The economic viability of container mega-ships

Imai, Akio
Nishimura, Etsuko
Papadimitriou, Stratos
Liu, Miaojia

(Citation)
Transportation Research Part E: Logistics and Transportation Review,42(1):21-41

(Issue Date)
2006-01

(Resource Type)
journal article

(Version)
Accepted Manuscript

(URL)
https://hdl.handle.net/20.500.14094/90000084

The economic viability of container mega-ships

Akio Imai[*]

Faculty of Maritime Sciences, Kobe University

Fukae, Higashinada, Kobe 658-0022 Japan

&

World Maritime University, PO Box 500, S-201 24 Malmo, Sweden

Etsuko Nishimura

Faculty of Maritime Sciences, Kobe University

Fukae, Higashinada, Kobe 658-0022 Japan

Stratos Papadimitriou

Department of Maritime Studies, University of Piraeus

80, Karaoli & Dimitriou Str., GR-185 32 Piraeus, Greece

and

Miaojia Liu

Faculty of Maritime Sciences, Kobe University

Fukae, Higashinada, Kobe 658-0022 Japan

[*] Corresponding author

Abstract

In this study, we analyze the container mega-ship viability by considering competitive circumstances. We adopt a non-zero sum two-person game with two specific strategies based on different service network configurations for different ship sizes: hub-and-spoke for mega-ship and multi-port calling for conventional ship size. A shipping characteristic for each route is approximately optimized to set up pay-off (or profit) matrixes for both players. Throughout model applications for Asia-Europe and Asia-North America trades, the mega-ship is competitive in all scenarios for Asia-Europe, while it is viable for Asia-North America only when the freight rate and feeder costs are low.

Keywords: Container transportation; Mega-containership; Game theory; Mathematical programming; Network design

1. Introduction

The purpose of this study is to examine the economic viability for deploying container mega-ships by applying game theory in analyzing competition in the shipping industry. We model a non-zero sum two-person game to obtain the optimal strategies (or equilibrium points).

Over the past few years there has been a steady increase in the size of containerships servicing the world's densest maritime routes. This can be attributed partially to the fact that more flexible and encompassing forms of co-operation have emerged in the maritime industry, "the global alliances." Global alliances have become predominant in the major routes, having proved to be very successful in benefiting from the economies of scale achieved through the employment of larger ships.

Thus, major container shipping routes have witnessed a large increase in ship size to over 7000TEUs. Classification society Germanischer Lloyd has developed a design for 9300TEU containership in conjunction with the shipbuilder, Samsung Heavy Industries of South Korea. Some key players in the shipping industry, such as carriers, alliances, classification societies, shipbuilders and port authorities are also envisaging the possibility of a further increase to over 10,000TEU ship capacity (which is called *Mega-ship* or *Malaccamax-ship*). French classification society Bureau Veritas has produced independent design plans for a 12,500TEU vessel. Lloyd's Register has also investigated the possibility of 12,500TEU ship known as "Ultra Large Container Ship (ULCS)." Three major Japanese shipyards recently launched a joint venture of designing 10,000TEU and 12,500TEU containerships.

This is not, however, the predominant market trend. According to the literature, the operation of container mega-ship is expected to benefit from the economies of scale achieved in the maritime segment of the trip. However, when comparing the service offered to shippers by container mega-ships to that of smaller ships, it is pointed out that there are some drawbacks as it is inevitable for the former to reduce the calling frequency if there is not an enormous increase in cargo demand (van der Jagt, 2003). This in effect results in withdrawal from the market. On the other hand, if the present calling frequency is maintained, the container mega-ship turns out to be under-utilized, which increases the operating cost per carried container (Willmington, 2002).

In addition to the above disadvantages as viewed from the shippers' perspective, there are some other negative aspects that relate to the technical and operating characteristics of container mega-ship deployment. A major impediment is draft restrictions in ports such as the low water depth of access channels and berths to accommodate deep-draft ships (Damas, 2001). Furthermore, no marine diesel engine has yet been developed, which powers a vessel of over 10,000TEUs at 25 knots (i.e., the standard service speed of deep-sea containership) with a single engine (Willmington, 2002). In addition, the container mega-ship raises issues concerning container-handling operational needs at ports. Some of the major container ports have ordered or already have in service gigantic quay cranes with an outreach capable of servicing a container mega-ship. We note, however, that the issue is not limited to the crane size, because quay cranes must feature much faster handling capabilities due to the quick turnaround time required in the selected mega-hub ports (Damas, 2002). Nevertheless, all these physical and technical restrictions will sooner or later be overcome if the shipping market really desires the container mega-ship.

Therefore, our study on container mega-ship viability will only focus on operational and economic factors related to the competitiveness within the container shipping industry. As there are a number of deep-sea shipping operators (most of them belonging to alliances) competing intensely between themselves, the shippers' perspective regarding the quality of service offered would be a crucial dimension for the viability of the container mega-ship. The authors have already investigated the container mega-ship viability by using a two objective mathematical model in designing a hub-and-spoke network (Imai and Papadimitriou, 1997). Their study examined trade-offs between operating cost savings of the container mega-ship versus increase in the total cost (including transit inventory carrying cost of goods) incurred to shippers. In their study it was demonstrated that while a shipping operator benefits from the operation of container mega-ships, he is likely to suffer from a reduced market share resulting from the shipper's increased overall transport cost. However, the gain or loss of the market share for a particular operator (or an alliance when it has a strong integration) not only depends on his own service strategy but also on strategies adopted by his competitors.

As will be reviewed in the following section, most analyses on container liner shipping are based on a single shipping operator, while some implicitly assume competitive circumstances with other operators (or alliances). In terms of economics, an analysis can assume no profit in the market under perfect competition, allowing a single (representative) operator to exist in the market, who tries to minimize the relevant transportation costs that compose the freight rate. However, from the microscopic point of view, at least for the time duration of a ship's life span, shipping operators aim to maximize profit based on the freight rate, which is not necessarily based on the transportation costs. While an analysis on how the freight rate is determined is beyond the scope of this study, we analyze the container mega-ship viability by taking into account competitive factors reflected by game theory with some alternative freight rates defined explicitly.

This paper is organized as follows. Section 2 contains a brief literature survey of ship operation problems. Section 3 formulates a competitive model by using a game. Some model applications are demonstrated in Section 4 while Section 5 presents the conclusions of the paper.

2. Related literature

There is a huge body of the literature on liner ship operations. This literature review is not exhaustive and discusses only relatively recent works. Lim (1998), Gilman (1999), Cullinane and Khanna (2000), and Ircha (2001) provide general discussions on the economies of scale achieved by large containerships. Bergantino and Veenstra (2002) investigate the process of alliance formation, discussing effects of interconnection and integration of liner shipping networks. More detailed analyses of constructing liner networks and routing strategies are examined by Cho and Perakis (1996) and Imai and Papadimitriou (1997). The former study does not consider competition in the market and proceeds by proposing two models: a profit maximization model and a cost minimization model. The latter study deals with trade-offs between the objective of a carrier and that of its customers. Implicitly taking into account competition by other carriers, it concludes that there is a potential in deploying a mega-ship in the container trade route between Europe and the Far East. Like Imai and Papadimitriou (1997), Yang (1999) introduces an equilibrium model between a shipping company and shippers, by using game theory for a more explicit treatment of their conflicting interests. The objective of Yang's study is to assess container port policy and to investigate how shipping companies' strategies affect shippers' port selections relevant to their shipment. He does not analyze trade-offs between the objective of the shipping company and that of the shippers. While Yang's approach is similar to this study, it aims to assess the port investment without any explicit consideration on the growth of ship size.

