XVII	pus/sha	623
XVIII	pus/usn/kan/sha	655
XIX	pus/usn/kan/sha	655
XX	pus/usn/sha	673
XXI	pus/usn/sha	673
XXII	pus/txg/dlc/tao/ngb/sha	710
XXIII	pus/txg/dlc/tao/ngb/sha	725
XXIV	pus/osn/sha/ngb	750
XXV	pus/ngb/sha	762
XXVI	pus/txg/dlc/tao/ ngb/sha	933
XXVII	pus/sha	957
XXVIII	pus/sha	1204
XXIX	pus/sha	1204
XXX	pus/sha	1,240
XXXI	pus/sha	1,240
XXXII	pus/sha	1295
XXXIII	pus/sha	2,031
XXXIV	pus/sha	2,031
Average size		756

Source : AXS-Alphaliner and Schedulebank website (Accessed March 2009)

By applying the model, $\overline{Q}$ for Pusan – Shanghai for existing shipping service is USD 62, which means that 655 TEUs at 14 metric tonnes per TEU is optimal ship size for Pusan-Shanghai in terms of lowest operation costs. The model results seem to indicate that ship operators for Pusan – Shanghai would better adjust vessel deployment by using smaller container vessels since average ship size is bigger than optimal ship size.

Table 12
Operation cost per TEU for existing shipping service for Shanghai

Vessel Name	Service Route	Effective carrying capacity (in TEUs)	Cost per TEU (US$)
XIV	pus/kan/sha	618	75
XIX	pus/usn/kan/sha	655	62
XX	pus/usn/sha	673	69
XXV	pus/ngb/sha	762	108
XXXIV	pus/sha	2,031	107

Source : AXS-Alphaliner, Own calculation

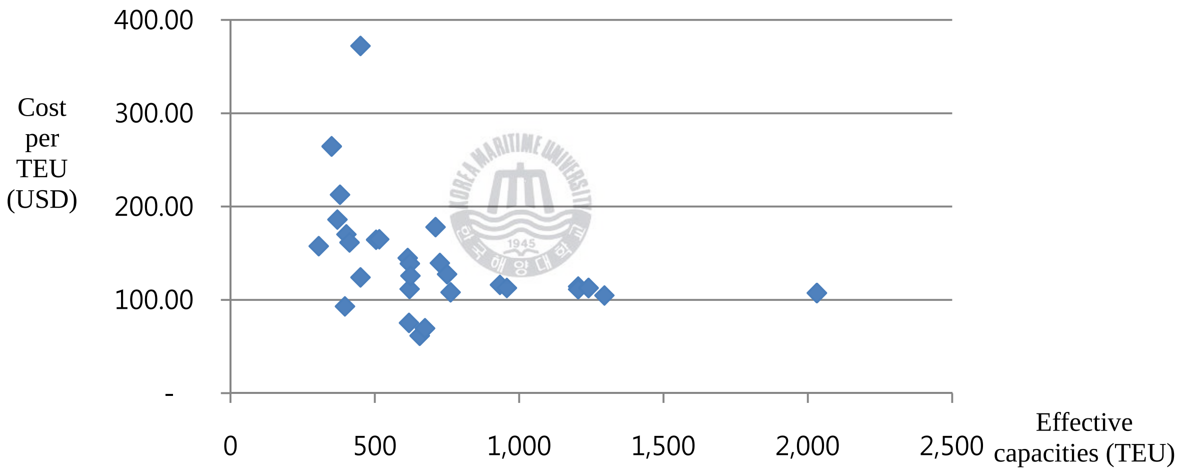

Figure 11. Pusan-Shanghai Cost per TEU with equal to ships effective capacity

4.1.4 Pusan – Tianjin

As shown in Table 13, a total of 21 container vessels was deployed in March 2009 for Pusan – Tianjin. The average ship capacity (14mt per TEU) for Tianjin was 703 TEUs. The nearest average size is 701 TEUs, with $\overline{Q}$ equal to USD 205 as shown in Table 14. The largest deployed vessel is 2417 TEUs (effective carrying capacity at 14 metric tonnes per TEU). Due to the data's confidential nature, vessel names are denoted by Roman numerals.

