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Multi-port versus hub-and-spoke port calls by containerships

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ABSTRACT

This paper addresses the design of container liner shipping networks taking into consideration container management issues including empty container repositioning. We examine two typical service networks with different ship sizes: Multi-port calling by conventional ship size and Hub-and-Spoke by mega-ship. The entire solution process is performed in two phases: the service network design and container distribution. A wide variety of numerical experiments are conducted for the Asia-Europe and Asia-North America trade lanes. In most scenarios the Multi-port calling is superior in terms of total cost, while the Hub-and-Spoke is more advantageous in the European trade for a costly shipping company.

Keywords: Container transportation; Empty Container; Network design; Mathematical programming

1. Introduction

Over the past few years there has been a rapid 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", which are very 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. In this background, the container liner shipping market witnessed in 2006 the deployment, by an Europe-based shipping line, of the so-called mega-containership with a carrying capacity of more than 10,000TEUs. This ship-size could become a standard for deepsea shipping as other liner companies are also placing orders to ship yards for such huge containerships.

The issue of empty containers, as an intrinsic element of vehicle fleet management and overall logistics scheduling process, is one of the most intractable and important problems that the container shipping industry is confronted with and as such both practitioners and researchers have been paying much attention to it. The purpose of this study is to examine preferred liner shipping networks in the mega-containership era with consideration of container fleet management issues. Large numbers of loaded and subsequently empty containers as the result of trade flow imbalance are continuously being moved from one place to another on these huge size vessels. Thus, container management issues are having a greater impact on the shipping network structures than ever before.

This study compares two different design alternatives of liner shipping networks: the Hub-and-Spoke network (H&S) by mega-containerships and the Multi-port-calling network (MPC) by smaller containerships. The authors has already studied, in Imai et al.

(2006), the economic viability of mega-containership by using relatively simplified game models with hypothetical case study scenarios. That study assumed a sufficiently huge fleet size of containers operated by competing shipping lines in the game; therefore the study ignored, for the game analysis, the costs related to container investment and empty container repositioning. These issues are however crucial for shipping companies operating in the major world trade routes. Although these problems are expected and partially unavoidable, shipping lines have been attempting the downsizing of their container fleet through the timely repositioning of containers. From this point of view, the study of Imai et al. (2006) does not necessarily reflect the present situation of liner shipping.

The shipping models we employ in this paper explicitly take into account container management, i.e., container fleet size determination and empty container repositioning. Empty container repositioning is an operation planning issue, while network design is a tactical (or even strategic) one. It is almost impossible to consider sophisticated repositioning of empty containers at the strategic shipping network (or route) construction phase. However, shipping lines try to optimize (not necessarily by theory but empirically) the fleet size and repositioning practice in a given shipping network as a determinant of strategic planning. Thus, in the comparison between the MPC and H&S networks, the choice between the two network alternatives may be affected by the consideration of container management. For this reason, in this paper we investigate if optimization of container fleet size and empty repositioning affect the network choice.

As mentioned above, this study considers the MPC and H&S networks, as shown in Fig.1, The entire network analysis is performed in two-phases; in the first phase MPC and H&S are optimally constructed for a given set of calling ports in a trade lane without taking

into account empty container repositioning. In the second phase, the optimization of container fleet size determination and empty container repositioning are performed simultaneously in the obtained MPC and H&S networks. Assuming the same transport demand and its complete satisfaction by the shipping service, the costs (or profits if the revenue is taken into account) are compared in order to choose the most suitable network from the MPC and H&S.

Fig. 1

In the study of Imai et al. (2006), the construction of MPC and H&S networks were formulated with the objective of the minimization of O-D traffic travel length (in time) weighted by traffic volume. However, for easy computation the MPC was identified as the Traveling Salesman Problem, while H&S was constructed as the Minisum Location Problem. However, these solution procedures have a weakness: The MPC is identified with the total travel length and not with travel length that is weighted by its associated traffic, while the H&S separately finds hubs in end areas of a trade lane. Therefore, networks constructed by these simplified methods may be far inferior to the optimal ones.

In order to overcome the above issues, this paper finds the MPC network with the minimization of the total O-D traffic's travel length weighted by traffic volume by using a genetic algorithm (GA)-based heuristic. The MPC has similar model characteristics to the Traveling Salesman Problem with Pickup and Delivery, which finds one round route starting from a depot and returning to the depot after visiting all customers whereas pickup customers are visited before counterpart delivery customers without overutilization of

vehicle capacity. See chapter 1 of Toth and Vigo (2002) for details of the Traveling Salesman Problem with Pickup and Delivery. The MPC does not care about such precedence constraints, since a ship is not based in any specific port and therefore pickup cargoes are transported to delivery ports in any calling sequence. Also, the MPC does not take into account a ship's capacity overutilization, since shipping capacity is, in general, not tied to the fluctuation in shipping demand.

For the H&S, this study identifies the hub in the respective end area of a trade lane at the same time so as to minimize the total of O-D traffic's travel length weighted by traffic volume. The algorithm is based on the brute-force method.

The paper is organized as follows: Section 2 reviews the relevant literature. Section 3 presents the problem formulation. Section 4 demonstrates a solution procedure. Section 5 illustrates computational experiments. Finally Section 6 concludes this study and discusses future research directions.

2. Literature review

Existing literature for containership routing problems is rather limited. We will here review only relatively new research works. Bendall and Stent (2001) propose a model for determining the optimal fleet configuration and associated fleet deployment plan in a containership hub and spoke application. Imai et al. (2006) study the economic viability of mega containership by applying game theory, assuming two strategies for two game players: MPC of two port callings per week by 5,000TEU ships and H&S of one port calling by a 10,000TEU mega-ship. Their results show that the mega-ship is highly viable for the Asia-Europe trade lane while it is advantageous in some cases for the Asia-North America

route.

Considerable research has been performed on the subject of empty container management. Imai and Rivera (2001) deal with fleet size planning for refrigerated containers where they determine the necessary number of containers required to meet predicted future transportation demand. Choong et al. (2002) develop an Integer Programming formulation for empty container relocation with use of both long and short-term leased containers. However, the treatment of the short-term leased container in their study is not appropriate, since the cost of the short-term leased containers is independent of the lease length. The studies of Imai and Rivera (2001) and Choong et al. (2002) deal with empty container distribution in a relatively broad geographical area. In contrast, the following two papers focus on empty container repositioning in the hinterland of a specific port, in spite of many similarities that exist in theory and in practice with repositioning in a broad area. Li et al. (2004) study the empty container allocation in a port with the aim to reduce redundant empty containers. They consider the problem as a nonstandard inventory problem with simultaneous positive and negative demand under a general holding cost function. Also, Li et al. (2007) recently extend the model of Li et al. (2004) to a model for a multi-port case. Erera et al. (2005) treat a fleet management problem for a quite unique type of container: tank container. They formulate the problem as a multi-commodity flow problem. They solve the problem using a commercial solver and demonstrate that by integrating container routing and repositioning decisions in a single model, the total operating costs and fleet size can be reduced. Jula et al. (2006) consider empty container repositioning, which they refer to as empty container reuse, from a different perspective than that of the above studies. Their aim is the reduction of the traffic

congestion in the Los Angeles and Long Beach port area caused heavily by empty maritime container traffic. A network flow formulation is constructed, in order to optimize empty container movements from consignees to shippers directly and/or via inland depots. The problem is solved in two phases: in the first phase they deal with the model transformation to a bipartite transportation network (i.e. a classical Transportation Problem) and in the second phase they solve the Transportation Problem by Linear Programming. Coslovich et al. (2006) discuss a container fleet management problem by formulating it as an Integer Programming. They propose a decomposition method for solving that problem. From the original formulation they generate three decomposed sub-problems: pairing definition, resource assignment and container repositioning. They evaluate the solution quality by using upper and lower bounds. Shintani et al. (2007) propose a method to design container shipping networks for shortsea shipping. Taking into account empty container management, they develop a GA-based heuristic for network design where all the cargo traffic is not necessarily satisfied if it is not profitable from the viewpoint of the entire shipping business. Lam et al. (2007) propose a dynamic stochastic model for empty container repositioning. The model is constructed for the case with two-ports and two-voyages. They develop a heuristic that produces a good approximate solution, compared with an exact solution. Also, they extend that model to a realistic multi-port multi-voyage case.

3. Problem description

3.1. Network construction phase

(1) MPC network construction

For the formulations of MPC and H&S network constructions, refer to Imai et al.

(2006). The outline of the MPC construction is as follows. Given a set of ports to be called and loaded container traffic between origin and destination port pairs, we find one round route calling at all the ports once and exactly once so as to minimize the total travel length weighted by traffic's volume. As mentioned in section 1, there is no ship's carrying restriction as commonly seen in the container liner services. The MPC network is constructed by GA. As GA is widely used for optimization problems, it is not described in detail in this paper. The chromosome used in a GA computation consists of a series of digits that represents a sequence of calling ports. The procedure is performed over a predetermined number of generations, where at each generation chromosomes are changed through crossover and mutation so as to hand over better chromosomes (calling sequences) to the subsequent generations. Chromosomes to be handed over to the next generation are chosen based on the fitness value that is, in this study, the reciprocal of the total travel length weighted by loaded container traffic's volume. This weighted travel length associated with a chromosome is computed by $\sum_i LGT_i \cdot TV_i$ where i is an OD pair number of loaded container traffic, LGT_i is the travel length between OD pair i on the MPC network defined by the chromosome and TV_i is loaded container traffic's volume between OD pair i .

Based on some preliminary tests, we set 200 to the number of generations, 0.9 to crossover rate and 0.08 to mutation rate for the GA-heuristic.

(2) H&S network construction

The outline of H&S construction is as follows. Given two sets of calling ports, each set in a region of a trade lane, and traffic volumes between origin and destination port pairs

over the trade lane; we find two ports as hubs, each hub in a region, so as to minimize the total traffic's travel length weighted by loaded container traffic's volume. In the H&S, there is also no ship's carrying capacity restriction. We utilize a brute-force method for choosing a hub pair in the entire trade lane. First the procedure lists up all combinations of hub pair where a hub is chosen from each area of the trade lane. Next, for each hub pair, we calculate the total of OD travel lengths weighted by associated OD traffic's volume through the hub pair by $\sum_i LGT_i \cdot TV_i$. Finally, from the total weighted OD travel lengths of all the hub pairs that are computed as above we choose a hub pair with the minimum weighted OD travel length.

3.2 Container repositioning phase

(1) Model outline

For each network alternative constructed in the first phase, we develop, for the planning horizon, a container flow network in a space-time configuration based on ship voyages, which call at the ports in the sequence being determined by the first phase. Fig. 2 graphically illustrates five ships' voyages calling at four ports in a space-time network for MPC.