It is also interesting to note that due to the continuous increase in ship size, we are also witnessing changes occurring in the service networks from a multi-port-calling to a hub-and-spoke. Mourao et al. (2001) develop a cost minimization optimization model that assigns ships to a hub-and-spoke network. McLellan (1997) and Ircha (2001) provide an overview of some underlying issues on the container mega-ship. Drewry (2001) and Wijnolst et al. (1999, 2000) carry out extensive feasibility studies on the container mega-ship without taking into account market competition.

Thus, no researcher has dealt up to now with the issue of container shipping network design by explicitly considering the existence of the fierce competition among shipping lines as well as the significant trend of ship size growth, both of which the market has been witnessing in recent years.

3. A game theory model of shipping competition

In order to explicitly look into implications on shipping strategies in competitive circumstances, we employ game theory. Game theory has been well utilized to assess business strategies to be undertaken in competitive circumstances (Chatterjee and Samuelson, 2001).

As also observed in other business fields, the liner shipping industry is characterized by the differentiated cost structure of the relevant shipping companies in the market. A typical case of this differentiation is the observed cost structure difference between Europe-based and Asia-based companies. While an in-depth analysis on the freight rate is beyond the scope of this study, we can safely argue that the same or approximately the same freight rates are applied for particular origin-destination port pairs in most trade routes. Therefore, the cost structure is the main factor in the differentiation of the profits generated by the different shipping companies.

Based on the above discussion, we employ a non-zero sum game with two players to identify optimal liner service mixes that correspond to Nash equilibrium points with profit pay-off matrixes, assuming that each player has a knowledge of his competitor's set of potential services (or strategies in the game terminology). Nash equilibrium points can be interpreted as non-regrettable solutions, given involved competitors' strategies that are known each other. Being more precise, this means that if a player adopted any other strategy rather than the equilibrated strategy, his profit would be decreased. Consequently, each of the two players has no reason to change his strategy to be undertaken.

Usually business related decision-making is not a one-off decision but rather a repeating series of decision-making for an infinite time length for the duration of the business life. However, development of liner shipping network and associated deployment of ships are subjects of long-term decision-making, which are basically maintained throughout the lifetime of the system, though minor (or major) modifications are made during the prospective business life cycle. If repeated decision-making is envisaged, sequential equilibria of extensive-form of the game (Myerson, 1991) should be applied. However, as the one-off decision-making is assumed in this study, equilibria of strategic-form of the game are employed. Also we assume complete information on strategies of the competitors. While the details of the competitor's strategies are not available to the other player, basic information to reason the competitor's strategies is normally shared by all the competitors in the market. This justifies the game with complete information.

3.1. *The game*

The non-zero sum game is defined as follows:

Shipping companies compete to sell transport services to shippers (or consignees). Denote the set of companies by H and the set of shippers by D. We assume that a shipper represents the total traffic from an origin port to a destination port. Each shipping company can set the service parameters of its shipping service. Let σ_i be a vector for company i's decisions (or strategies) on service, which affect its shipping potential as well as its shipping costs. The services offered by the companies may have different levels of quality as perceived by the shippers, denoted by $v^d, d \in D$. Shipping companies also specify freight rates for each type of shippers. Let $p_i(d)$ be the rate company i specifies for shipper $d \in D$, and $\vec{p}_i = (p_i(d))_{d \in D}$. Shippers are differentiated by their sensitivity to the rate and the quality of service. Unlike the manufacturing field and other types of shipping, container shipping is barely differentiated with respect to service quality offered by the different companies involved in the market, since the entire transport is highly systematic and the product offered is basically indistinguishable. We assume, therefore, service quality to be defined only by the transit time. If p is the freight rate charged and the service quality shipper d perceives with transit time t is denoted by $v^d = v^d(t)$, then the utility (or value) to shipper d is defined by Eq. (1), since a service with the high rate and long transit time results in a lower level of utility.

$$U^d(t, p) = v^d(t) - p. \tag{1}$$

The interactions between shippers and shipping companies are as follows. First, companies make their strategic choices. Each shipper selects a company to assign its transport of goods so as to maximize his utility based on the information about the price and the service quality as expressed by the transit time. That is, shipper d places a commitment to company i if

$$E\left[U^d(t_i, p_i)\middle|F^d\right] = \max_{j \in H} E\left[U^d(t_j, p_j)\middle|F^d\right], \tag{2}$$

where F^d represents the information available to shipper d. If we looked only at an individual shipper, we would have Eq. (2). However, we assume that shipper d is representative for all individual shippers of a trade from one port to another and that he does not necessarily commit the transport to the company that maximizes the utility as measured by Eq. (2), since each individual shipper may have different values for his own utility, all of which are not measurable. Consequently, we substitute the following equation for Eq. (2).

$$E\left[U^d(t_i, p_i)\middle|F^d\right] = \frac{\left[U^d(t_i, p_i)\middle|F^d\right]}{\sum_{j \in H}\left[U^d(t_j, p_j)\middle|F^d\right]}. \tag{3}$$

The shipper's behavior described above leads to a mapping of companies' decisions on shipping service (i.e., $\sigma = (\sigma_i)_{i \in H}$, quality, $v = (v_i)_{i \in H}$ and $\vec{p} = (\vec{p}_i)_{i \in H, d \in D}$) into the expected market share of V^d (the traffic volume of shipper d) for each company and for each shipper, which is denoted by $\lambda_i(d, \sigma, v, \vec{p})$ for $i \in H$ and $d \in D$. Let $\lambda_i(\sigma, v, \vec{p}) = (\lambda_i(d, \sigma, v, \vec{p}))_{d \in D}$ be the market share of company i for all shippers. Then, expected profit for company i is:

$$\pi_i(\sigma, v, \vec{p}) = \sum_{d \in D} p_i(d) \lambda_i(d, \sigma, v, \vec{p}) - C_i(\lambda_i, \sigma_i, v_i), \tag{4}$$

where $C_i(\lambda_i, \sigma_i, v_i)$ is shipping costs for a given strategy.

The shipping company i's strategy set can then be defined as a vector of decisions, $s_i \subseteq \{\sigma_i, v_i, \vec{p}_i\}$. A Nash equilibrium is a vector of strategies for shipping companies, $s^* = (s^*_i)_{i \in H}$, such that for each company i , $\pi_i(s^*) = \max_{S_i} \pi_i(s_i, s^*_{-i})$, where $s_{-i} = (s_j)_{j \in H - \{i\}}$. Note that a solving method of a non-zero sum two-person game is illustrated in Stahl (1999).