Table 13
The deployed feeder container vessels between Pusan and Tianjin

Vessel Name	Service Route	Effective carrying capacity (in TEUs)
I	pus/usn/txg	239
II	pus/kan/txg	338

III	pus/txg/dlc/tao/ngb/sha	350
IV	pus/txg/dlc/tao/ngb/sha	350
V	pus/txg/dlc/tao/ngb/sha	370
VI	pus/txg/dlc/tao/ngb/sha	504
VII	pus/usn/txg	590
VIII	pus/kan/uls/txg	600
IX	pus/kan/txg	623
X	pus/txg/dlc	655
XI	pus/usn/kan/txg	655
XII	pus/lku/txg/dlc	655
XIII	pus/txg/dlc	701
XIV	pus/txg/dlc	701
XV	pus/txg/dlc	701
XVI	pus/txg	710
XVII	pus/txg	725
XVIII	pus/txg	725
XIX	pus/txg/dlc/tao/ngb/sha	933
XX	pus/txg/dlc	1210
XXI	pus/dlc/txg	2417
Average size		703

Source : AXS-Alphaliner and Schedulebank website (Accessed March 2009)

The optimal feeder ship size for Pusan – Tianjin is USD 78, which means that 655 TEUs at 14 metric tonnes per TEU is optimal ship size for Pusan-Tianjin in terms of lowest operation costs. Similar to the situation for Shanghai, the model outputs seem to indicate that ship operators for Pusan – Tianjin would better adjust deployment with slightly smaller container vessels since average ship size is larger than optimal ship size.

Table 14

Operation cost per TEU for existing shipping service for Tianjin

Vessel Name	Service Route	Effective carrying capacity (in TEUs)	Cost per TEU (US$)
II	pus/kan/txg	338	97
VIII	pus/kan/uls/txg	600	90
XI	pus/usn/kan/txg	655	78
XIII	pus/txg/dlc	701	205
XXI	pus/dlc/txg	2417	126

Source : AXS-Alphaliner, Own calculation

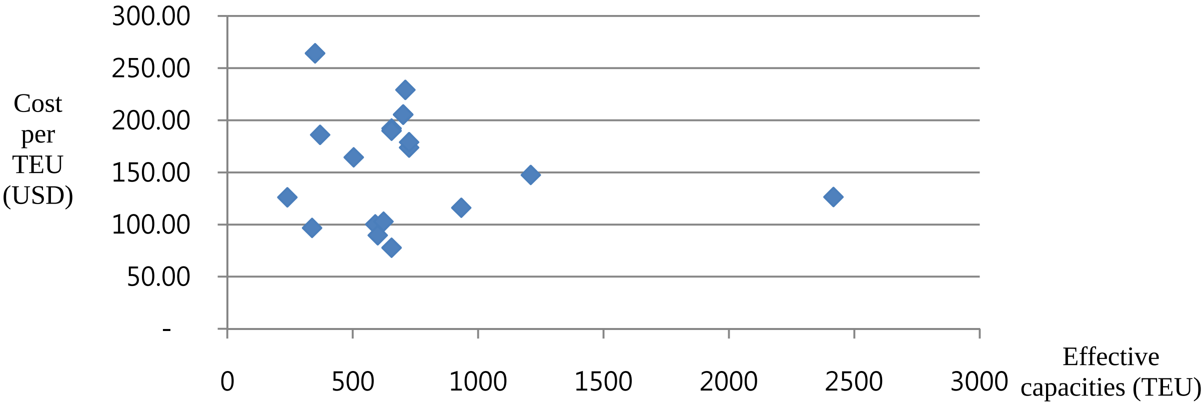

Figure 124. Pusan-Tianjin Cost per TEU with equal to ships effective capacity

4.2 Japanese ports

The model results for the main feeder connections, Pusan-Hakata, Pusan-Osaka, Pusan-Yokohama and Pusan-Tokyo cases are illustrated in this section. Average distance between Pusan and Japanese ports is shorter than North Chinese ports and container volumes between Pusan port are smaller than North Chinese ports. Feeder ship operators calling at Japanese ports are offering liner services showing a tendency to visit more ports during roundtrip than Chinese ports in order to secure more container volumes. Tokyo port is located the farthest away from Pusan port and is very close to Yokohama port. Hakata port is close to Pusan port, away from only 116 nm, which takes about 7 hours from Pusan port.