Fig. 2

In the second phase, assuming that all cargo demand is satisfied which in reality is a normal practice, a ship operator has to lease containers when no own empty containers are available for a specific demand. To avoid leasing, the operator may opt for a larger own

container fleet (or long-term leased containers). Therefore, a decision that defines the own fleet size and the short-term (spot) leased fleet has to be made so as to minimize the total container management costs. Note that both fleet sizes are evaluated in different planning horizons: The own fleet is a strategic (or tactical) decision making, while the short-term leased fleet is an operational (or daily, weekly) decision. In practice, the decision of the own fleet size may be made based on the transportation demand forecast, but theoretically, it is made by the minimization of the total cost of the own and leased fleets based on the demand. Also, other cost factors such as storage cost for keeping the own empty fleet and handling costs of empty container repositioning have to be taken into account in the decision making process.

We compare two typical shipping networks: MPC and H&S. The MPC is provided by two ship callings per week (a ship calls every 3 or 4 days) by 5,000TEU ships, while the H&S has one calling per week by a 10,000TEU ship. In H&S, a feeder ship connects the selected hub port in the trade region of the lane with all other ports in the trade region with one calling per week.

Note that whereas the network construction phase determines a calling sequence of the ports, the voyage calling sequences can be easily constructed as a form of the space-time network. In more detail, we can compute the number of ships to be deployed by the following equation:

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

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. The CI is 3.5 and 7 days for MPC and H&S, respectively. Based on FS , the space-time network's configuration is geographically

determined.

In this study, we focus on container flow in detail, where a container with cargo arrives at a port by a calling ship and is delivered to a consignee. It becomes empty at the consignee's site and then returns to the port for storage. It is sent to a shipper on request and is stuffed. Then, it comes back to the port and is loaded on a calling ship. This detailed container itinerary in and around the port hinterland is portrayed in Fig. 3, where

$G_i(t)$: number of empty containers transferred by a ship to port i at time t

$N_i(t)$: number of empty containers required to be sent from port i to shippers in its hinterland for stuffing at time t

$O_i(t)$: number of empty containers transferred by a ship from port i at time t

$R_i(t)$: number of empty containers returning, after import, from consignees of port i at time t

$S_i(t)$: number of empty containers stored at port i at time t

Fig. 3

In the container shipping networks of MPC and H&S, we formulate the problem of own and leased container flow as the mathematical programming problem with the objective function of minimizing the total cost of container management, which is described in the next section, and solve the problem optimally by a commercial solver.

(2) Formulations

There are two fundamental container flows in both MPC and H&S models: own and leased containers' flows. Through the space-time network shown in Fig. 2, only the own container flow has to be preserved at nodes in calling ports, which are detailed as those in Fig. 3. When there is a shortage of own empty containers at loading ports, some containers are leased to fulfill the shortage, but they are not explicitly traveling through the network because leased containers ought to stay in the network till their shipment is completed and then they exit from the network. Note, however, that their flows are preserved on board a ship when traveling to the destinations in order to compute an empty carrying space onboard the ship that is used for empty containers to be repositioned.

The assumptions made are as follows:

- (i) The leased containers that this model considers are short-term (or spot) ones.
- (ii) Homogeneous containers are assumed.
- (iii) All of the cargo demand at all calling ports is to be satisfied.
- (iv) Containers travel through a hinterland for stuffing at shippers and unloaded at consignees for a specific time period.
- (v) The costs incurred for repositioning own empty containers cover only loading costs at origin ports of repositioning and unloading costs at destination ports. In the H&S, the feeder costs for repositioning empties by feeder ships between hubs and local ports are also included.
- (vi) For validity of this model to be used in a real situation, one hypothetical shipping line is assumed in the case that shipping service is provided by one individual shipping line like Maersk or a shipping alliance. In more detail, when the service is operated by the alliance, normally containers are not shared by the alliance members. However, the alliance is

interpreted as a representative of all the shipping lines in the alliance, so that any empty containers can be repositioned to any places and be used for the next shipments.

(a) MPC formulation

The formulation of MPC may be constructed as follows where “empty containers” in the subsequent discussions refer to “empty own containers”:

[MPC]

$$\text{Minimize} \quad C^F CF + \sum_{t \in T} \sum_{i \in I} \sum_{j \in I} (C_i^H + C_j^H) E_{ij}(t) + \sum_{t \in T} \sum_{i \in I} C_i^S S_i(t) + \sum_{t \in T} \sum_{i \in I} \sum_{j \in I} C_{ij}^L L_{ij}(t) \quad (1)$$

$$\text{Subject to} \quad S_i(t) = S_i(t-1) + R_i(t) + G_i(t) - N_i(t) - O_i(t)$$

$$\forall t \in T, i \in I, \quad (2)$$

$$R_i(t) = D_i(t - \alpha_i) \quad \forall t \in T, i \in I, \quad (3)$$

$$D_i(t) = \sum_{h \in I} B_{hi}(t - \beta_{hi}) \quad \forall t \in T, i \in I, \quad (4)$$

$$G_i(t) = \sum_{h \in I} E_{hi}(t - \beta_{hi}) \quad \forall t \in T, i \in I, \quad (5)$$

$$O_i(t) = \sum_{j \in I} E_{ij}(t) \quad \forall t \in T, i \in I, \quad (6)$$

$$N_i(t) = \sum_{j \in I} B_{ij}(t + \alpha_i) \quad \forall t \in T, i \in I, \quad (7)$$

$$L_{ij}(t) = F_{ij}(t + \alpha_i) - B_{ij}(t + \alpha_i) \quad \forall t \in T, i, j \in I, \quad (8)$$

$$S_i(t) \leq H_i \quad \forall t \in T, i \in I, \quad (9)$$

$$CF = \sum_{i \in I} \{S_i(0) + R_i(1) + G_i(1)\} \quad (10)$$

$$\sum_{q=2}^{|I|} \{E_{1q}(t) + F_{1q}(t)\} + \sum_{p=3}^{|I|} \sum_{q=2}^{p-1} \{E_{pq}(t - \beta_{p1}) + F_{pq}(t - \beta_{p1})\} \leq V$$

$$\forall t \in T, \quad (11)$$

$$\sum_{q(\neq i)=1}^{|I|} \{E_{iq}(t) + F_{iq}(t)\} + \sum_{p=1}^{i-1} \sum_{q=i+1}^{p-1} \{E_{pq}(t - \beta_{pi}) + F_{pq}(t - \beta_{pi})\} \\ + \sum_{p=i+2}^{|I|} \sum_{q=i+1}^{p-1} \{E_{pq}(t - \beta_{pi}) + F_{pq}(t - \beta_{pi})\} \leq V \quad \forall t \in T, i(\neq 1, |I|) \in I, \quad (12)$$

$$\sum_{q=1}^{|I|-1} \{E_{|I|q}(t) + F_{|I|q}(t)\} + \sum_{p=2}^{|I|-1} \sum_{q=1}^{p-1} \{E_{pq}(t - \beta_{p|I|}) + F_{pq}(t - \beta_{p|I|})\} \leq V \\ \forall t \in T, \quad (13)$$

$$CF \geq 0 \text{ and integer} \quad (14)$$

$$B_{ij}(t), E_{ij}(t), L_{ij}(t) \geq 0 \text{ and integer}, \quad \forall t \in T, i \in I, j \in I \quad (15)$$

$$D_i(t), G_i(t), N_i(t), O_i(t), R_i(t), S_i(t) \geq 0 \text{ and integer}, \forall t \in T, i \in I \quad (16)$$

where,

I : set of calling ports

T : set of chronological time

V : carrying capacity of a deepsea vessel

α_i : time taken by a container travel through the hinterland of port i for import or export

β_{ij} : transit time from port i to port j

C_{ij}^L : leasing cost of a container for use from port i to port j

C_i^H : handling (i.e., loading or unloading) cost at port i per container

C_i^S : storage cost of a container at port i

C^F : capital cost of a container for the planning horizon

H_i : storage capacity of empty containers at port i

$F_{ij}(t)$: number of loaded containers (own and leased) leaving port i at t for port j .

$F_{ij}(t)$ is given cargo traffic

CF : number of own containers

$D_i(t)$: number of loaded own containers imported to port i at time t

$L_{ij}(t)$: number of leased containers to be used for transportation that leaves port i at time t for

j

$B_{ij}(t)$: number of loaded own containers transported, leaving port i at time t for port j

$E_{ij}(t)$: number of empty containers transferred by ships, leaving port i at time t for j

Notice that all the other variables in the formulation are defined previously. CF , $E_{ij}(t)$, $L_{ij}(t)$ and $S_i(t)$ are decision variables and $B_{ij}(t)$, $D_i(t)$, $G_i(t)$, $N_i(t)$, $O_i(t)$ and $R_i(t)$ are auxiliary variables, where a coordinate (i, t) defines a specific node that represents a ship calling at port i at time t as shown in Fig. 2.

Objective (1) is the minimization of the total cost comprised of the following cost factors: the capital costs of own container fleet, repositioning costs of empty containers, empty container storage costs at ports and leasing container costs. In Fig. 3, the container flows at a port is shown in detail. Unloaded empty containers from a calling ship, those kept stored at the port from previous calling and empty containers that return from importing consignees in the hinterland are summed up to form the total empty container inventory that can be used for export cargos arising in the hinterland, for repositioning to other ports on request and for the empty stock at the present port for the next time period. Constraints (2) guarantee this empty container flow conservation. Eqs. (3) ensure that empty container return from the hinterland comes from imported containers unloaded from a calling ship in the previous time period. Eqs. (4) imply that unloaded containers are the sum of containers

imported from different ports h . Eqs. (5) assure that unloaded empty containers at port i come from different ports h . Eqs. (6) imply that the total of empty repositioning from port i , $O_i(t)$, go to different ports j . Eqs. (7) ensure that the total of empty containers sent to shippers in the hinterland is equal to the total cargos to be exported by own containers. Eqs. (8) guarantee that the total quantities of leased containers used from ports i to j are equal to the shortage of containers to be shipped as export cargos by a future calling ship at the port. Those export shipments actually will be made in α_i from the time when empty containers are requested. Thus, leased containers at time t , i.e., the left hand side of (8) are utilized to fulfill the shortage of empty containers for the shipments at $t + \alpha_i$, i.e., the right hand side of (8). Constraints (9) assure that the empty container quantities stocked at a port is restricted by the port's storage capacity. Constraint (10) provides all the own containers to the flow network at initial nodes in the space-time network. This implies that at the initial time over the planning horizon in the space-time network, the total own container volumes available at Nodes $(i,1)$ in Fig. 3 (or the total incoming traffic flow into these nodes, i.e., $\sum_{i \in I} \{S_i(0) + R_i(1) + G_i(1)\}$) is equal to CF . All empty repositioning is performed by own ships; therefore, the number of empties to be sent from a port is restricted by the spare space of the ship's capacity after loading export containers at the port. All of constraints sets (11)-(13) guarantee this relationship. In other words, these constraint sets determine the excess capacity of a ship to reposition empty containers from ports of container surplus to those of shortage. Set (11) is applied for port 1 as a departing port of a calling ship, (13) is for the last port in the entire one round trip of a voyage where $|I|$ is the cardinality of set I (i.e., the last port to be called), and (12) is dedicated to all the other ports. In all these sets,

the first term implies the number of containers empty or loaded that depart from the port of concern, i , while the second term provides container traffic through the voyage segment from port i to port j .