As pointed out in Myerson (1991), there may be more than one equilibrium point. We may define, as the optimal equilibrium or the equilibrium in the narrow sense, $\{\pi_i(s^*_k), \pi_j(s^*_k)\}$, an equilibrium satisfying the following criterion:

$$\pi_i(s^*_k) > \pi_i(s^*_{k'}), \quad \pi_j(s^*_k) > \pi_j(s^*_{k'}) \qquad \forall k'(\neq k), \tag{5}$$

where $\pi_i(s^*_k)$ is an equilibrium associated with a strategy $k \in s_i$ for company i. The equilibrium logically seems superior to the other equilibriums for all players. If there is no such equilibrium in the narrow sense, then we need consider "focal equilibrium". For the details of the focal equilibrium, see Myerson (1991).

3.2. *Service network*

The ultimate aim of this study is to examine the container mega-ship viability;

therefore, for model simplification purposes, we permit each shipping company to have only two strategies: either by container mega-ships or by smaller ships (hereafter referred to as *ordinary ships*). We assume export and import trades between two regions: A and B. We also assume no intra-regional trades within each region.

There are a large number of different service network structures in container liner shipping. For the sake of simplicity in model building, we assume only two: the multi-port-calling and hub-and-spoke as shown in Fig. 1. Also for simplicity, we correlate the two types of deep-sea ships to the types of service networks as follows:

Mega-ship $\Rightarrow$ Hub-and-spoke

Ordinary-ship $\Rightarrow$ Multi-port-calling

Fig. 1 about here

In any given strategy, regardless of the multi-port-calling or the hub-and-spoke, a company constructs a service network with the aim of maximizing its market share. Of course, the market share results from the compounding effects of the strategies chosen by a company and its competitors. However, the company can independently maximize its share by properly designing its own service network. The share is also influenced by the freight rate as defined by Eq. (3). With the presumption that the rate is not directly related to the network structure as observed in reality, the network should be designed such that it maximizes $v^d = v^d(t)$. This corresponds to the minimization of the weighted transit time defined by $\lambda_i(d,\alpha,v,\vec{p})\cdot t_i^d$, where t_i^d is the transit time offered by company i for shipper d. As the market share is not known prior to the network construction, we substitute V^d, the whole traffic volume of shipper d, for $\lambda_i^d(\alpha,v,\vec{p})$.

3.2.1. *Multi-port-calling network*

A multi-port-calling route is formed with the aim to minimize the total transit time of shipment from origin ports to destination ports. By solving the following problem, we identify the optimal route for the multi-port-calling:

$$\text{[MPC]} \quad \text{Minimize} \quad \sum_{i \in N} \sum_{j \in N} \sum_{d \in D} V^{d} CT_{ij} y_{ij}^{d} + \sum_{d} V^{d} W^{d} \tag{6}$$

Subject to

$$\sum_{j \in N} y_{ij}^{d} = 1 \qquad \forall i \in S^{d}, d \in D, \tag{7}$$

$$\sum_{j \in N} y_{ij}^{d} = \sum_{j \in N} y_{ji}^{d} \qquad \forall i \in N(\neq T^{d}, S^{d}), d \in D, \tag{8}$$

$$\sum_{j \in N} y_{ji}^{d} = -1 \qquad \forall i \in T^{d}, d \in D, \tag{9}$$

$$x_{ij} = y_{ij}^{d} \qquad \forall i, j \in N, d \in D, \tag{10}$$

$$\sum_{j \in N} x_{ij} = 1 \qquad \forall i \in N, \tag{11}$$

$$\sum_{i \in N} x_{ij} = 1 \qquad \forall j \in N, \tag{12}$$

$$\sum_{i \in Q} \sum_{j \notin Q} x_{ij} \geq 1 \qquad \forall Q \subset N, \tag{13}$$

$$W^{d} = \sum_{i \in N} \sum_{j \in N} f^{i}\{XW^{i} y_{ij}^{d}\} + \sum_{i \in N} \sum_{j \in N} f^{j}\{MW^{j} y_{ij}^{d}\} \qquad \forall d \in D, \tag{14}$$

$$x_{ij} \in \{0,1\} \qquad \forall i, j \in N, \tag{15}$$

$$y_{ij}^{d} \in \{0,1\} \qquad \forall i, j \in N, d \in D, \tag{16}$$

where

N set of ports,

D set of shipments,

CT_{ij} direct sailing time from ports i to j,

$f^{j}\{a\}$ function that defines the handling time at port j for cargo volume a,

S^d, T^d origin and destination of shipment d ,

V^d volume of shipment d ,

W^d total handling time (actually this corresponds to the turnaround time) at ports on the route, which shipment d goes through in its itinerary,

XW^i total volume originating from port i , which is defined as $XW^i = \sum_{d=\{d \in N | S^d = i\}} V^d$,

MW^i total volume destined for j , which is defined as $MW^i = \sum_{d=\{d \in N | T^d = i\}} V^d$,

x_{ij} =1 if the ship sails directly from ports i to j , =0 otherwise,

y_{ij}^d =1 if the itinerary of shipment d moves directly from ports i to j , =0 otherwise,

x_{ij} s and y_{ij}^d s are decision variables. Objective (6) is the minimization of the total transit times weighted by the shipment volume, where the first term defines the total sailing time and the second specifies the total turnaround time in all visited ports. Constraint sets (7) – (9) specify the itinerary of shipment d . Constraint set (10) defines the relationship between a segment of the entire itinerary of shipment d and a segment of the multi-port calling route. Constraint sets (11) – (13) ensure that a ship's itinerary forms a multi-port-calling route that calls at every port only once. Constraint set (14) defines the turnaround time associated with shipment d .

The problem [MPC] is an integer programming problem and likely has no efficient solution methods to identify the optimal solution. While commercial mathematical programming solvers are available, for realistic problem settings the problem size is very huge and a long computation time is necessary. We, therefore, developed a heuristic. For details, see Appendix A.

3.2.2. *Hub-and-spoke network*

Assuming there are two regions which trade goods, one port serves as a hub in one region, while the other serves as a hub in another region. Like the multi-port-calling, the optimal network for the hub-and-spoke is formed so as to minimize the total transit time of the shipment. This problem may be formulated as follows:

[H&S] Minimize $SCT + HCT + TCT + SHT + HHT + THT$ (17)