Navigation hours in Table 15 are calculated based on average service speed, which has been mentioned as 17 knots/ hour in Northeast Asia on Dynamar B.V. (2007) and each different speed of vessels is applied in accordance with practical data in modeling.

Table 15
Port Distance between Pusan and Japanese ports

	Hakata		Osaka		Yokohama		Tokyo	
	nm	hours	nm	hours	nm	hours	nm	hours
Pusan	116	6.82	368	21.65	664	39.06	676	39.76
Hakata			305	17.94	600	35.29	613	36.06
Osaka	-				362	21.29	375	22.06
Yokohama			-				22	1.29
Tokyo					-		-	

Source : Dataloy
Note : nm – Nautical Mile , Service Speed – 17 knot

4.2.1 Pusan – Hakata

As shown in Table 16, a total of 9 container vessels was deployed in March 2009 for Pusan - Hakata and the average ship capacity (14mt per TEU) for Hakata was 329 TEUs. The nearest average size is 329 TEUs, with $\overline{Q}$ equal to USD 27, which is the optimal ship size in terms of operation cost as shown in Table 17. The largest deployed vessel is 700 TEUs effective carrying capacity at 14 metric tonnes per TEU. Due to data's confidential nature, vessel names are denoted by Roman numerals.

Table 16
The deployed feeder container vessels between Pusan and Hakata

Vessel Name	Service Route	Effective carrying capacity (in TEUs)
I	pus/kan/mas/hkt	137
II	pus/moj/hkt	143
III	pus/hkt	143
IV	pus/hkt	240
V	pus/hkt	342
VI	pus/kan/moj/hkt	396
VII	pus/ukb/osk/ngo/hkt	398
VIII	pus/kan/moj/hkt	458
VIX	pus/hkt/yok/ngo/ukb	700
Average size		329

Source : AXS-Alphaliner and Schedulebank website (Accessed March 2009)

$\overline{Q}$ for Pusan – Hakata for existing shipping service is USD 27, which means that 342 TEUs at 14 metric tonnes per TEU is optimal ship size for Pusan-Hakata in terms of lowest operation costs. The model output seems to indicate that ship operators for Pusan – Hakata should keep the container vessels size in this service route.

Table 17
Operation cost per TEU for existing shipping service for Hakata

Vessel Name	Service Route	Effective carrying capacity (in TEUs)	Cost per TEU (US$)
I	pus/kan/mas/hkt	137	35
IV	pus/hkt	240	36
V	pus/hkt	342	27
VIII	pus/kan/moj/hkt	458	32
VIX	pus/hkt/yok/ngo/ukb	700	114