Here we describe the details of derivation of constraints (11)-(13). As mentioned above, there are three cases regarding departing port i among the calling port set I . We derive only constraints (12), while constraints (11) and (13) can be easily derived in a similar way. The total of all loaded and empty traffic through port i and its next port to be called along the voyage must be no more than the ship's capacity. In Fig. 4, the thick solid line is the voyage segment in concern. The first term of (12), $\sum_{q(\neq i)=1}^{|I|} \{E_{iq}(t) + F_{iq}(t)\}$, is the traffic (loaded and empty) departing from port i . The traffic through port i consists of two parts. The second term of the left hand side of (12), $\sum_{p=1}^{i-1} \sum_{q=i+1}^{p-1} \{E_{pq}(t - \beta_{pi}) + F_{pq}(t - \beta_{pi})\}$, is part 1 that originates from a port between port 1 and port $i-1$ on the voyage and terminates at port $i+1$ or at a port beyond it, while the third term of (12), $\sum_{p=i+2}^{|I|} \sum_{q=i+1}^{p-1} \{E_{pq}(t - \beta_{pi}) + F_{pq}(t - \beta_{pi})\}$, is part 2 that originates from a port between port $i+2$ and port $|I|$ (note that $i+2$ corresponds to $|I|$ by chance in Fig. 4) and terminates at port $i+1$ or at a port beyond it. Note that for part 2, the traffic departing from $p = i+1$ is not included because it terminates before or at port i on the voyage.

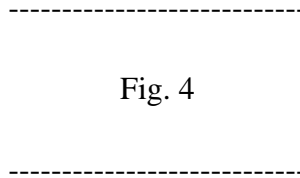


Fig. 4

(b) H&S formulation

The H&S formulation is equivalent to the formulation of MPC with a substitution of flow constraints relevant to the trunk line between the two hubs and feeder transportation between the hubs and local ports, for one round trip flow conservation of MPC, and therefore it may be constructed as follows:

[H&S] Minimize (1)

Subject to (2)-(10)

$$\sum_{i \in I^A} \sum_{j \in I^B} \{E_{ij}(t - \beta_{i,h^A}) + F_{ij}(t - \beta_{i,h^A})\} \leq V \quad \forall t \in T, \quad (17)$$

$$\sum_{i \in I^B} \sum_{j \in I^A} \{E_{ij}(t - \beta_{i,h^B}) + F_{ij}(t - \beta_{i,h^B})\} \leq V \quad \forall t \in T, \quad (18)$$

$$\sum_{j \in I(\neq i)} \{E_{ij}(t) + F_{ij}(t)\} \leq VF_i \quad \forall t \in T, i(\neq h^A, h^B) \in I, \quad (19)$$

$$\sum_{j \in I(\neq i)} \{E_{ji}(t - \beta_{ji}) + F_{ji}(t - \beta_{ji})\} \leq VF_i \quad \forall t \in T, i(\neq h^A, h^B) \in I, \quad (20)$$

where,

I^A : set of calling ports in region A

I^B : set of calling ports in region B

h^A : hub port in region A

h^B : hub port in region B

VF_i : carrying capacity of a feeder ship calling at port i . It is assumed that

$$\sum_{j \in I(\neq i)} F_{ij}(t) \leq VF_i \quad \text{and} \quad \sum_{j \in I(\neq i)} F_{ji}(t) \leq VF_i \quad \text{for} \quad \forall t \in T$$

In addition to all the constraints of the formulation [MPC], which work out as flow conservation constraints at calling ports, the formulation [H&S] has trunk line deepsea

vessel and feeder ship voyage constraints. Inequalities (17) and (18) define a relationship of containers on board a deepsea vessel's carrying capacity from regions A to B and vice versa, respectively. Constraint sets (19) and (20) are the same relationships, but for a feeder ship providing a shuttle service between a hub (h^A or h^B) and a local port i . Constraints (19) are those for departing from port i and (20) are those for arriving at port i .

Notice that empty containers are transferred through the two hubs on the way from the supply ports to demand ports. Therefore, the handling costs at hubs as well as the feeder costs between the hubs and local ports, in addition to handling costs at supply and demand ports, should be taken into account in the objective function of the H&S formulation. For convenience, those additional costs are included in loading costs at supply port, C_i^H , and unloading costs at demand port C_j^H in objective (1).

4. Numerical analysis

4.1. Settings

(1) Assumptions

The models of MPC and H&S were solved by using a commercial mathematical programming solver, LINGO version 10.0, on a DELL DIMENSION 8400 computer.

We set the following assumptions:

- (i) The planning horizon length is 52 weeks (or a year)
- (ii) Two trade lanes are considered: Asia-Europe and Asia-North America
- (iii) Ports covered are as follows:

Asia: Busan (Korea), Hong Kong (China), Kaohsiung (Taiwan), Keelung (Taiwan),

Kobe (Japan), Laem Chabang (Thailand), Shanghai (China), Singapore,

Yokohama (Japan) and Xiamen (China).

Europe: Antwerp (Belgium), Felixstowe (UK), Hamburg (Germany), Le Havre (France)

and Rotterdam (The Netherland)

North America (USA): Los Angeles, Portland, Oakland and Seattle

- (iv) Deepsea vessel carrying capacity: 5,000 TEUs for MPC and 10,000 TEUs for H&S
- (v) Feeder carrying capacity for port i : $1.5 \times$ one way (loaded) traffic of one ship calling at port i
- (vi) Feeder cost depends on feeder routes while the average cost is US\$200 per TEU
- (vii) Calling frequency at each port: every 3.5 days (MPC) and 7 days (H&S), assuming the same carrying capacity of deepsea vessel per week for both service networks
- (viii) Container capital cost, $C^F = \text{US\$400/TEU/year}$
- (ix) Storage cost, $C_i^S = \text{US\$364/TEU/year}$ for any port
- (x) Handling cost, $C_i^H = \text{US\$100-150 per TEU}$ depending on port
- (xi) Leasing cost $C_{ij}^L = \text{US\$14} \times \beta_{ij}$
- (xii) The time spent in a hinterland $\alpha_i = 1$ week for all ports.
- (xiii) Total traffic (only loaded containers) of each direction of both trade lanes is 7,000 TEUs

The above costs are estimated based on various information sources such as container logistics related journals, trade magazines and some conducted surveys to shipping and forwarding companies.

As for assumption (xii), in realty, each port (or each container shipment) has a different time length for traveling in the hinterland. A typical situation is observed in the US.

A number of container shipments unloaded at the west coast travel to mid-west and even east coast hinterlands. Their travel time is much longer than the ones traveling in close hinterlands to ports in the west coast. However, as such statistics are not readily available, we consider a constant travel time for all ports.

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 consider the traffic volume for a specific trade section so that the maximum aggregate traffic is 7,000TEUs per week for each direction for both European and North American trades. This traffic volume is assumed for each trade lane for the following reasons:

- (i) The total transportation capacity per week is assumed to be 10,000TEUs for both MPC and H&S for a simpler analysis.
- (ii) As will be described later, there are six settings for traffic with seasonal variance throughout a year and directional volume difference in a trade lane. In any case, the peak traffic per week is set, so that all weekly traffic is covered in that week by the liner service and no delay in transit occurs.
- (iii) It is well known in practice that the average load factor, which is the occupancy rate of ship carrying capacity, is approximately 0.7. Note that this study considers the load factor only with loaded containers, while in the models empty containers are repositioned by ships. No other (special) ships are engaged for empty repositioning.

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. Throughputs of existing hubs such as Busan, 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 each trade lane, we prepare three different settings of cargo traffic. The basic setting is that the traffic between two trade regions (and between each trading port pair) is completely balanced. In reality, however, we witness imbalanced traffic for all trade lanes; therefore, in order to take into account the influence of such an imbalanced trade flow on empty container management, we introduce two more settings: dominant traffic from Asia to both Europe and North America in an imbalanced ratio of: 1.5 vs. 1 and 2 vs. 1 where ratio “1” is traffic from the other region to Asia in each trade. Note however, that as described already we assume that the total traffic for east and westbound traffic in each trade lane is 14,000 TEUs per week in order to keep an unvarying relationship between cargo demand and ship capacity..

Furthermore, for both balanced and imbalanced traffic scenarios as described above, we set two different seasonal variances of traffic volume where both variances have the same annual traffic volume: one is flat traffic over a year and the other is a varying traffic as shown by Fig. 5. This varying traffic trend may be unrealistic, but we use this to investigate the impact of traffic fluctuation on the choice of network.

Fig. 5

As mentioned earlier, we set up port-to-port traffic in both Asia-Europe and Asia-North America trade lanes by using various statistics of container traffic. For illustration purposes, the total export and import traffic per week of each port in the trade lanes for the balanced trade scenario with flat traffic is shown in Table 1. Also, we look into four different empty container storage capacities (half, standard, double and triple) at each port in order to investigate the influence of storage size on the empty container management.

Table 1

(2) The MPC and H&S network construction

We first constructed the MPC and H&S networks. For the H&S network construction, we use weekly traffic based on a balanced trade with a flat yearly traffic scenario. For the MPC, as weekly traffic is transported by two ship callings, half of the weekly traffic is used. In those networks, the assumed ship capacities can cover all loaded container traffic.

Note that the networks built in the first phase with these traffic data are used for second phase computation for all different traffic scenarios. The reason is that ship's service network (or calling port sequence) construction is a long-term decision; therefore future traffic fluctuations cannot be forecasted precisely in order to build robust shipping networks. Also, notice the computation times of the network constructions, i.e., GA for MPC and brute-force method for H&S, are quite small, e.g., nearly 1 minute for MPC (with 200 GA generations) and less than 1 second for H&S.

The MPC itinerary obtained in the first phase computation for Asia-Europe is: Kobe, Yokohama, Shanghai, Busan, Hong Kong, Keelung, Xiamen, Kaohsiung, Laem Chabang, Rotterdam, Antwerp, Hamburg, Le Havre, Felixstowe and Singapore; while the one for Asia-North America is: Kobe, Laem Chabang, Kaohsiung, Yokohama, Keelung, Singapore, Hong Kong, Xiamen, Portland, Los Angeles, Oakland, Seattle, Busan and Shanghai.

Hubs for the H&S for Asia-Europe are: Singapore and Le Havre, whereas those for Asia-North America are: Busan and Oakland.