Subject to
$$\sum_{i \in N^{\alpha}} z_i = 1, \tag{18}$$

$$\sum_{i \in N^{\beta}} z_i = 1, \tag{19}$$

$$x_{ij} = z_j \qquad \forall i, j \in N^{\alpha}, \tag{20}$$

$$x_{ij} = z_j \qquad \forall i, j \in N^{\beta}, \tag{21}$$

$$x_{ij} = z_i \qquad \forall i, j \in N^{\alpha}, \tag{22}$$

$$x_{ij} = z_i \qquad \forall i, j \in N^{\beta}, \tag{23}$$

$$x_{ij} = z_j \qquad \forall i \in N^{\alpha}, j \in N^{\beta}, \tag{24}$$

$$x_{ij} = z_i \qquad \forall i \in N^{\alpha}, j \in N^{\beta}, \tag{25}$$

$$SCT = \sum_{d \in D} \sum_{i \in N} V^{d} CT_{S^d i} x_{S^d i}, \tag{26}$$

$$TCT = \sum_{d \in D} \sum_{i \in N} V^{d} CT_{iT^d} x_{iT^d}, \tag{27}$$

$$HCT = \sum_{d \in D^+} \sum_{i \in N^{\alpha}} \sum_{j \in N^{\beta}} V^{d} CT_{ij} x_{ij} + \sum_{d \in D^-} \sum_{i \in N^{\beta}} \sum_{j \in N^{\alpha}} V^{d} CT_{ij} x_{ij}, \tag{28}$$

$$SHT = \sum_{d \in D} \sum_{i \in S^d} V^{d} f^{i} \left\{ MW^{i} + XW^{i} \right\} (1 - z_i), \tag{29}$$

$$THT = \sum_{d \in D} \sum_{i \in T^d} V^{d} f^{i} \left\{ MW^{i} + XW^{i} \right\} (1 - z_i), \tag{30}$$

$$\begin{aligned} HHT = & \sum_{d \in D^+} V^{d} \sum_{i \in S^d} \sum_{j \in N^{\alpha}} f^{j} \left\{ XW^{i} (1 - z_i) + VT^{+} \right\} (1 - z_j) \\ & + \sum_{d \in D^-} V^{d} \sum_{i \in T^d} \sum_{j \in N^{\alpha}} f^{j} \left\{ MW^{i} (1 - z_i) + VT^{-} \right\} (1 - z_j) \\ & + \sum_{d \in D^+} V^{d} \sum_{i \in T^d} \sum_{j \in N^{\beta}} f^{j} \left\{ MW^{i} (1 - z_i) + VT^{+} \right\} (1 - z_j) \\ & + \sum_{d \in D^-} V^{d} \sum_{i \in S^d} \sum_{j \in N^{\beta}} f^{j} \left\{ XW^{i} (1 - z_i) + VT^{-} \right\} (1 - z_j), \end{aligned} \tag{31}$$

$$x_{ij} \in \{0,1\} \qquad \forall i,\ j \in N, \tag{32}$$

$$z_j \in \{0,1\} \qquad \forall j \in N, \tag{33}$$

where

N^{α} set of ports in region A,

N^{β} set of ports in region B,

D^{+} set of shipments bound for region B,

D^{-} set of shipments bound for region A,

SCT sailing time weighted by the shipment volume from origin ports to the hub in the region they belong to,

TCT sailing time weighted by the shipment volume to destination ports from the hub in the region they belong to,

HCT sailing time weighted by the shipment volume between the hub ports,

SHT total turnaround time weighted by the shipment volume in the origin ports,

THT total turnaround time weighted by the shipment volume in the destination ports,

HHT total turnaround time weighted by the shipment volume in the hub ports,

x_{ij} =1 if the ship sails directly from ports i to j, =0 otherwise,

z_j =1 if port j is selected as a hub, =0 otherwise,

x_{ij} s and z_j s are decision variables. Objective (17) is the minimization of the total transit time weighted by the shipment volume. Constraint sets (18) and (19) ensure that one port is selected as the hub in each region. Constraints (20) - (23) define spoke segments from the hub in each region. Constraint sets (24) and (25) specify trunk routes between the hubs. Constraints (26) – (30) define the sailing and turnaround times. In constraint set (31), the first and second terms define the turnaround times in the hub of region A, whereas the third and fourth terms specify those in the hub of region B. The solution approach for this problem is detailed in Appendix B.

4. Model applications

4.1. *Assumptions*

We investigate the economic viability of deploying container mega-ships in two trade routes: between Asia and Europe and between Asia and North America. The largest traffic volume of import and export containers between Asia and each corresponding region (Europe and North America) is assumed to be 15,000TEUs per week. As there are no detailed statistics available for traffic volumes between each particular pair of ports, we base our estimated annual traffic for the ports under examination on various trade statistics. Then, we reduce the traffic volume for a specific trade section so that the maximum aggregate traffic is 15,000TEUs per week for both European and North American trades. The total weekly export and import volumes for the ports under examination are summarized in Appendix C. Note, that if a particular port is located very close to other ports, which are not included in these trade scenarios, the trade volume of these excluded ports has been added to the volume of the included port. In Table C.1 throughputs of existing hubs such as Pusan, Hong Kong and Rotterdam include transshipment traffic from/to local ports in their vicinity. Although the transshipment should be separated from the throughputs, this was not done due to the difficulty in estimation. However, this treatment may be justified by the fact that these local ports are implicitly involved in the service networks and are represented by these hubs.

For computational ease in solving the game, we focus on only two shipping companies (or two alliances), although in reality some others may be also involved in the market. The transit time includes the waiting time for arrival of the next ship at the port of origin, and it is considered to be the half of the interval between port calls.

The two companies' market share of the total traffic depends on the respective transit times with the assumption that for every trade section they adopt an identical freight rate. In other industries, especially manufacturing, firms save production costs to offer competitive product prices that result in a higher market share. This is basically true in the shipping industry as well. However, in liner shipping, in order to avoid fierce competition especially in the freight rate, liner conferences function in introducing uniformed rates despite a small diversity in rate among member carriers due to special contracts with shippers. Furthermore, though non-conference members offer lower rates, according to our survey the degree of discount is rather insignificant. In addition, it is quite difficult to obtain freight rates of different shipping companies in order to identify the utility function (1). The above discussion justifies our assumption on the use of identical rates.

As discussed above, identical freight rates are applied. A Nash equilibrium (s) is defined based on a payoff (or profit) matrix. This implies that an equilibrium is implemented by the profit amount (by freight rate if the cost matrix remains). The freight rate varies throughout time; however, if we assume that a constant rate is applied over the ship's life span, implications of the relationship between the equilibrium (or the optimal ship size) and the applied rate will be obtained. Consequently, we set three different rates for each trade route as it will be mentioned later.

Both companies have two ship deployment strategies: provide service either by container mega-ships with a 10,000TEU capacity or by ordinary ships with a 5000TEU capacity. For simplicity in comparisons, both strategies offer the same transport capacity per week; therefore a 10,000TEU ship calls at a port once a week, while a 5000TEU ship calls twice a week.

The shipping related cost is composed of the operating costs (manning, stores, repair and maintenance, insurance and administration), the voyage costs (fuel, port charges and canal dues), the cargo handling costs and the capital costs. Note that we do not include any costs for the fleet of containers, assuming that both carriers prepare the same size of container fleet, which is large enough to satisfy the maximum of potential market share, and that the fleet size is not affected by the service strategy.

As payoff matrixes in a game have weekly profits, all cost elements are reported on a weekly basis and the capital cost is computed as depreciation cost, assuming a 20-year ship lifetime and a 5% residual ship price. In order to differentiate the two companies in terms of their investment policy, we assume that one of the shipping companies is European-based (called company E) and hires European crews while the other is Asian-based (called company A) and hires Asian crew members. Company E also builds its ships in Europe, whereas company A builds them in Asia for 2/3 of the price of the European-built ones. All other cost elements are identical between both companies. The costs were estimated from various sources (Drewry, 1997; Wijnolst and Wergeland, 1997).

