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Foldable and standard containers in empty container repositioning

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ABSTRACT

Strategies to reposition empty containers are an unabated issue for shipping companies. This study compares the repositioning costs of foldable containers to those of standard containers. Mathematical models are used to minimize the total relevant cost, which includes the folding/unfolding cost, the inventory storage cost, the container purchasing cost, and the repositioning cost. Heuristic algorithms are proposed to solve the mathematical models. Numerical experiments are carried out in several scenarios to demonstrate the economic feasibility of foldable containers. The sensitivity analysis shows that the purchasing cost and the transportation cost affect the use of foldable containers.

1. Introduction

The acceleration in the rate of the world economic growth and the consequently widened global trade network have led to an increasing demand for transporting goods. The explosion of global trade has also been accompanied by the increase in the use of containers as a safe and inexpensive mode of transportation of goods. A container that is fully loaded with goods from the shipper is transported across the ocean to the destination port and then delivered to the consignee and unloaded. Subsequently, the container is usually emptied and stored at the destination port until it is required for another consignment. When there is an imbalance in the number of import and export containers, some ports have a surplus of empty containers, while others have a deficit. Shipping companies must then reposition empty containers from surplus ports to deficit ports or lease or purchase containers for deficit ports. At surplus ports, empty containers are stored in depots.

In 1995, the container cargo flow from Asia to the US involved 4 million twenty-foot equivalent units (TEUs), while that from the US to Asia involved 3.5 million TEUs. By 2005, the annual flow had increased to 12.4 million TEUs from Asia to the US and 4.2 million TEUs from the US to Asia. In 2007, the annual flow was 15.4 million TEUs from Asia to the US and 4.9 million TEUs from the US to Asia (source: http://people.hofstra.edu/geotrans/eng/ch3en/conc3en/worldcontainerflows.html). These data show that not only have containerized cargo flows increased very rapidly in a short amount of time, but also that the growth of flows has been dramatically larger in the trade route from Asia to the US than from the US to Asia. As a result, the imbalance in the container flows between these regions has also significantly increased: from 0.5 million TEUs in 1995 to 8.2 million TEUs in 2005 and 10.5 million TEUs in 2007. The situation is similar for container flows between Asia and Europe. It is evident that repositioning empty containers is unavoidable to balance the flow of cargo containers, although it is quite costly.

The use of foldable containers can be an effective strategy to reduce the repositioning cost as well as to save more than 75% of storage space, depending on their design. Several foldable (collapsible) container designs have been developed.

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Fallpac AB developed a Fallpac container in which four folded units can be stacked inside a fifth erected unit. In this way, the complete package of five empty containers occupies the space of a single standard container. The Six-in-One Container Company introduced a six-in-one container where six folded, bundled containers have exactly the same dimensions as a single standard container. More recently, two professors from the Department of Mechanical Engineering of the Indian Institute of Technology designed a new type of foldable container that allows four foldable containers to be folded into the size of a single standard container. Additionally, foldable containers are currently being developed by Holland Container Innovations (HCIs) and Cargoshell in the Netherlands and Compact Container Systems (CCSs) in the US. All these designs are also based on the 4:1 folding principle. These recent initiatives have refreshed the interest in using foldable containers as a way to control container repositioning cost and, hence, have also encouraged further research into this trend.

Several studies have looked at the application of foldable containers in the real world. Konings and Thijs (2001) identified several conditions that are necessary for the success of foldable containers. Konings (2005) analyzed the opportunities for the commercial application of foldable containers and considered the costs and profits of using them. Recently, Shintani et al. (2010) studied how the use of foldable containers could reduce repositioning costs in the hinterland.

In this paper, we compare the empty container repositioning costs of foldable and standard containers. The scope of our research is ocean transportation in which empty containers are repositioned by vessels. The paper is structured as follows. Section 2 reviews the current literature. The problem definition and mathematical models are discussed in Section 3, and heuristic algorithms are presented in Section 4. The numerical experiments are presented in Section 5, and some conclusions are shown in Section 6 to end this paper.