4.2. Container management cost analysis

Figs. 6 and 7 illustrate the total Container Management Costs (hereafter abbreviated as *CMC*) per year, which is comprised of four cost factors: fleet, storage, repositioning and leasing costs. The CMCs are computed from solutions to the MPC and H&S. The fleet cost implies the total capital costs of own containers. The repositioning cost basically consists of the handling costs incurred at the supply port and demand port of empty containers; however, for H&S we also add the handling costs at hub ports of both trade regions and feeder costs between the hubs and local ports as the supply and demand points.

Figs. 6 & 7

It was computed that for both trade lanes the MPC has a smaller CMC than the H&S. This trend is more considerable in a largely imbalanced trade (i.e., MPC_1.5:1, MPC_2:1 and those for H&S), while both networks have nearly the same CMC in the

completely balanced trade of North America (i.e., MPC_1:1 and H&S_1:1). To further explain this, largely imbalanced trades result in large leasing cost gaps and consequently large CMC gaps (i.e., differences of CMC between MPC and H&S), since more “imbalance” leads to a larger scale of container shortage in Asia where import is dominated by export. Also for both MPC and H&S in the North American trade, the repositioning cost is low when the leasing cost is high, and vice versa. It was expected that empty container repositioning is not easy in H&S since the H&S has less frequent calling port per week. A lower CMC for MPC than for H&S can result from more frequent calling at port by smaller ships for MPC than for H&S.

The CMCs of both MPC and H&S for European trade are higher than those for North American trade. The reason is attributed to the fact that as the trade lane of the former is much longer than that of the latter, the transit of loaded and empty containers for the former trade takes much more time and this container distribution results in inefficient reuse of empty containers. Also, surprisingly there is no significant difference in the CMC between flat and varying traffic.

Comparing leasing cost differences of MPC and H&S between both trade lanes, the North American trade has more significant leasing cost differences for all imbalanced trade scenarios. The reason is probably that the area covering ports to be called for the entire Asia-North American trade lane is geographically denser compared to that of the European trade and therefore the entire travel of empty transfer from a port to another via hubs in H&S takes much longer time than a direct transfer between the ports in MPC for the American trade. Also for this reason, timely empty transfer is not so easy and this causes more containers to be leased. In contrast to this, the American trade bears fewer

repositioning costs. Noticeably, the gap of leasing (and reposition) costs between the two networks grows with more imbalanced trades, especially in the North America trade.

The European trade bears a smaller leasing cost and reversely higher repositioning cost. This implies that the European trade enjoys more efficient usage of own containers.

4.3. Empty container behavior

Figs. 8 and 9 show the amount of containers in different behaviors (or states) which is measured by “container-days” that is days that empty containers spend in different states such as in repositioning, storage and leasing. The trend and variation in these graphs is apparently impacted by the corresponding cost breakdown depictions in Figs. 6 and 7. That is,

- (i) H&S has much more leasing and less repositioning volumes than MPC for both trades.

Therefore, the storage volume in H&S is less than in MPC.

- (ii) Gaps of those volumes between the two service networks increase with more significant trade imbalances. Also, the growth of these volumes is more significant in the North American trade.

- (iii) The European trade experiences a large scale of empty repositioning and this implies own containers are efficiently used with less leasing.

- (iv) The storage volume in Europe is higher than in America. This is reflected by the observation that empty repositioning is more effectively performed in Europe.

Figs. 8 & 9

Interestingly, while the storage costs are not so significant from Figs. 6 and 7, daily container quantities stored at port are not negligible. As the unit cost for container storage is much lower than other cost factors, the total storage costs are not fully exposed when shown alongside other container costs.

As observed above, the H&S network has a less storage volume than the MPC. Two reasons are considered:

- (i) The long transit time of empty containers in the H&S requires considerable leasing because sufficient quantities of empty containers cannot necessarily arrive at the demand ports in the timely manner. In fact this reasoning is justified since containers in repositioning are fewer in the H&S than in the MPC. Less repositioning does not require much empty container storage at port.
- (ii) The transshipment at hubs requires a longer transit time for empty transfer between a specific port pair than the MPC, therefore containers are likely sent to the places of demand as soon as they turn out to be empty in a ready state after coming back to ports from consignees' sites.

4.4. Analysis for impact by storage capacity at port

We designed the experiments with different empty container storage capacities at ports. All the results discussed in sections 4.2 and 4.3 were the ones associated with the standard storage capacity. We also carried out experiments with larger and smaller storage capacities, but there is no significant difference in the CMC for both MPC and H&S with those larger and smaller capacities compared to the standard one. Thus, we do not provide any figures showing results for these cases. The outcome can be explained by the observation of the results of the standard capacity in that the number of empty containers

kept stacked at ports is quite few, especially compared with other empty containers' states such as repositioning and leasing. The varying yearly traffic cases in both trade lanes with the balanced trade are the cases with fairly significant empty stocks at ports. This implies that empty containers are transferred to demand places in a timely manner and many of them do not stay at ports for a long time; therefore a larger storage capacity does not work to decrease the CMC.

4.5. Analysis for impact by transshipment cost

We have already observed that the H&S network associates higher CMC in all the cases in both European and North American trade lanes. The main reason we can envisage is that the transit time of empty transfer potentially takes a longer time in H&S than MPC. This raises the leasing cost in H&S and as a result its CMC is higher than the one of MPC. Whilst the repositioning as a cost factor in the CMC is minor, it is interesting to examine how container repositioning is intensified, benefiting from lower transshipment cost (it is actually the handling cost of loading on and unloading from ships) incurred to empty containers at hubs, and subsequently how this increased repositioning replaces container leasing to cover cargo demand. Fig. 10 demonstrates a variation of CMC for the H&S in the American trade with imbalance rate of (2:1) and flat yearly traffic. For a comparison purposes the horizontal line indicates CMC for the MPC. The CMC decreases by decreasing the transshipment cost. It seems that the transshipment cost decrease directly leads to an increase of repositioning containers, since the leasing cost decreases with the transshipment cost reduction. However, the increased volume of repositioning raises the total repositioning cost including feeder cost, while the unit transshipment cost is low.

Fig. 10

4.6. Analysis with total cost and profit by different shipping companies

The above discussions were intensively made based on the CMC only. In this sub-section, we examine what are preferred network choices by different shipping companies with different cost structures. Lastly, we look into how the introduction of the container management cost (in other words, consideration of the optimized fleet size and empty repositioning) affects the network choice.

As demonstrated in Imai et al. (2006), both service networks assume different network configurations and service infrastructures, which turn out to have different overall cost structures in providing shipping services to cargo owners. Besides the CMC, the overall costs include the deepsea ship related cost which 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 at port and the capital costs. The H&S service also requires the feeder cost, which is defined as the freight rate with the assumption that the shipping company charters a feeder fleet, and the cargo (loaded and empty containers) handling cost that is incurred at hubs and local ports.

As examined in Imai et al. (2006), we assume two typical shipping companies in terms of cost structure: Asia and Europe based companies, where the former company's cost is lower than the latter. For the Asia-Europe trade lane, the average freight rates per TEU bound for Europe and for Asia are assumed to be \$1800 and \$720, respectively, while the Asia-North America lane has average freight rates for traffic bound for North America and

for Asia at \$2210 and \$995, respectively. These rates are relatively close to the published rates (UNCTAD, 2001).

Tables 2 and 3 display annual profit, revenue, total cost and cost breakdown for European and North American trade lanes by the Europe-based shipping company (E-Co), while Tables 4 and 5 shows those by the Asia-based company (A-Co). Note that as both flat and varying traffic assume the same amount of annual traffic (import + export) and the same ship size for a specific network, “ship cost” and “handling and feeder cost” have identical values for all types of imbalance and yearly traffic of a specific company.

Looking into all these tables, we observe that as analyzed in section 4.2, the CMC increases with larger imbalanced trade volumes in any traffic scenarios of either trade lane for both shipping companies. However, the imbalance also increases the revenue. This is because the relative increase of traffic from Asia, while the total of import and export traffic is the same in any imbalanced scenarios, leads to a higher revenue due to a higher freight rate for Europe compared to the one for the reverse traffic. As a result, the profit increases with larger imbalanced trade volumes. Notice also that “handling and feeder cost” in the tables covers only the handling task for loaded containers and “CMC” is incurred in handling empty containers.

Tables 2-5

Referring to Tables 2 and 3, we examine result profiles for E-Co. Surprisingly, in contrast to the analysis made for only the CMC, Table 2 shows that the H&S has superiority in terms of the total cost and consequently the profit (because of the same revenue assumed

for both service networks) than the MPC for European trade. Nevertheless, superiority declines with more imbalanced traffic. On the other hand, Table 3 shows that for the North American trade the MPC has superiority for both total cost and profit. The MPC's superiority grows with more imbalanced traffic. The fleet of mega-ships in the H&S benefits from the enormous economies of scale in terms of ship costs, i.e., the ship fleet cost of H&S is 1/4 of the one of MPC. However, such cost superiority cannot offset inferiority of the CMC for North American trade. It is interesting and surprising that depending on situation and ship size, for all the trade lanes the CMC accounts for 12% (MPC with imbalance rate of 1:1 for European trade) to 120% (H&S with imbalance rate of 2:1 for North American trade) of the deepsea ship cost.

Referring to Tables 4 and 5, we next examine A-Co cases. Unlike the E-Co, the MPC has superiority in terms of the total cost and profit for both trade lanes except for balanced trade cases for the European trade.

It is very interesting to note that in the European trade lane, the E-Co has a lower total cost with the H&S than with the MPC. While the cost structure of the pioneering shipping company in the mega-ship era, Maersk Line, is unknown to the public, these computational results confirm Maersk's strategy toward the introduction of mega containerships. In the container shipping market, it seems that other major shipping lines, especially Europe-based lines such as MSC and CMA CGM are following Maersk's way in terms of ultra large ship size. The study's outcome justifies this tendency.

As discussed above, the MPC is superior to the H&S for most cases, but it is noticed that the ship cost for MPC is three times higher than the one for H&S. The reason is as follows: For the European trade, round trip lengths in time are 56 and 35 days for the

MPC and H&S, while for the American trade those are 49 and 28 days. To maintain the calling frequency for each service network, the numbers of ships to be deployed, FS , are 16 and 5 ships for the MPC and H&S of the European trade and 14 and 4 ships for those of the North American trade. This results in a large difference of ship fleet sizes between MPC and H&S.

All the above analyses for different shipping companies take into account the CMC. With the implicit assumption that the same container fleet size is assumed for both shipping companies, we analyzed shipping networks in Imai et al. (2006). However, as the container fleet cost in terms of both fleet investment and operation comprises a large portion of the total cost, as shown in Tables 2-5, the container cost is included in the network choice exercise. We, then, examine the influence of container fleet consideration on the network choice. For this, we compute the total cost by excluding the CMC. As there is unvarying revenue for both networks in each traffic scenario, the network selection is made based on cost. As shown in Table 6, the H&S network is superior for the A-Co, unlike the analysis with the CMC, for imbalanced trade traffic cases in the European trade.