In the hub-and-spoke strategy, both companies are not involved in feeder transport, which is assumed to be provided by a third party. For both the multi-port-calling and hub-and-spoke services, the number of ships deployed is determined by the following formula:

$$FS = \frac{RT}{CI} \tag{34}$$

where FS is the number of ships, RT is the transit time for one roundtrip voyage and CI is the time interval between port callings.

In order to determine the transit time of a particular shipment from its origin to its destination and the ship related costs, we need to compute the ship's turnaround time in port (mainly the handling time), which is based on the market share of a specific company. As discussed before, the market share is dependent on and is the output of the transit time calculation; therefore we have to make an assumption for the market share. We assume the worst-case scenario with respect to the turnaround time, that is, a ship is assumed to carry as much of the whole volume of weekly traffic up to its capacity. The turnaround time depends not only on the volume handled but also on the handling speed of loading and unloading containers. We assume that all containers to be transported are 20 footers and that on average a 5000TEU ship is served with two container moves per minute (this does not mean that a quay crane moves two containers in that time), a 10,000TEU ship is served with four containers per minute, and a feeder is treated with one container per minute.

The earned profit is computed by subtracting the incurred costs from the generated revenues. We illustrate how to compute the market share of each shipping company and the resulting revenue with a small example. If the two players adopt the identical network in a specific combination of strategies (corresponding to a specific entry in the pay-off matrix for each player), both players' shares and resulting revenues are even. If they offer different strategies (multi-port-calling and hub-and-spoke), their shares and revenues are not necessarily even. Given traffic between six ports (three in a region and the other three in another region) as shown in Table 1, we compose a multi-port-calling and hub-and-spoke networks (or strategies) as portrayed in Fig.1. Note that a ship sails clockwise in the multi-port-calling. Transit times for both networks are shown in Table 2. Notice that the transit time from an origin port to a destination port and the time between both ports in the opposite direction are identical in the hub-and-spoke network. As assumed in Section 3.1, market share is defined as being inversely proportional to the transit time ratio given identical freight rates. The inverse ratio and the share computed by the ratio are given in Table 3. Assuming that the freight rate from the region covering ports A, B and C to the one with ports D, E and F is US$2000 and the rate for the trade in the opposite direction is US$1000, the revenues for the multi-port-calling and hub-and-spoke are US$189,000 and US$215,000, respectively.

Tables 1, 2 & 3 about here

4.2. *Results for the Asia-Europe trade*

For a multi-port-calling route, we solved a Traveling Salesman Problem (see Appendix A) by the heuristic, resulting in the best itinerary as follows: Singapore, Laem Chabang, Hong Kong, Xiamen, Kaohsiung, Keelung, Shanghai, Pusan, Kobe, Yokohama, Hamburg, Rotterdam, Felixstowe, Antwerp and Le Havre. In a hub-and-spoke network, Hong Kong and Rotterdam are selected as hubs in their respective regions. The weekly costs for the two different strategies for both companies are: US$8.3 million (Multi-port-calling) and US$6.5 million (Hub-and-spoke) for company A and US$9.3 million (Multi-port-calling) and US$6.9 million (Hub-and-spoke) for company E. Note that the costs for the hub-and-spoke network do not include the feeder costs, which will be included later.

Based on various statistical data, we estimate the standard freight rate for Asia-Europe trade, which varies depending on the specific trade and its direction. The average rates per TEU bound for Europe and for Asia are assumed to be $1800 and $720, respectively, which are relatively close to the published current rates (UNCTAD, 2001). For both directions of the trade, we also set two different rates at 2/3 and 1/2 levels of the aforementioned rates in order to examine how changes in rate affect optimal strategies. These rates are hereafter referred to as high, medium and low rates, respectively. Both companies adopt as their strategies the identical service networks and freight rates. Table 4 illustrates weekly revenues for a company in different strategy mixes involving itself and its competitor. It is important to note that both companies have the same revenue matrixes, as there is no difference in each strategy (except for the costs) between them. Depending on the strategy mix in games, a ship has a load factor that ranges from 60% to 80% of its capacity in TEU, which is reasonable in practice.

Table 4 about here

The optimal service mixes, which are defined as Nash equilibrium points satisfying $\pi_i(s*) = \max_{S_i} \pi_i \left(s_i, s*_{-i}\right)$, are mapped on weekly profit matrixes with three different feeder costs and three different rates, as shown in Tables 5-7, which correspond to payoff matrixes for games. Notice that while a non-zero sum game may have both pure and mixed strategies as equilibria, we only show pure strategies. We set three different average feeder costs per TEU: \$50, \$100 and \$500, where the average cost is obtained by dividing the total feeder cost by the total traffic volume that each company is carrying. Considering the average of east and westbound freight rates, these feeder costs account for 4%, 8% and 40% of the average freight rate, respectively. Profit is defined as the difference between revenues and costs, where the cost includes the feeder cost in the hub-and-spoke case. According to Tables 5-7, both companies employ the hub-and-spoke service network with the container mega-ship for all the freight rates and feeder costs. The reason for the selection of container mega-ship is that due to the low freight rates (especially compared to those for North American trade) the generated revenues are too low to make the multi-port calling of ordinary ship profitable. The rates for the European route are lower than those for the American route especially when taking into account the entire route length. A practical interpretation for the solution in the European trade is that the achieved economies of scale by the container mega-ship deployment are greater in the case of the longer shipping route with low freight rates.

Tables 5 - 7 about here

4.3. *Results for the Asia-North America trade*

Next, we investigate the trade between Asia and North America. Basic assumptions are the same as for the Asia-Europe trade. The best multi-port-calling route is: Singapore, Laem Chabang, Hong Kong, Xiamen, Kaohsiung, Keelung, Shanghai, Pusan, Kobe, Yokohama, Seattle, Portland, Oakland and Los Angeles. In a hub-and-spoke network, Hong Kong and Los Angeles are selected as hubs in their respective regions. The weekly costs for the two different routing strategies are: US$7.2 million (Multi-port-calling) and US$5.7 million (Hub-and-spoke) for for company A, and US$7.9 million (Multi-port-calling) and US$5.9 million (Hub-and-spoke) for for company E.

The average freight rates for traffic bound for North America and for Asia are $2210 and $995 respectively, which are relatively close to the published rates (UNCTAD, 2001). In addition, we define two different freight rates with the same discount rates as in the European trade case. Table 8 illustrates weekly revenue matrixes for each company. Similarly to the European trade case, a ship carries from 60% to 80% of its cargo capacity in TEUs.