Source : AXS-Alphaliner, Own calculation

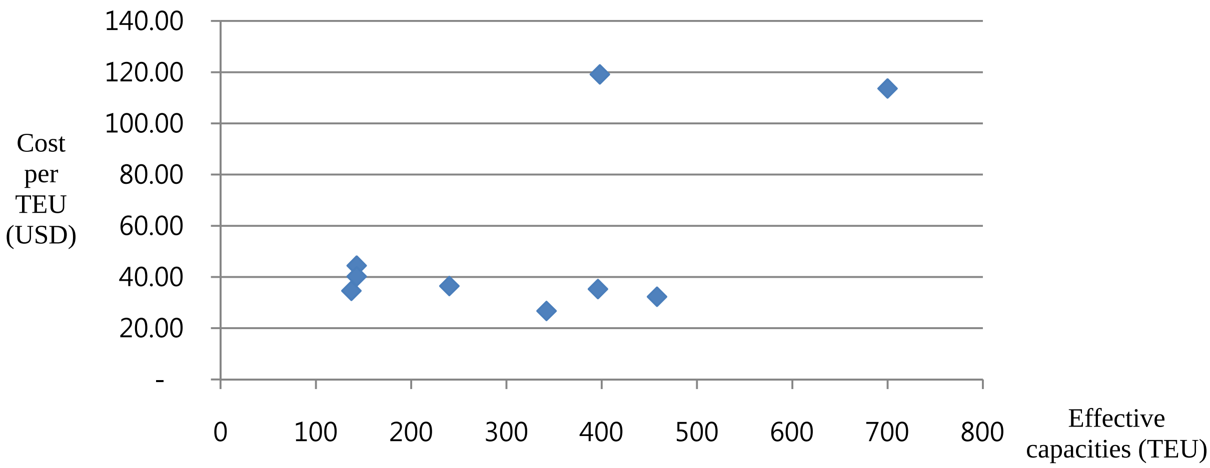

Figure15. Pusan-Hakata Cost per TEU with equal to ships effective capacity

4.2.2 Pusan – Osaka

As shown in Table 18, a total of 14 container vessels was deployed in March 2009 on the Pusan - Osaka route and with an average ship capacity (14mt per TEU) for Osaka is 387 TEUs. The nearest average size is 382 TEUs, with $\overline{Q}$ equal to USD 193 and this vessel is the optimal ship size as shown in Table 19. The largest deployed vessel is 800TEUs effective carrying capacity at 14 metric tonnes per TEU. Due to data's confidential nature, vessel names are denoted by Roman numerals.

Table 18
The deployed feeder container vessels between Pusan and Osaka

Vessel Name	Service Route	Effective carrying capacity (in TEUs)
I	pus/ukb/osa	56
II	pus/ukb/osa	69
III	pus/ukb/osa	79
IV	pus/osa/ukb/tak/miz	239
V	pus/osa/ukb/miz	239
VI	pus/osa/ukb/miz	239
VII	pus/tyo/osa	382
VIII	pus/ukb/osk/ngo/hkt	398
IX	pus/osa/ukb	412
X	pus/osa/ukb	494
XI	pus/osa/ukb	504
XII	pus/osa/ukb	702
XIII	pus/osa/ukb	800
XIV	pus/osa/ukb	800
Average size		387

Source : AXS-Alphaliner and Schedulebank website (Accessed March 2009)

By applying modeling, $\bar{Q}$ for Pusan – Osaka for existing shipping service is USD 85, which means that 702TEUs at 14 metric tonnes per TEU is optimal ship size for Pusan-Osaka in terms of lowest operation costs. The modeled result seems to indicate that there is not big difference between 700 TEUs and 800TEUs and their capacity can be the optimal size in Osaka.

Table 19
Operation cost per TEU for existing shipping service for Osaka

Vessel Name	Service Route	Effective carrying capacity (in TEUs)	Cost per TEU (US$)
VI	pus/osa/ukb/miz	239	111
VII	pus/tyo/osa	382	193
XI	pus/osa/ukb	504	105
XII	pus/osa/ukb	702	85
XIII	pus/osa/ukb	800	87

Source : AXS-Alphaliner, Own calculation

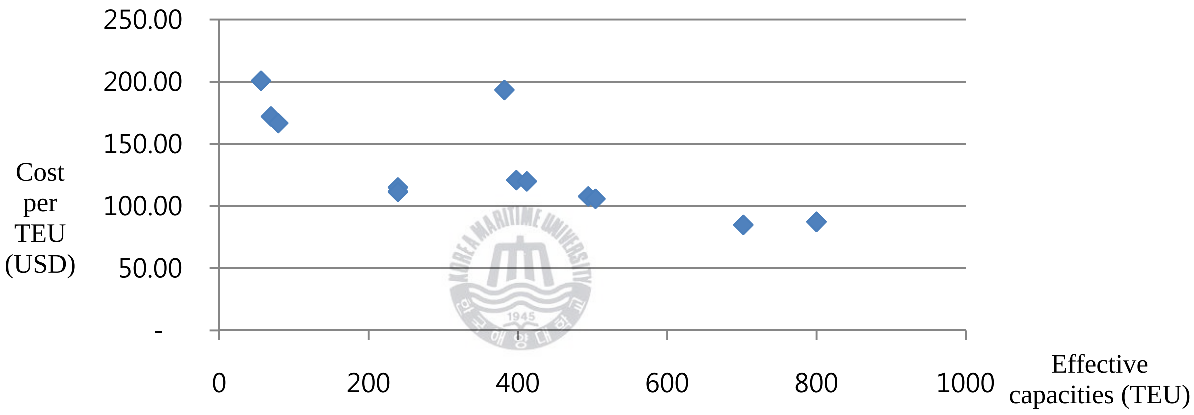

Figure 13. Pusan-Osaka Cost per TEU with equal to ships effective capacity

4.2.3 Pusan – Yokohama

As shown in Table 20, a total of 23 container vessels was deployed in March 2009 for Pusan – Yokohama and the average ship capacity (14mt per TEU) for Yokohama was 449 TEUs. The nearest average size is 436 TEUs, with $\bar{Q}$ equal to USD 205 and this vessel is the optimal ship size as shown in Table 21. The largest deployed vessel is 800TEUs effective carrying capacity at 14 metric tonnes per TEU. Due to data's confidential nature, vessel names are illustrated in Roman.