2. Literature review

There have been many recent studies in the literature related to empty container repositioning. Crainic et al. (1989) proposed models for the multi-commodity capacitated location problem with balancing requirements (MCLB) with inter-depot balancing requirements. The decision variables of MCLB included a set of binary variables that determined the opening or closing of depots and a set of continuous variables that represented the empty container flows between supply customers, depots, and demand customers. The objective function was to minimize the total cost, which involves the cost of opening the depot and transportation costs, while satisfying the demand for empty containers. Many other studies have also attempted to solve the MCLB problem. Crainic and Delorme (1993) developed dual-ascent procedures for the proposed model. Crainic et al. (1993a) solved the problem using a Tabu search procedure. Crainic et al. (1993b) developed deterministic and stochastic models to support decisions on a short-term land transportation planning problem. Gendron and Crainic (1997) presented a parallel branch and bound approach, which is based on the dual-ascent procedure previously proposed by Crainic and Delorme (1993). Gendron et al. (2003) also solved the problem using a Tabu search procedure, but they used the slope scaling method to identify the initial solution. Li et al. (2004) analyzed the management of empty containers in a port with stochastic demand based on a multi-stage inventory problem and Markov decision processes with discrete time. They focused on optimizing the pair-critical policy (U, D), which implies that, if the number of empty containers at a port is less than U, empty containers are imported up to the amount U; if the number is greater than D, the empty containers are exported until D containers are left behind. Li et al. (2007) extended the problem for multi-port applications. Shen and Khoong (1995) proposed a decision support system (DSS) for empty container distribution planning based on network optimization models. In the network, they considered the leasing-in, off-leasing, repositioning-in, and repositioning-out at a port. The problem was decomposed into three levels; terminal (port) planning, intraregional planning, and interregional planning considering a single type of container. Dong and Song (2009) studied container fleet sizing and empty container repositioning for multi-port, multi-vessel, and multi-routing systems under uncertain demand and proposed an algorithm that combines simulation and a genetic algorithm (GA) to solve the problem. Song and Zhang (2010) considered an optimal policy for empty container repositioning with stochastic demand by modeling the flows of empty containers as continuous fluids. The optimal policies were given in terms of threshold levels. Song and Dong (2010) studied another aspect of empty container repositioning. They considered the case in which destination ports are unknown in advance and empty containers are unloaded from vessels when they are required. Song and Dong (2011) conducted a study on empty container repositioning in shipping service routes. Two types of repositioning policies were considered in their study: a point-to-point repositioning policy based on point-to-point balance and a coordinated repositioning policy that considered the empty container balance in the whole service. Recently, Moon et al. (2010) studied an empty container repositioning problem that considered leasing and purchasing. To solve the overall cost-minimization problem, they developed a mixed-integer linear optimization model and proposed genetic algorithms to reduce the computation time.

Few papers have examined the use of foldable containers in empty container repositioning. Konings and Thijs (2001) reported several conditions for the success of foldable containers based on the folding/unfolding cost and the production cost. Additionally, the technical features of foldable containers, the choice of the logistic concept, and product marketing were also considered. Recently, Shintani et al. (2010) investigated the repositioning cost savings in the hinterland. Based on the possible movement of empty containers and the locations available for folding and unfolding activities, three unique scenarios were proposed for investigation. In this paper, we focus on the potential cost savings in the repositioning of empty containers at sea by using foldable containers.

3. Mathematical model

The purpose of this study is to compare the total cost of Case I (using standard containers) with that of Case II (using foldable containers). Mathematical models are developed for the two cases (one for each case) for multiple ports across multiple periods. Another mathematical model that considers the mixed use of both standard and foldable containers is also presented.

Fig. 1 shows the flows of empty containers. At a port in a given period, containers can flow in or out. The inbound flows result from the following activities.

- *Supply*: the number of containers from the consignee after the freight is unloaded and/or after maintenance.
- *Purchase*: the number of containers that are purchased when the on-hand inventory cannot satisfy demand.
- *Repositioning*: the number of containers previously repositioned from other ports.
- *Inventory*: the number of containers that have been kept in inventory from the last period.

The outbound flows cover the following activities.

- *Demand*: the demand for empty containers in this period.
- *Repositioning*: the number of containers that are repositioned to other ports in this period.

The assumptions are as follows.