Table 8 about here

Tables 9-11 present the optimal service mixes with weekly profit matrixes. The variation of feeder costs is the same as in the European case, where the feeder costs account for 3%, 6% and 31% of the average freight rate, respectively. In the case of the high freight rate, both companies employ the multi-port-calling with the ordinary ship. However, when the rate is decreased by 30% (medium rate case), company E uses the hub-and-spoke with the container mega-ship with lower feeder costs, i.e., $50 and $100, while it still utilizes the multi-port-calling in the case where the feeder cost equals $500 because the hub-and-spoke is not competitive due to the high feeder cost. On the other hand, company A still adopts the multi-port-calling for all feeder cost cases. Interestingly, even when the feeder cost is low, the ordinary ship service is still inexpensive (and profitable) for company A because of its lower ship and crew costs compared to those of company E. In the case of the low freight rate, both companies use the container mega-ship, since it is profitable especially with low and medium feeder costs. However, when the feeder service is expensive, company A changes its strategy to the ordinary ship, whilst the container mega-ship is still profitable for company E due to the company's high cost structure.

Tables 9 - 11 about here

Focusing on a specific feeder cost, company A keeps deploying the ordinary ship service as long as the freight rate is high enough to make its business profitable. When the rate is very low, it changes its strategy in favor of the container mega-ship except for the case of very high feeder cost. The general tendency for company E is the same, however it has a higher level of freight rate that triggers changes in its strategy.

For the American trade, as shipping lines benefit from the relatively high freight rate in contrast to the European trade, the economies of scale by the container mega-ship are not advantageous. Therefore, in general the deployment of the container mega-ship is only justified if the shipping market is less profitable due to lowered freight rates like the general tendency in the European trade.

5. Conclusions

In this paper, we studied the economic viability for the deployment of container mega-ships by applying game theory in analyzing competition in the shipping industry. We considered two different service strategies: one with container mega-ships and the other with ordinary ships, having assumed that the container mega-ship service used a hub-and-spoke network while the ordinary ship service employed a multi-port-calling network. The optimal multi-port-calling route was found by the Traveling Salesman Problem (see Appendix A). The optimal hub-and-spoke network was identified by the Minisum location problem (see Appendix B). Having applied the solution methods developed here to two trade routes: Asia-Europe and Asia-North America, it was found that the container mega-ship service was competitive in all scenarios for the European trade, while it was viable for the North American trade only when the freight rate and feeder costs were low. It is noticed that the container mega-ship was "viable", not only because that strategy was profitable but also because the choice of the strategy was non-regrettable in the competition. It is interesting also to note that through the model applications the relationship between ship size selection and freight rate became very evident.

Although this study tried to analyze the viability of the so-called container mega-ship by the game approach with limited scenario settings, its consequences are insightful; since, in the past literature ship routing and related research topics are examined by minimizing the relevant transportation cost or by the maximization of profit with assumption of the constant cargo share. To authors' knowledge, no studies address ship routing by explicitly taking into consideration competitive circumstances as they occur in the shipping market. This study models the shipping market (or actually the shipping network construction) with respect to multiple players involved with different or same strategies but with differentiated cost structures, especially from the viewpoint of ship size. This paper contributes to the research on the economic viability of container mega-ships by revealing the relationship between their ship size, the cost structure of ship operator and the market freight rate in competitive situations.

Appendix A. Multi-port calling network composition

The sailing network for a multi-port calling service is defined by the solution of problem [MPC]. As a solution of [MPC] is not easily identified, it is obtained as an approximate solution of a simpler formulation [MPC] as follows:

[MPC] Minimize $$\sum_{i \in N} \sum_{j \in N} CT_{ij} x_{ij} \tag{A.1}$$

Subject to $$\sum_{j \in N} x_{ij} = 1 \qquad \forall i \in N, \tag{A.2}$$

$$\sum_{i \in N} x_{ij} = 1 \qquad \forall j \in N, \tag{A.3}$$

$$\sum_{i \in Q} \sum_{j \notin Q} x_{ij} \geq 1 \qquad \forall Q \subset N, \tag{A.4}$$

$$x_{ij} \in \{0,1\} \qquad \forall i,\ j \in N. \tag{A.5}$$

The above problem is a classical Traveling Salesman Problem (TSP). Objective

(A.1) is to minimize the total roundtrip sailing time. Constraint sets (A.2) and (A.3) ensure that each and every port is visited only once. Constraint set (A.4) does not form a set of small tours visiting the ports.

The TSP has no efficient exact solution methods, but some efficient heuristics are available. The solution of the TSP defines a multi-port-calling route with the minimum sailing time, which one unit of shipment spends in traveling from one port and returning to the same port after visiting all the other ports, having no turnaround times in the ports. The heuristic we employed for the TSP is a well-known method, the “Nearest-Neighbor” method, which is as follows:

Step 1: Select one port as the starting node.

Step 2: Proceed to an unvisited port, which is the nearest to the present port.

Step 3: Repeat Step 2 until all ports are visited.

Step 4: Go back to the starting node to form one roundtrip.

Assuming a symmetric network where the distance (or the sailing time) is not directional, we have two paths associated with the resulting tour: a clockwise path and a counterclockwise path. By computing the travel time along each path including the turnaround times in the ports, we identify the best multi-port-calling route with the minimum travel time weighted by the cargo traffic.

Appendix B. Hub-and-spoke network composition

No efficient methods exist that define the optimal solution to the hub-and-spoke problem [H&S]. If we assume that the trading regions are located far apart as is the case in most international trades (i.e., the trunk lines do not substantially vary depending on the hub locations), the problem will be split into two independent hub-selection problems. Assuming undirected distances like the multi-port-calling, each of them is reduced to the so-called Minisum location problem as defined in the following:

[H&S] Minimize $$OCT = \sum_{i \in N^{\alpha}} \sum_{j \in N^{\alpha}} VT^{\,i} CT_{ij} x_{ij} \tag{B.1}$$

Subject to $$\sum_{i \in N^{\alpha}} z_i = 1, \tag{B.2}$$

$$x_{ij} = z_j \qquad \forall i, j \in N^{\alpha}, \qquad \text{(B.3)}$$

$$x_{ij} \in \{0,1\} \qquad \forall i, j \in N^{\alpha}, \qquad \text{(B.4)}$$

$$z_j \in \{0,1\} \qquad \forall j \in N^{\alpha}. \qquad \text{(B.5)}$$

The above problem refers to region A where VT^i is the total amount of exports and imports associated with port i. Objective (B.1) is the minimization of the total transit times weighted by the shipment volume in a region. Constraint sets (B.2) and (B.3) have already appeared and been explained in Section 3.2.2. Note that no turnaround times are considered in [H&S] as we make the assumption that ports selected as hubs have the same handling capabilities and performance characteristics.

The optimal solution to [H&S] is easily identified by the following enumerating procedure:

Step 1: Select one port as a hub.

Step 2: Compute the associated objective function value.

Step 3: Repeat Steps 1 and 2 until all ports are examined.

Step 4: Select as the hub the port with the minimum objective function value.

Appendix C. Traffic in the trades between Asia and Europe and between Asia and North America

Weekly traffic in the trade between Asia and Europe and the one between Asia and North America is shown in Table C.1. Note that identical exports and imports of Asian ports are applied to both Europe and North America.

Table C.1 about here

References

Bergantino, A.S., Veenstra, A.W., 2002. Interconnection and co-ordination: an application of network theory to liner shipping. *International Journal of Maritime Economics* **4**, 231-248.