Table 20
The deployed feeder container vessels between Pusan and Yokohama

Vessel Name	Service Route	Effective carrying capacity (in TEUs)
I	pus/yok	56
II	pus/yok	56
III	pus/yok	71

IV	pus/tyo/yok	239
V	pus/tyo/yok/ngo	305
VI	pus/tyo/yok/chb	398
VII	pus/tyo/yok/chb	399
VIII	pus/tyo/yok/chb	408
IX	pus/tyo/yok/ngo	410
X	pus/yok/tyo/ngo	420
XI	pus/tyo/yok	436
XII	pus/tyo/yok/chb	474
XIII	pus/tyo/yok/ngo	491
XIV	pus/tyo/yok/ngo	491
XV	pus/tyo/yok/ngo	494
XVI	pus/tyo/yok/ngo	494
XVII	pus/yok/tyo/ngo	504
XVIII	pus/tyo/yok/ngo	588
XIX	pus/tyo/yok/ngo	590
XX	pus/hkt/yok/ngo/ukb	700
XXI	pus/tyo/yok/ngo	702
XXII	pus/tyo/yok/ngo	800
XXIII	pus/tyo/yok/ngo	800
Average size		449

Source : AXS-Alphaliner and Schedulebank website (Accessed March 2009)

$\bar{Q}$ for Pusan – Yokohama for existing shipping service is USD 115, which means that 700 TEUs at 14 metric tonnes per TEU is optimal ship size for Pusan-Yokohama in terms of lowest operation costs. The model result seems to indicate that ship operators can deploy larger container vessels on the Pusan-Yokohama ship route since average ship size is less than optimal ship size.

Table 21
Operation cost per TEU for existing shipping service for Yokohama

Vessel Name	Service Route	Effective carrying capacity (in TEUs)	Cost per TEU (US$)
XI	pus/tyo/yok	436	205
XVIII	pus/tyo/yok/ngo	588	135
XX	pus/hkt/yok/ngo/ukb	700	115
XXI	pus/tyo/yok/ngo	702	143
XXIII	pus/tyo/yok/ngo	800	150