Table 6

5. Conclusions

For the last decade, there has been a trend of increasing containership size and finally in 2006 the maximum ship size (or carrying capacity) surpassed the 10,000TEUs milestone. Also one of the crucial issues in container shipping is imbalanced trade which

imposes on shipping lines enormous constraints and requires immense effort to properly manage container operations. Potentially, empty container management issues are not avoidable as long as major trade lanes have an “imbalance” nature. Shipping lines benefit from the economies of scale of the mega-ship, which is basically deployed in a Hub-and-Spoke network (not necessarily pure Hub-and-Spoke) in order to ensure its efficiency. Given constant cargo traffic, a mega-ship provides a lower frequency of port calls than a smaller ship. This implies that the mega-ship service could be considered as a large “batch” of transportation with a large calling interval; therefore it is envisaged that the Hub-and-Spoke by the mega-ship has a disadvantage for efficient empty container repositioning.

In the above background, this study compared MPC and H&S networks by analyzing the Container Management Cost (CMC) with various scenarios. It was found that the MPC is superior to the H&S in terms of CMC for all scenarios in both European and North American trade lanes. Next, this paper investigated network choice using the profit parameter, where the various costs including the CMC are taken into consideration, with various traffic scenarios for shipping companies with different ship cost structures. As for the total cost and subsequently the profit, the MPC has superiority in both trade lanes in most cases; however, for the European shipping line, the H&S is less costly and more profitable in the European trade lane. Due to the high component of the CMC in the entire shipping cost, this study took into account the CMC. Lastly, we examined whether different networks are chosen if we ignore the CMC. It was found that for the Asian company this influences the network choice for the European trade with imbalanced trade cases, since the H&S is chosen without the CMC while the MPC is selected with the CMC. This shows the

importance of the CMC in the network choice, especially due to large trade flow imbalances in major trade lanes.

While the actual cost structure of shipping lines is not publicly available, this study is able to examine advantages and disadvantages of different service networks with different ship size. It, therefore, seems that actual shipping market trends are in conformity with the research outcome of this paper. As a result, the models we developed in this paper are useful for network design in deepsea liner services.

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Table 1 Weekly throughput at ports with balanced trade (in TEUs)

Areas	Ports	Export	Import
Asia	Kobe	323 / 352	407 / 420
	Hong Kong	1813 / 1794	1883 / 1850
	Kaohsiung	852 / 850	815 / 810
	Keelung	278 / 272	287 / 290
	Laem Chabang	185 / 192	65 / 78
	Busan	612 / 626	564 / 580
	Shanghai	432 / 460	384 / 386
	Singapore	1836 / 1746	1886 / 1878
	Yokohama	588 / 628	626 / 630
	Xiamen	81 / 80	83 / 78
Europe	Antwerp	1487	1402
	Felixstowe	794	770
	Hamburg	1524	1622
	Le Havre	586	589
	Rotterdam	2609	2617
North America	Los Angeles	4088	4484
	Oakland	1143	887
	Portland	317	147
	Seattle	1492	1482

Note: Throughput of Asian ports shows “Europe / North America”

Table 2. Profits, revenues and costs (US\$'000,000) for the Asia-Europe trade by an Europe-based shipping company

(a) Flat yearly traffic

	Imbalance rate	Profit	Revenue	Total annual cost	Ship cost	Handling and feeder cost	CMC
MPC	1:1	275.3	917.6	642.3	436.3	172.2	33.9
H&S		357.8	917.6	559.9	136.9	385.7	37.2
MPC	1.5:1	334.4	996.0	661.6	436.3	172.1	53.2
H&S		398.7	996.0	597.3	136.9	386.6	73.8
MPC	2:1	376.3	1,055.9	679.6	436.3	172.1	71.2
H&S		424.4	1,055.9	631.5	136.9	387.3	107.2

(b) Varying yearly traffic

	Imbalance rate	Profit	Revenue	Total annual cost	Ship cost	Handling and feeder cost	CMC
MPC	1:1	273.0	917.6	644.6	436.3	172.2	36.2
H&S		355.5	917.6	562.2	136.9	385.7	39.5
MPC	1.5:1	332.6	996.0	663.4	436.3	172.1	55.0
H&S		398.4	996.0	597.6	136.9	386.6	74.1
MPC	2:1	377.0	1,055.9	678.9	436.3	172.1	70.6
H&S		429.6	1,055.9	626.2	136.9	387.3	102.0

Table 3. Profits, revenues and costs (US\$'000,000) for the Asia-North America trade by an Europe-based shipping company

(a) Flat yearly traffic

	Imbalance rate	Profit	Revenue	Total annual cost	Ship cost	Handling and feeder cost	CMC
MPC	1:1	609.8	1,166.6	556.8	349.0	172.5	35.3
H&S		577.9	1,166.6	588.7	83.3	468.4	36.9
MPC	1.5:1	681.6	1,255.1	573.6	349.0	172.5	52.1
H&S		637.3	1,255.1	617.9	83.3	469.4	65.1
MPC	2:1	727.5	1,314.5	587.0	349.0	171.5	66.5
H&S		672.7	1,314.5	641.8	83.3	469.3	89.2

(b) Varying yearly traffic

	Imbalance rate	Profit	Revenue	Total annual cost	Ship cost	Handling and feeder cost	CMC
MPC	1:1	608.9	1,166.6	557.8	349.0	172.5	36.2
H&S		578.1	1,166.6	588.5	83.3	468.4	36.7
MPC	1.5:1	681.9	1,255.1	573.3	349.0	172.5	51.8
H&S		638.0	1,255.1	617.1	83.3	469.4	64.3
MPC	2:1	727.4	1,314.5	587.2	349.0	171.5	66.7
H&S		673.0	1,314.5	641.5	83.3	469.3	88.9

Table 4. Profits, revenues and costs (US\$'000,000) for the Asia-Europe trade by an Asia-based shipping company

(a) Flat yearly traffic

	Imbalance rate	Profit	Revenue	Total annual cost	Ship cost	Handling and feeder cost	CMC
MPC	1:1	384.9	917.6	532.8	326.7	172.2	33.9
H&S		391.1	917.6	526.5	103.6	385.7	37.2
MPC	1.5:1	444.0	996.0	552.1	326.7	172.1	53.2
H&S		432.0	996.0	564.0	103.6	386.6	73.8
MPC	2:1	485.9	1,055.9	570.0	326.7	172.1	71.2
H&S		457.7	1,055.9	598.2	103.6	387.3	107.2

(b) Varying yearly traffic

	Imbalance rate	Profit	Revenue	Total annual cost	Ship cost	Handling and feeder cost	CMC
MPC	1:1	382.6	917.6	535.0	326.7	172.2	36.2
H&S		388.8	917.6	528.8	103.6	385.7	39.5
MPC	1.5:1	442.2	996.0	553.8	326.7	172.1	55.0
H&S		431.7	996.0	564.3	103.6	386.6	74.1
MPC	2:1	486.5	1,055.9	569.3	326.7	172.1	70.6
H&S		463.0	1,055.9	592.9	103.6	387.3	102.0

Table 5. Profits, revenues and costs (US\$'000,000) for the Asia-North America trade by an Asia-based shipping company

(a) Flat yearly traffic

	Imbalance rate	Profit	Revenue	Total annual cost	Ships' cost	Handling and feeder cost	CMC
MPC	1:1	708.2	1,166.6	458.4	250.6	172.5	35.3
H&S		602.7	1,166.6	564.0	58.6	468.4	36.9
MPC	1.5:1	780.0	1,255.1	475.2	250.6	172.5	52.1
H&S		662.0	1,255.1	593.1	58.6	469.4	65.1
MPC	2:1	825.9	1,314.5	488.6	250.6	171.5	66.5
H&S		697.4	1,314.5	617.1	58.6	469.3	89.2

(b) Varying yearly traffic

	Imbalance rate	Profit	Revenue	Total annual cost	Ships' cost	Handling and feeder cost	CMC
MPC	1:1	707.2	1,166.6	459.4	250.6	172.5	36.2
H&S		602.9	1,166.6	563.7	58.6	468.4	36.7
MPC	1.5:1	780.2	1,255.1	474.9	250.6	172.5	51.8
H&S		662.8	1,255.1	592.4	58.6	469.4	64.3
MPC	2:1	825.7	1,314.5	488.8	250.6	171.5	66.7
H&S		697.8	1,314.5	616.8	58.6	469.3	88.9

Table 6. Network superiority analysis without CMC in the Asia-Europe trade for both flat and varying yearly traffic

	Imbalance rate	Total annual cost	Ships' cost	Handling and feeder cost	CMC
MPC	1.5:1	498.8	326.7	172.1	0
H&S		490.2	103.6	386.6	0
MPC	2:1	498.8	326.7	172.1	0
H&S		490.9	103.6	387.3	0

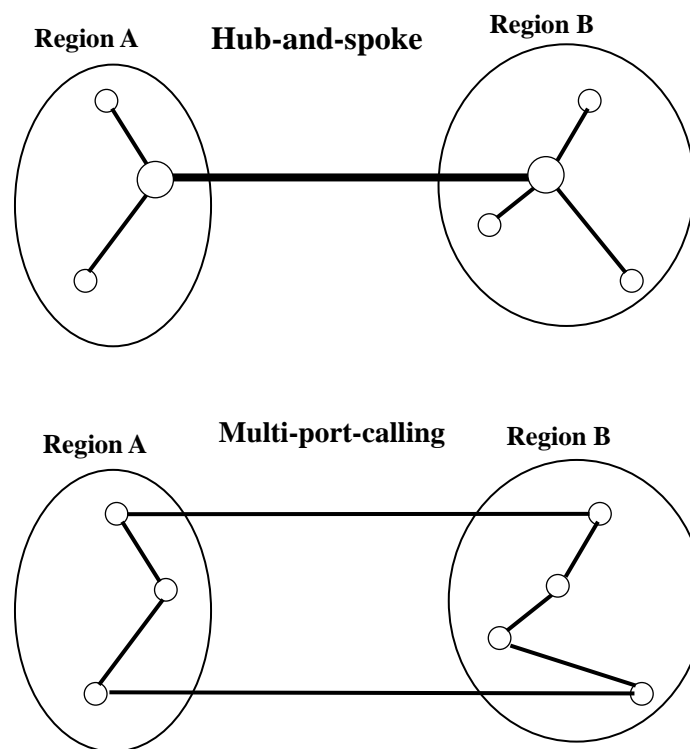


Fig. 1. Service networks.