Chatterjee, K., Samuelson, W.F., 2001. *Game Theory and Business Applications*. Kluwer Academic Publishers, Boston.

Cho, S.-C., Perakis, A.N., 1996. Optimal liner fleet routeing strategies. *Maritime Policy & Management* **23**, 249-259.

Cullinane,K., Khanna, M., 2000. Economies of scale in large containerships: optimal size and geographical implications. *Journal of Transport Geography* **8**, 181-195.

Damas, P., 2001. Big ships big problem. *American Shipper* **43**, 12-22.

Damas, P., 2002. Do mega-ships save money?. *American Shipper* **44**, 68-69.

Drewry, 1997. *Ship Costs: The Economics of Acquisition and Operation*. Drewry Shipping Consultants, London.

Drewry, 2001. *Post-panamax: The Next Generation*. Drewry Shipping Consultants, London.

Gilman, S., 1999. The size economies and network efficiency of large containerships. *International Journal of Maritime Economics* **1**, 39-59.

Imai, A., Papadimitriou S., 1997. A containerized liner routing in eastern Asia. *Infrastructure Planning Review* **14**, 843-850.

Ircha, M.C., 2001. Serving tomorrow's mega-size containerships: the Canadian solution. *International Journal of Maritime Economics* **3** , 318-332.

Lim, S.-M., 1998. Economies of scale in container shipping. *Maritime Policy & Management* **25**, 361-373.

Mourao, M.C., Pato, M.V., Paixao, A.C., 2001. Ship assignment with hub and spoke constraints. *Maritime Policy & Management* **29**, 135-150.

McLellan, R.G., 1997. Bigger vessels: how big is too big. *Maritime Policy & Management* **24**, 193-211.

Myerson, R.B., 1991. *Game Theory*. Harvard University Press, Cambridge.

Stahl, S., 1999. *A Gentle Introduction to Game Theory*. American Mathematical Society, Providence.

UNCTAD, 2001. *Review of Maritime Transport, 2001*. United Nations, New York.

van der Jagt, N., 2003. Please listen. *Containerisation International* **36**, 27.

Wijnolst, N., Wergeland, T., 1997. *Shipping*. Delft University Press, Delft.

Wijnolst, N., Scholtens, M., Waals, F., 1999. *Malacca-Max*. Delft University Press, Delft.

Wijnolst, N., Waals, F., Bello F., Gendronneau, Y., van Kempen, D., 2000. *Malacca-Max[2]*. Delft University Press, Delft.

Willmington, R., 2002. The bigger the better?. *Containerisation Internationa* **35**, 52-53.

Yang, Z., 1999. Analysis of container port policy by the reaction of an equilibrium shipping market. *Maritime Policy & Management* **26**, 369-381.

Table 1. Traffic matrix of the sample ports (in TEUs)

Destination ports / Origin ports	A	B	C	D	E	F
A	-	-	-	30	18	16
B	-	-	-	10	12	28
C	-	-	-	20	20	6
D	6	18	8	-	-	-
E	8	4	10	-	-	-
F	6	14	10	-	-	-

Table 2. Transit time matrix (in days)

Destination ports / Origin ports	A	B	C	D	E	F
A	-	-	-	16/15	20/19	24/18
B	-	-	-	14/14	18/18	22/17
C	-	-	-	12/12	16/16	20/15
D	21/15	24/14	26/12	-	-	-
E	17/19	20/18	22/16	-	-	-
F	13/18	16/17	18/15	-	-	-

Time by multi-port-calling / Time by hub-and-spoke

Table 3. Share matrix

Origin ports \ Destination ports	A	B	C	D	E	F
A	-	-	-	0.48/0.52	0.49/0.51	0.43/0.57
	-	-	-	14.5/15.5	8.8/9.2	6.9/9.1
B	-	-	-	0.5/0.5	0.5/0.5	0.44/0.56
	-	-	-	5.0/5.0	6.0/6.0	12.2/15.8
C	-	-	-	0.5/0.5	0.5/0.5	0.43/0.57
	-	-	-	10.0/10.0	10.0/10.0	2.6/3.4
D	0.42/0.58	0.37/0.63	0.32/0.68	-	-	-
	2.5/3.5	6.6/11.4	2.5/5.5	-	-	-
E	0.53/0.47	0.47/0.53	0.42/0.58	-	-	-
	4.2/3.8	1.9/2.1	4.2/5.8	-	-	-
F	0.58/0.42	0.52/0.48	0.45/0.55	-	-	-
	3.5/2.5	7.2/6.8	4.5/5.5	-	-	-

First row [ratio for multi-port-calling/ratio for hub-and-spoke]

Second row [share for multi-port-calling/share for hub-and-spoke] in TEUs

Table 4. Revenues (US$’ 000) of a company for the Asia-Europe trade

	The competitor’s strategy	
A company’s strategy	Multi-port-calling	Hub-and-spoke
(i) High freight rate		
Multi-port-calling	18,764	20,182
Hub-and-spoke	17,346	18,764
(ii) Medium freight rate		
Multi-port-calling	12,510	13,455
Hub-and-spoke	11,564	12,510
(iii) Low freight rate		
Multi-port-calling	9382	10,091
Hub-and-spoke	8673	9382

Table 5. Profit matrixes (US$' 000) and optimal service mixes for the Asia-Europe trade (high freight rate)

A's strategy	E's strategy Multi-port-calling	Hub-and-spoke
(i) Profits (A / E) with feeder cost/TEU=$50		
Multi-port-calling	10,467 / 9,480	11,885 / 10,417
Hub-and-spoke	10,834 / 10,898	**12,252 / 11,834**
(ii) Profits (A / E) with feeder cost/TEU=$100		
Multi-port-calling	10,467 / 9,480	11,885 / 10,417
Hub-and-spoke	10,814 / 10,898	**12,232 / 11,816**
(iii) Profits (A / E) with feeder cost/TEU=$500		
Multi-port-calling	10,467 / 9,480	11,885 / 10,244
Hub-and-spoke	10,661 / 10,898	**12,079 / 11,662**

Bold: Its relevant entry is the optimal strategies for companies A and E

Table 6. Profit matrixes (US$' 000) and optimal service mixes for the Asia-Europe trade (medium freight rate)

A's strategy	E's strategy Multi-port-calling	Hub-and-spoke
(i) Profits (A / E) with feeder cost/TEU=$50		
Multi-port-calling	4212 / 3225	5158 / 4635
Hub-and-spoke	5052 / 4170	**5997 / 5580**
(ii) Profits (A / E) with feeder cost/TEU=$100		
Multi-port-calling	4212 / 3225	5158 / 4615
Hub-and-spoke	5032 / 4170	**5978 / 5561**
(iii) Profits (A / E) with feeder cost/TEU=$500		
Multi-port-calling	4212 / 3225	5158 / 4462
Hub-and-spoke	4879 / 4170	**5824 / 5407**

Bold: Its relevant entry is the optimal strategies for companies A and E

Table 7. Profit matrixes (US$' 000) and optimal service mixes for the Asia-Europe trade (Low freight rate)