Source : AXS-Alphaliner, Own calculation

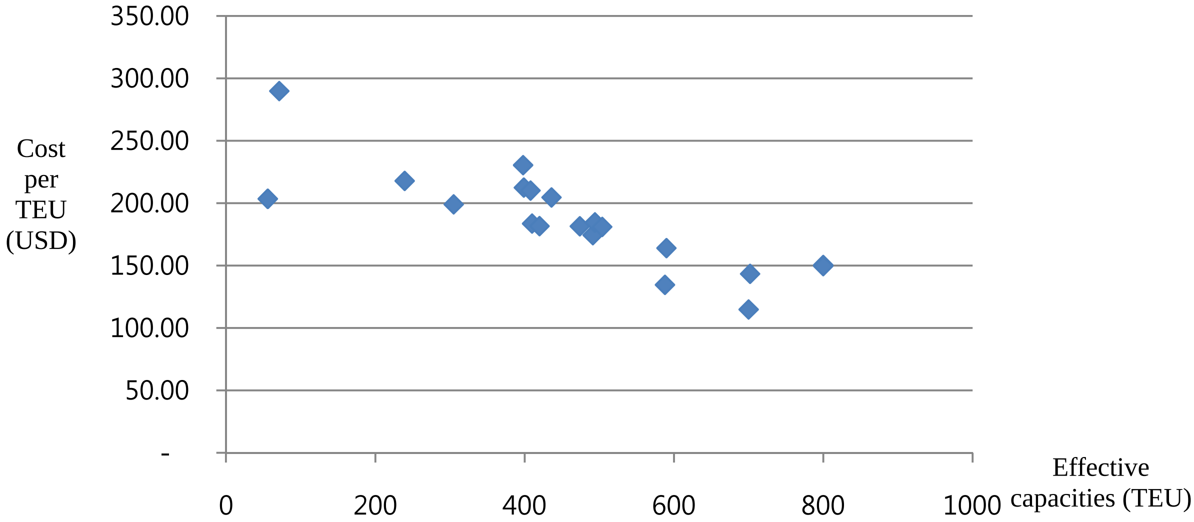

Figure 147. Pusan-Yokohama Cost per TEU with equal to ships effective capacity

4.2.4 Pusan – Tokyo

As shown in Table 22, a total of 20 container vessels was deployed in March 2009 for Pusan - Tokyo and the average ship capacity (14mt per TEU) for feeder container vessels calling Yokohama was 523TEUs. The nearest average size is 494TEUs, with $\overline{Q}$ equal to USD 188 and this vessel is the optimal ship size as shown in Table 23. The largest deployed vessel is 800TEUs effective carrying capacity at 14 metric tonnes per TEU. Due to data's confidential nature, vessel names are denoted by Roman numerals.

Table 22
The deployed feeder container vessels between Pusan and Tokyo

Vessel Name	Service Route	Effective carrying capacity (in TEUs)
I	pus/usn/tyo/yok/ngo	305
II	pus/tyo/yok/ngo	398
III	pus/tyo/yok	399
IV	pus/usn/tyo/yok	408
V	pus/usn/tyo/yok/ngo	410
VI	pus/yok/tyo/ngo	420
VII	pus/tyo/yok	436
VIII	pus/tyo/yok	436
IX	pus/tyo/yok	474
X	pus/mas/tyo/yok/ngo	491
XI	pus/mas/tyo/yok/ngo	491
XII	pus/usn/tyo/yok/ngo	494
XIII	pus/tyo/kws/yok/ngo	494
XIV	pus/tyo/ngo	573
XV	pus/usn/tyo/yok/ngo	588
XVI	pus/usn/tyo/ngo	620
XVII	pus/tyo/yok/ngo	702

XVIII	pus/tyo/yok/ngo	725
XIX	pus/tyo/yok/ngo	800
XX	pus/tyo/yok/ngo	800
Average size		523

Source : AXS-Alphaliner and Schedulebank website (Accessed March 2009)

By applying model, $\overline{Q}$ for Pusan – Tokyo for existing shipping service is USD 137, which means that 588TEUs at 14 metric tonnes per TEU is optimal ship size for Pusan-Tokyo in terms of lowest operation costs. The modeled result seems to indicate that ship operators for Pusan – Tokyo can deploy slightly larger container vessels since average ship size is less than optimal ship size.

Table 23

Operation cost per TEU for existing shipping service for Tokyo

Vessel Name	Service Route	Effective carrying capacity (in TEUs)	Cost per TEU (US$)
IV	pus/usn/tyo/yok	408	145
XV	pus/usn/tyo/yok/ngo	588	137
XVI	pus/usn/tyo/ngo	620	141
XVII	pus/tyo/yok/ngo	702	143
XX	pus/tyo/yok/ngo	800	149