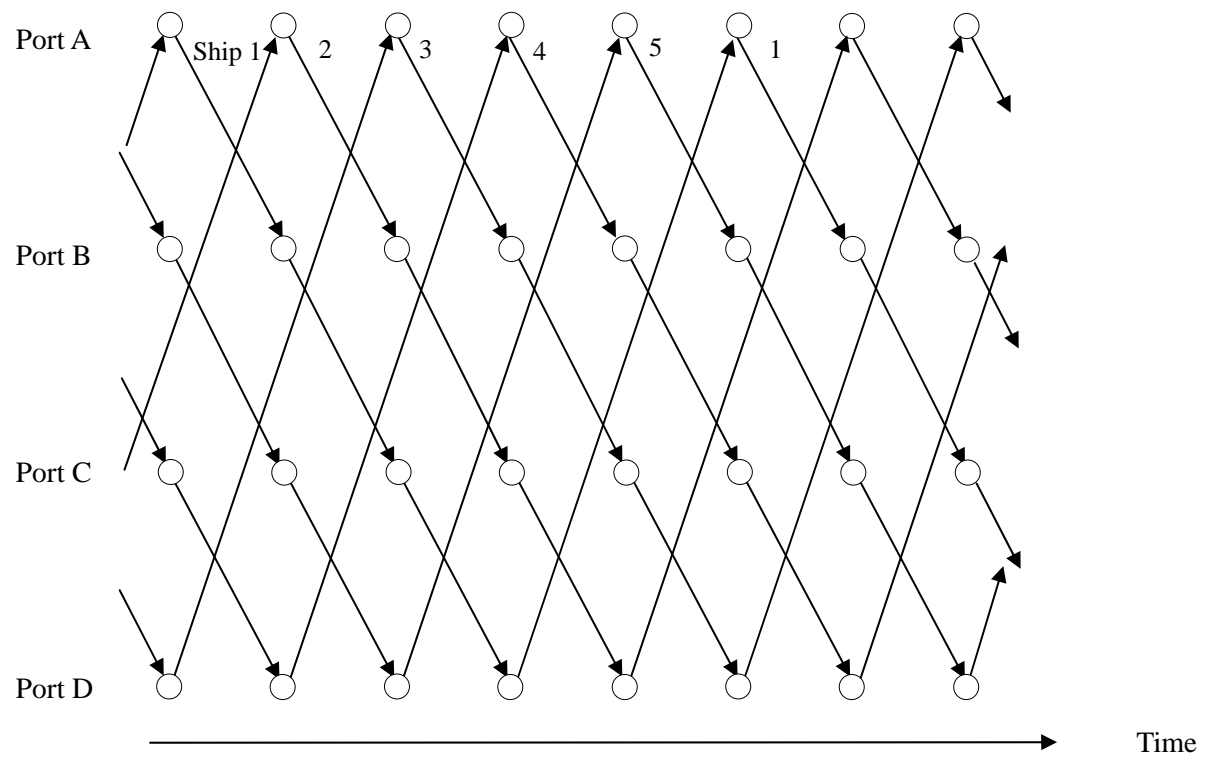


Fig. 2. Ships' voyages in the space-time network

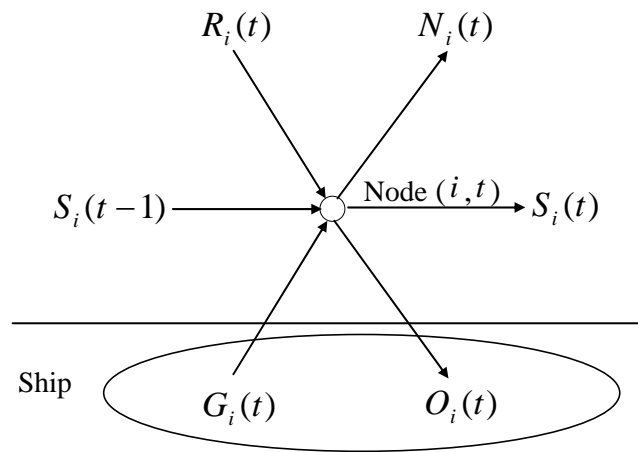


Fig. 3. Empty container flow conservation at a port

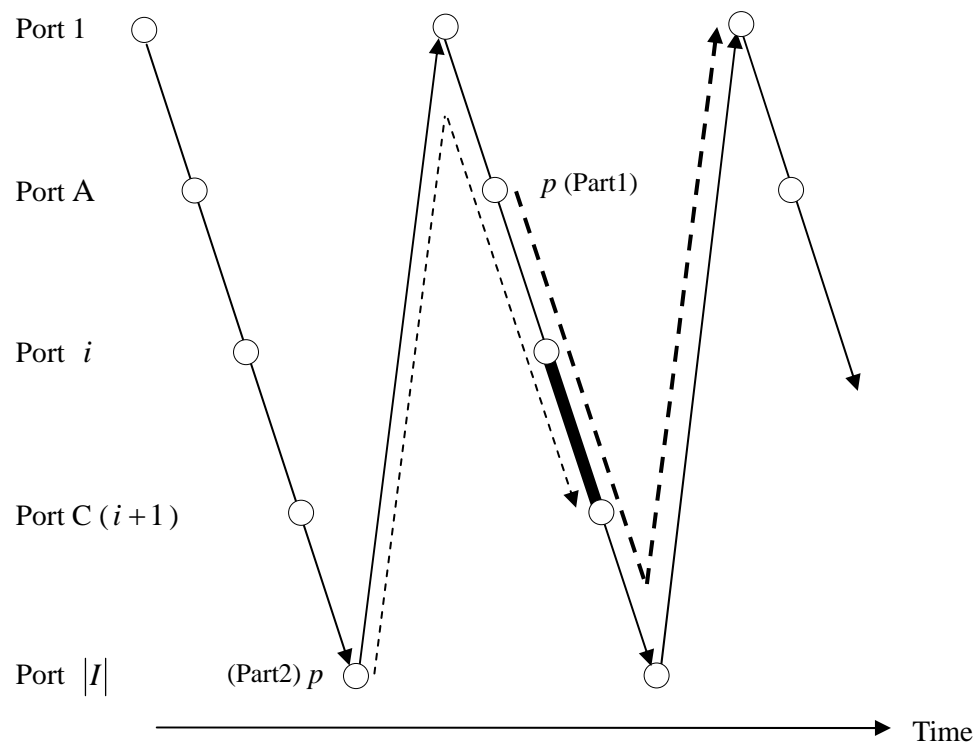


Fig. 4. Container flow on voyages of a ship

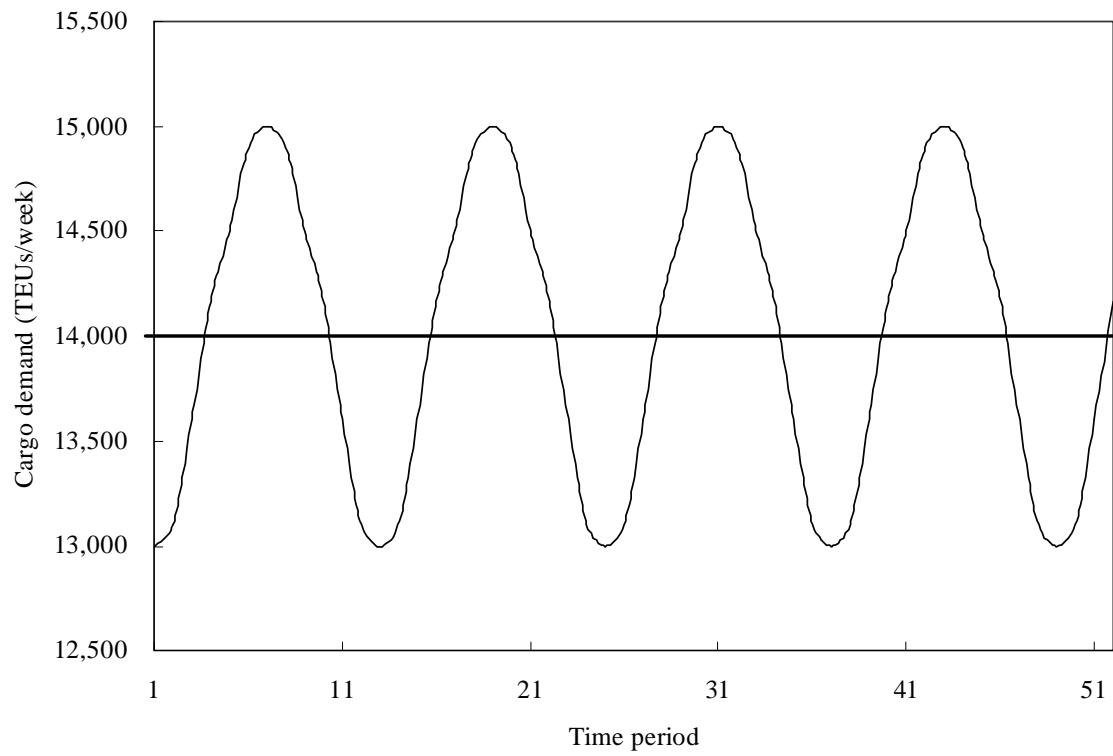
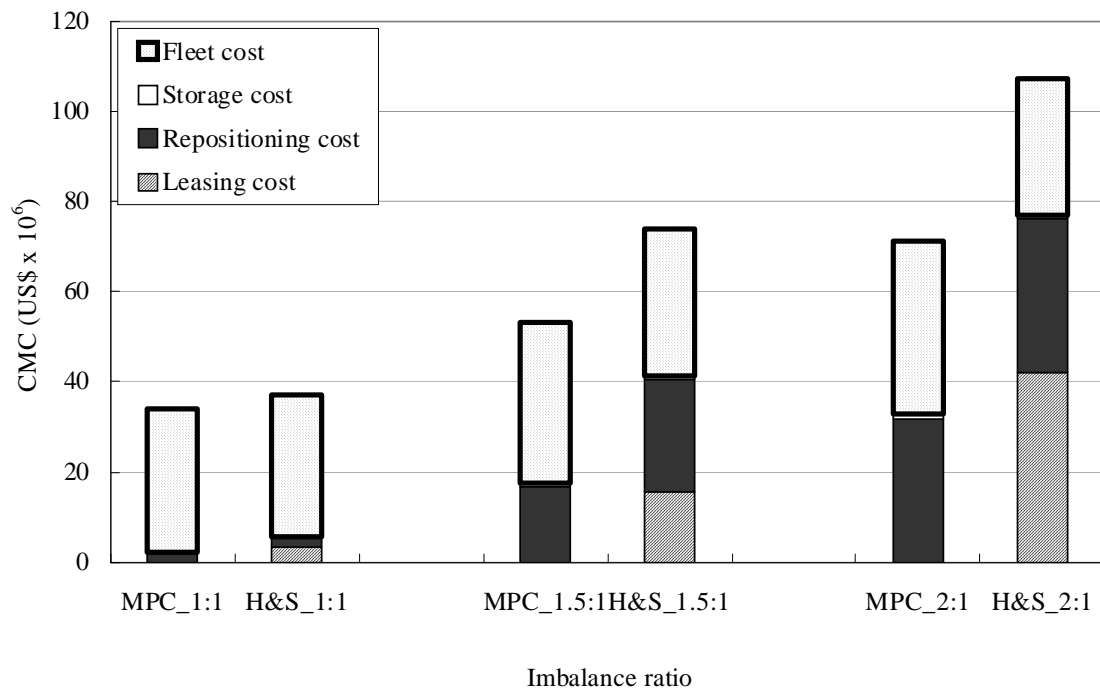
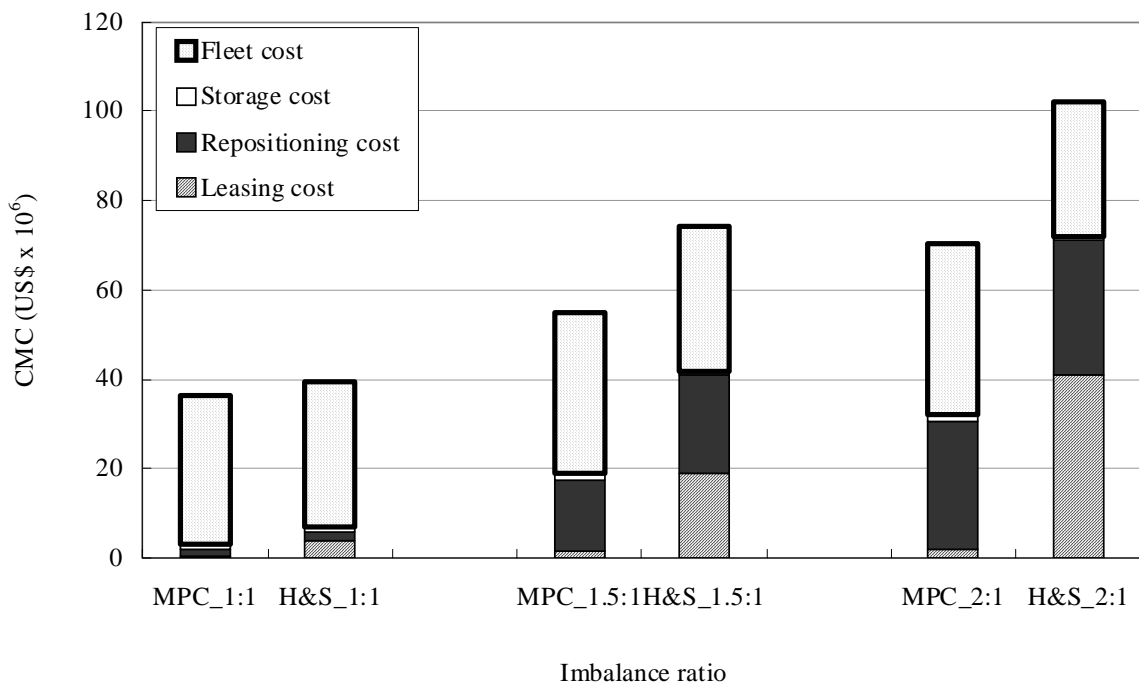