	E's strategy	
A's strategy	Multi-port-calling	Hub-and-spoke
(i) Profits (A / E) with feeder cost/TEU=$50		
Multi-port-calling	1085 / 97	1794 / 1744
Hub-and-spoke	2160 / 806	**2869 / 2452**
(ii) Profits (A / E) with feeder cost/TEU=$100		
Multi-port-calling	1085 / 97	1794 / 1724
Hub-and-spoke	2141 / 806	**2850 / 2433**
(iii) Profits (A / E) with feeder cost/TEU=$500		
Multi-port-calling	1085 / 97	1794 / 1571
Hub-and-spoke	1988 / 806	**2697 / 2280**

Bold: Its relevant entry is the optimal strategies for companies A and E

Table 8. Revenues (US$' 000) of a company for the Asia- North America trade

A company's strategy	The competitor's strategy: Multi-port-calling	The competitor's strategy: Hub-and-spoke
(i) High freight rate		
Multi-port-calling	24,682	27,453
Hub-and-spoke	21,910	24,682
(ii) Medium freight rate		
Multi-port-calling	16,455	18,302
Hub-and-spoke	14,608	16,455
(iii) Low freight rate		
Multi-port-calling	12,341	13,727
Hub-and-spoke	10,955	12,341

Table 9. Profit matrixes (US$’ 000) and optimal service mixes for the Asia-North America trade (high freight rate)

	E’s strategy	
A’s strategy	Multi-port-calling	Hub-and-spoke
(i) Profits (A / E) with feeder cost/TEU=$50		
Multi-port-calling	**17,452 / 16,766**	20,224 / 15,967
Hub-and-spoke	16,236 / 19,537	19,008 / 18,739
(ii) Profits (A / E) with feeder cost/TEU=$100		
Multi-port-calling	**17,452 / 16,766**	20,224 / 15,948
Hub-and-spoke	16,217 / 19,537	18,989 / 18,720
(iii) Profits (A / E) with feeder cost/TEU=$500		
Multi-port-calling	**17,452 / 16,766**	20,224 / 15,795
Hub-and-spoke	16,064 / 19,537	18,836 / 18,566

Bold: Its relevant entry is the optimal strategies for companies A and E

Table 10. Profit matrixes (US$' 000) and optimal service mixes for the Asia-North America trade (medium freight rate)

A's strategy	E's strategy Multi-port-calling	Hub-and-spoke
(i) Profits (A / E) with feeder cost/TEU=$50		
Multi-port-calling	9225 / 8538	**11,072 / 8664**
Hub-and-spoke	8933 / 10,386	10,781/ 10,512
(ii) Profits (A / E) with feeder cost/TEU=$100		
Multi-port-calling	9225 / 8538	**11,072 / 8645**
Hub-and-spoke	8914 / 10,386	10,762 / 10,493
(iii) Profits (A / E) with feeder cost/TEU=$500		
Multi-port-calling	**9225 / 8538**	11,072 / 8491
Hub-and-spoke	8760 / 10,386	10,608 / 10,339

Bold: Its relevant entry is the optimal strategies for companies A and E

Table 11. Profit matrixes (US$' 000) and optimal service mixes for the Asia-North America trade (low freight rate)

	E's strategy	
A's strategy	Multi-port-calling	Hub-and-spoke
(i) Profits (A / E) with feeder cost/TEU=$50		
Multi-port-calling	5111 / 4425	6497 / 5012
Hub-and-spoke	5281 / 5810	**6667 / 6398**
(ii) Profits (A / E) with feeder cost/TEU=$100		
Multi-port-calling	5111 / 4425	6497 / 4993
Hub-and-spoke	5262 / 5810	**6648 / 6379**
(iii) Profits (A / E) with feeder cost/TEU=$500		
Multi-port-calling	5111 / 4425	**6497 / 4840**
Hub-and-spoke	5108 / 5810	6495 / 6225

Bold: Its relevant entry is the optimal strategies for companies A and E

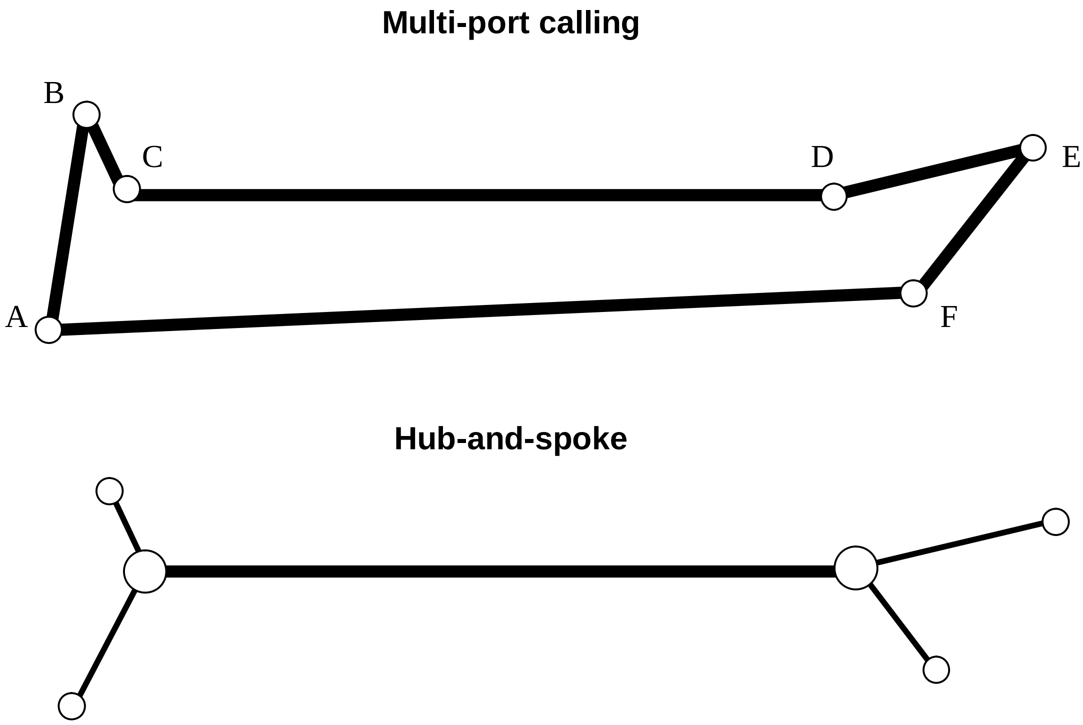

Fig. 1. Service networks

Table C.1. Weekly trade volumes (in TEUs) for Asia-Europe and Asia-North America

Area	Port	Export	Import
Asia	Kobe	698	843
	Hong Kong	3908	3908
	Kaohsiung	1792	1708
	Keelung	581	592
	Laem Chabang	402	140
	Pusan	1334	1200
	Shanghai	927	787
	Singapore	3936	3958
	Yokohama	1256	1306
	Xiamen	167	167
Europe	Antwerp	3045	3037
	Felixstowe	1607	1602
	Hamburg	3213	3447
	Le Havre	1214	1248
	Rotterdam	5530	5665
North America	Los Angeles	8609	9845
	Oakland	2368	1813
	Portland	484	207
	Seattle	3148	3135