Source : AXS-Alphaliner, Own calculation

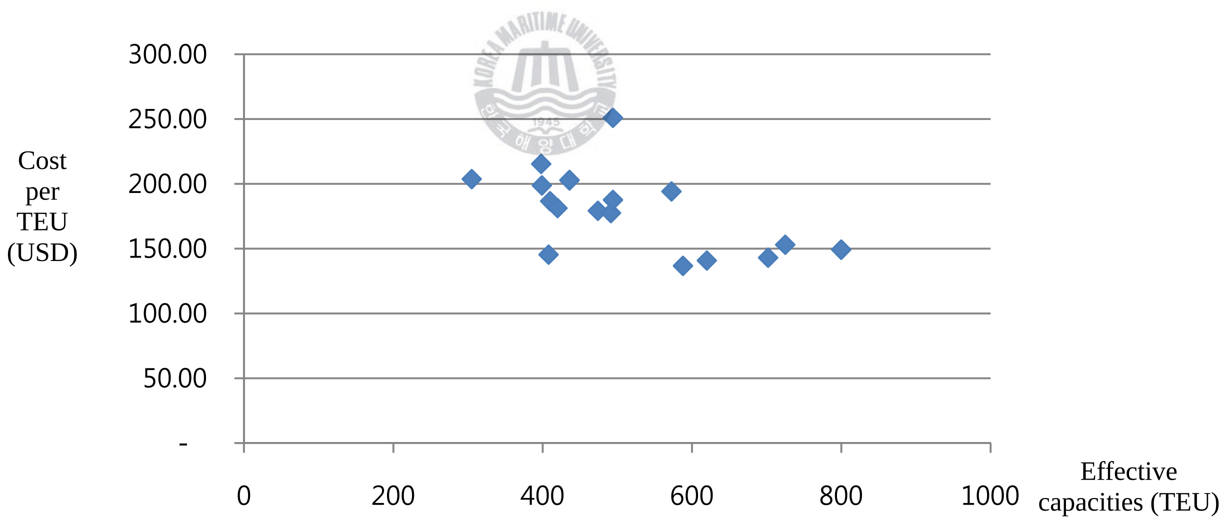

Figure 18. Pusan-Tokyo Cost per TEU with equal to ships effective capacity

5. Summary & Conclusions

The size of the container vessels deployed (in terms of fleet capacity) to ports depends on the size of demand. Additionally, optimal vessel size is determined by external limitations imposed by port facilities, e.g. draft, quay length and by the costs related to ship operations (eg bunker costs) and port dues. Demand fluctuations and the increasing intensity of competition between ship operators, further increases the complexity of vessel deployment.

By understanding these complexities, this paper has attempted to suggest the optimal feeder ship size of liner shipping services in Northeast Asia by means of a model based on Ng and Kee (2008). The model has been slightly adjusted to take into consideration different fuel types and to determine the optimal feeder ship size from a ship's operator's perspective using real-life data. The objective of model aims to identify for the lowest shipping cost per TEU including both ship and non-ship related components.

The model requires some real-life data. Data from shipping companies and websites was used to examine the optimal feeder ship in Northeast Asia. Every expense such as port dues, bunker price, etc. except cargo handling charges at ports was collected. Two shipping schedules were fed into the model. AXS-Alphaliner, which is based on annual service and the online Schedulebank data, which is consigners use in practice were taken. Ship's specifications such as gross tonnage, net tonnage, nominal TEU capacity, effective capacity (14mt per TEU), fuel consumption, speed and etc. were obtained from AXS-Alphaliner website (accessed in March 2009). Charter rates and port expenses such as tonnage due, port due, pilotage and tuggage are based on the information collected from a Korean shipping company. Bunker price and nautical distance are taken from www.bunkerworld.com, www.dataloy.com respectively.

Every feeder port in China and Japan from/to Pusan port is located within 1,000 nautical miles. The size of deployed feeder ships in effective capacities (14mt per TEU) varies from 50TEUs up to about 2,400 TEUs. In general, feeder ships to Chinese ports are marginally larger than ships to Japanese ports due to the higher volumes on their trade routes.

The analysis showed that the optimal ship sizes to Qingdao, Dalian, Shanghai and Tianjin port in North China are 744 TEU, 963 TEU, 655 TEU and 655 TEU respectively and to Hakata, Osaka, Yokohama and Tokyo port in Japan are 342 TEU, 702 TEU, 700 TEU and 588 TEU respectively. When comparing the current average ship size and the optimal ship size, the optimal ship size is larger than current average ship. Especially, in the case of Dalian and Osaka port, there is a more than 300TEU capacity difference between average and optimal ship size. It seems that ship operators need to consider a vessel fleet replacement with large vessels to operate at the lowest possible unit cost.

In drawing conclusions from the simulated results, it is vitally important to emphasize that every port has its own optimal size of feeder ships. Diseconomies of scale in feeder vessels sizes are found in the most service routes as shown above, since large feeder vessels give rise to more expenses such as fuel consumption and port dues.

To the best of the author's knowledge, this paper is one of the first to investigate optimal feeder ship sizes in Northeast Asia using an accessible methodology with publicly available input data. Further research could aim at including forecast for the optimal ship size according to demand fluctuations or the hub-and-spoke network changes by investigating the changes of feeder ship size.

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