Fig. 5. Yearly trend of an annual throughput (for 51 weeks)



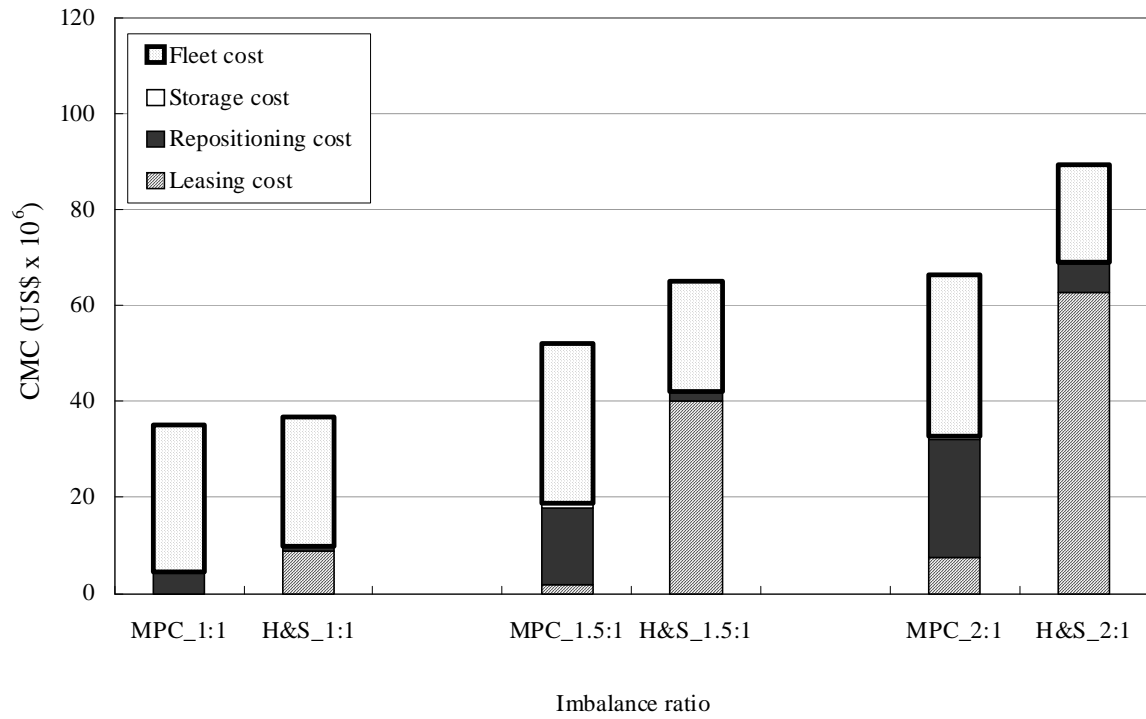
(a) Flat yaerly traffic



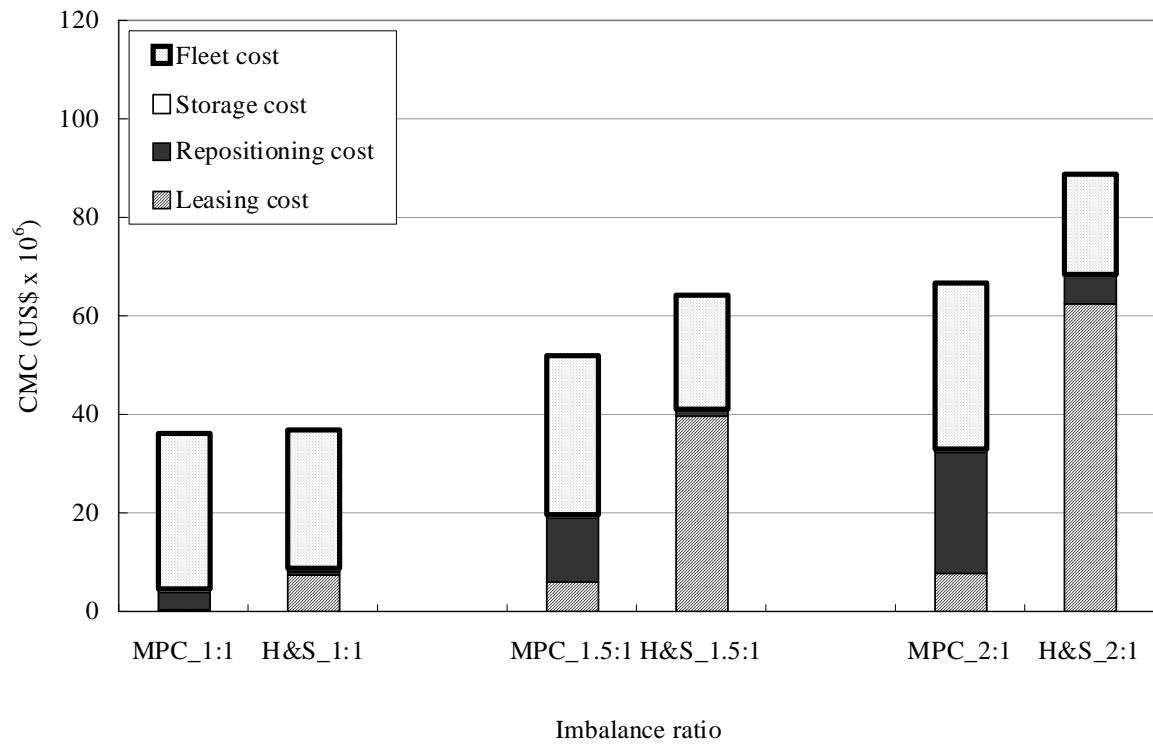
(b) Varying yearly traffic

Legend: MPC_1.5:1=MPC case with a scenario for imbalance traffic (1.5:1)

Fig. 6. CMC in the Asia-Europe trade

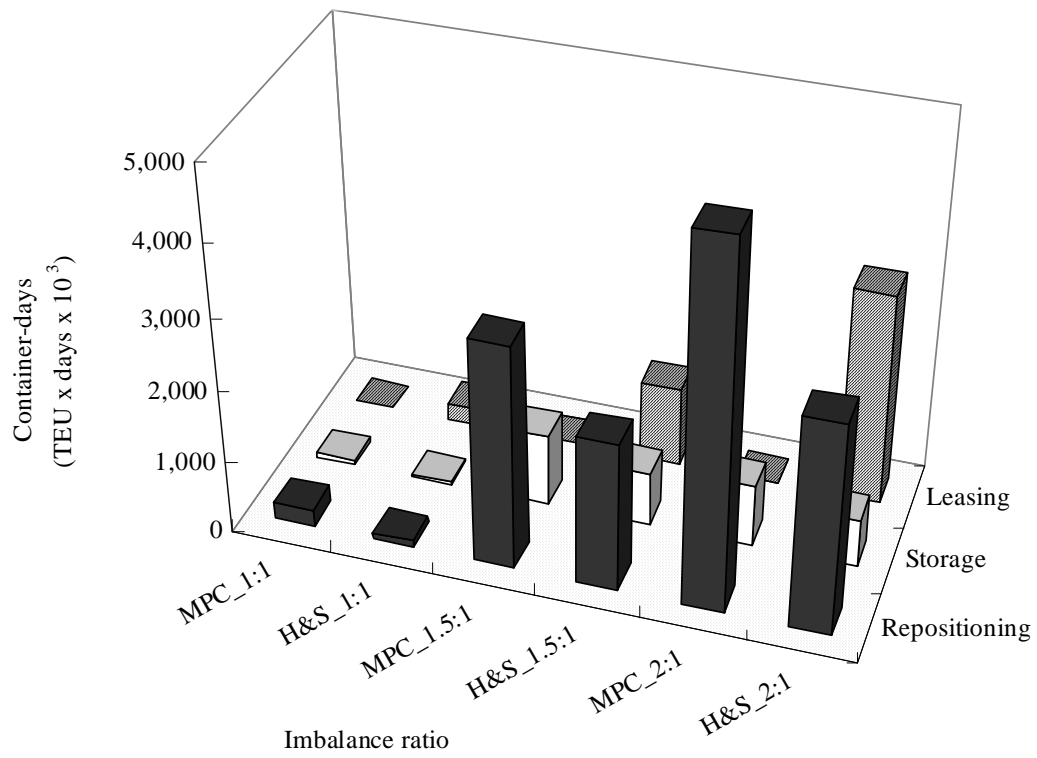


(a) Flat yearly traffic

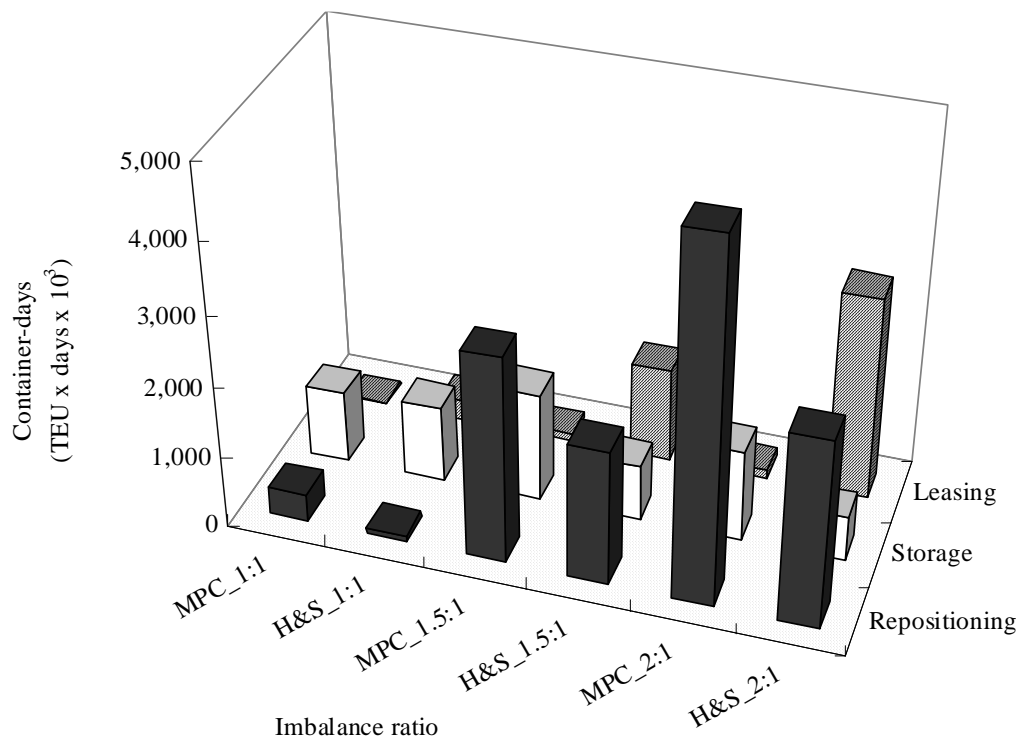


(b) Varying yearly traffic

Fig. 7. CMC in the Asia-North America trade

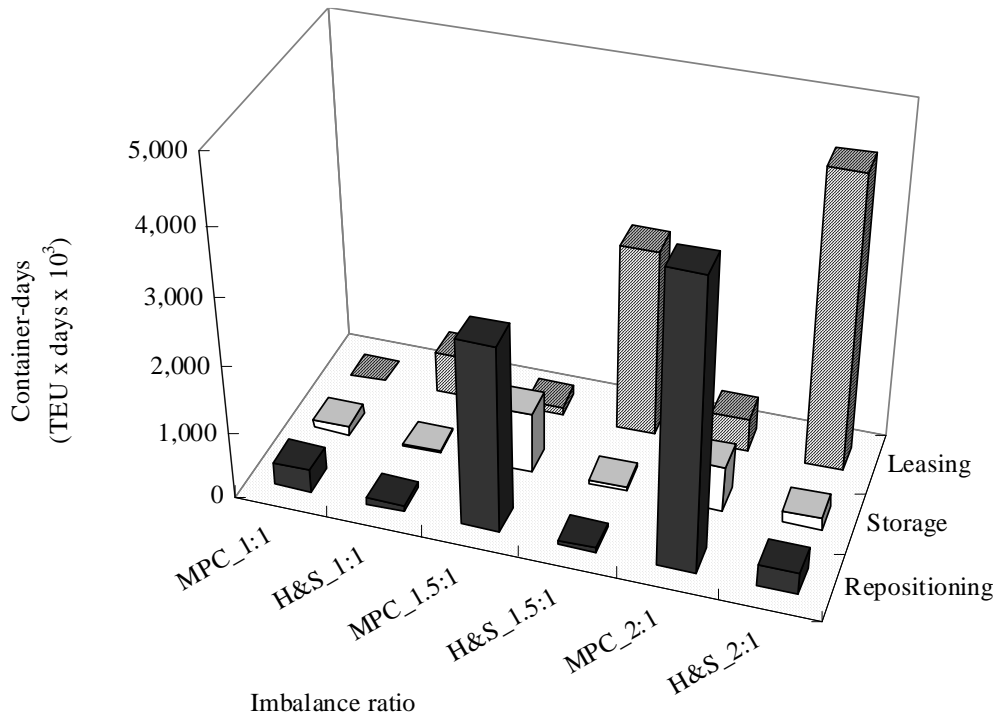


(a) Flat yearly traffic

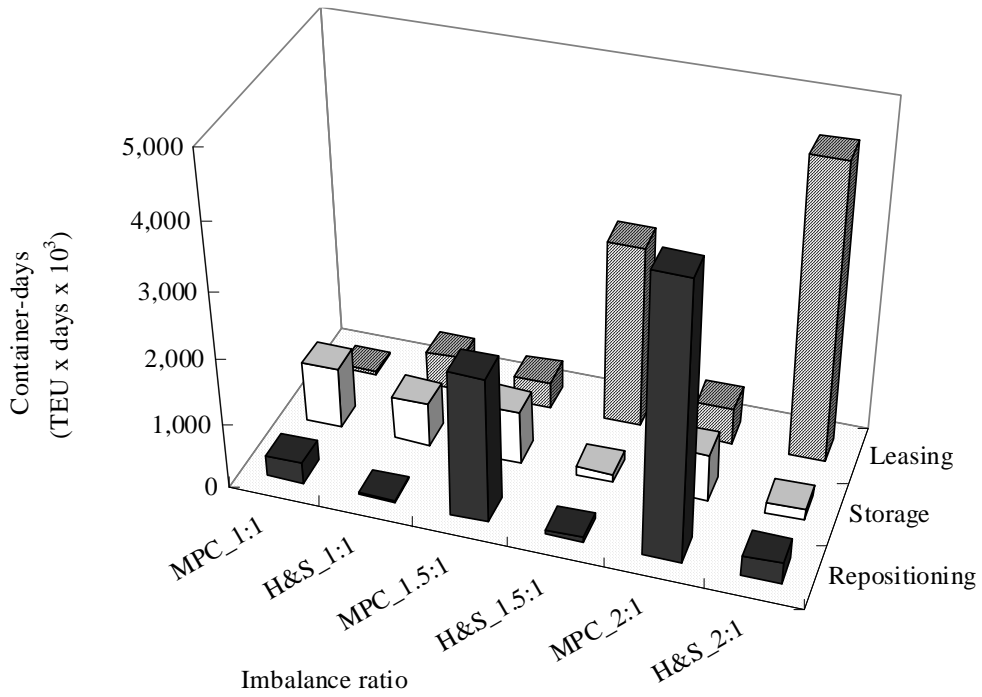


(b) Varying yearly traffic

Fig. 8. Empty container in different states in the Asia-Europe trade



(a) Flat yearly traffic



(b) Varying yearly traffic

Fig. 9. Empty container in different states in the Asia-North America trade

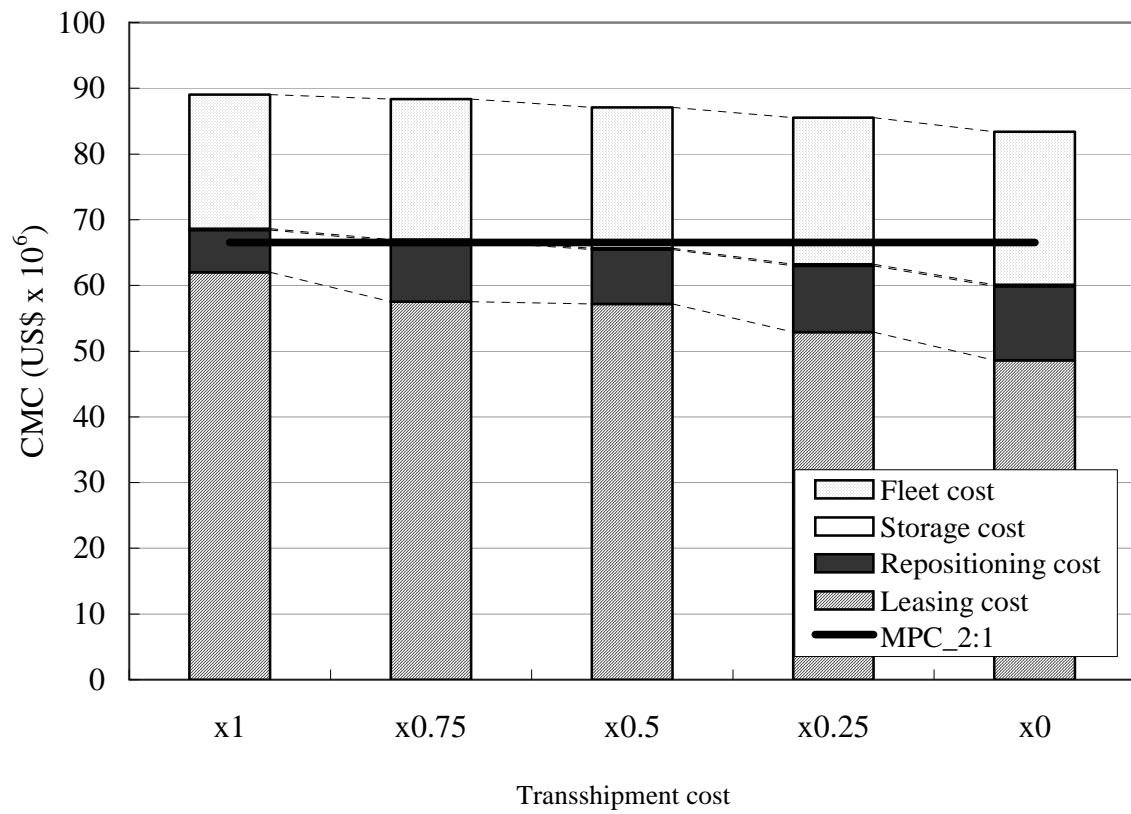


Fig. 10. Total costs by discounting the transshipment cost at hub ports (H&S_2:1)