- We consider multiple ports, where each port has a supply and/or demand for empty containers in each period.
- The demand must be satisfied; no backlog or shortage is allowed.
- The supply of containers is defined as the number of containers that are expected to be transported to a port in a period. This number includes the containers that are returned from the consignees. These containers will be in unfolded state when they are transported to the port.
- Containers must be purchased when the number of repositioned containers cannot satisfy the demand. Only standard containers will be purchased in Case I and only foldable containers in Case II.
- There is no limit on the number of purchased containers. These containers will be in folded state when they are transported to the port.
- Folding and unfolding operations can take place in every port.
- The unit repositioning cost of a container from port i to port j is the summation of the unit handling cost of a container at port i, the unit handling cost of a container at port j, and the unit transportation cost of a container from port i to port j.

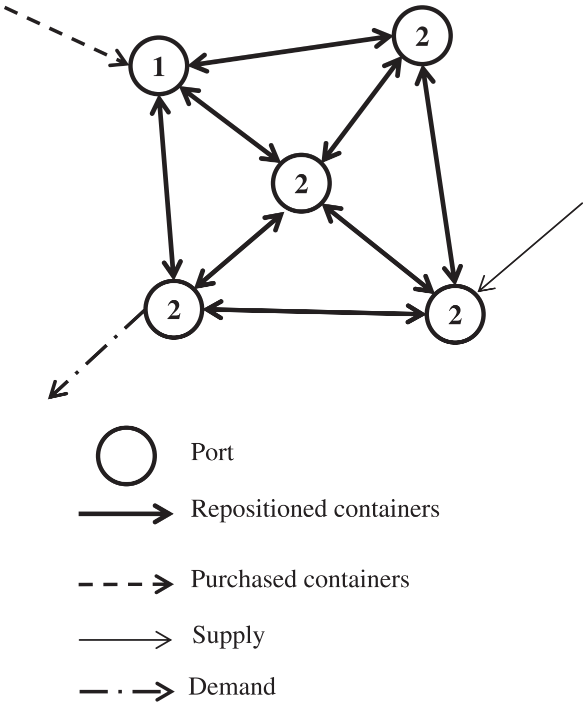

Fig. 1. Flows of empty containers.

- The storage cost and repositioning cost of a folded container will be calculated by dividing the equivalent costs of a standard container by the number of folded containers that can be packed in the size of a standard container.
- When foldable containers are kept in inventory or repositioned from port to port, they are in the folded state.
- In this study, we do not consider the vessel route. Empty containers can be repositioned to any port during any period.

The models are described in detail below:

Indices	
i, j	Ports, $i, j \in \{1,2,\ldots,P\}$ where P is the number of ports.
t	Periods, $t \in \{1,2,\ldots,T\}$ where T is the length of planning horizon.
Parameters	
W_{it}	Number of standard containers to be supplied to port i in period t
W_{it}^F	Number of foldable containers to be supplied to port i in period t
D_{it}	Demand for empty containers at port i in period t
H_i	Unit storage cost of a standard container at port i in a period
H_i^F	Unit storage cost of a foldable container at port i in a period
P_i	Unit purchasing price of a standard container at port i
P_i^F	Unit purchasing price of a foldable container at port i
C_{ij}	Unit repositioning cost of a standard container from port i to port j
C_{ij}^F	Unit repositioning cost of a foldable container from port i to port j
L_i^F	Unit folding cost of a foldable container at port i
L_i^U	Unit unfolding cost of a foldable container at port i
v_{ij}	Transportation time from port i to port j
K_{ijt}	Capacity that is available for repositioning empty containers from port i to port j in period t
N	Number of folded containers that can be packed in the size of a standard container
Decision variables	
I_{it}	Inventory level of standard containers at port i in period t
I_{it}^F	Inventory level of foldable containers at port i in period t
x_{ijt}	Number of standard containers to be transported from port i to port j in period t
x_{ijt}^F	Number of foldable containers to be transported from port i to port j in period t
y_{it}	Number of standard containers to be purchased at port i in period t
y_{it}^F	Number of foldable containers to be purchased at port i in period t

3.1. Model 1 – using standard containers only

3.1.1. The objective function

The goal of the objective function is to minimize the total relevant cost, which includes the cost of repositioning empty containers, the storage cost, and the purchasing cost.

The objective function can be expressed as follows:

$$\text{Min} \sum_i \sum_{j,j\neq i} \sum_t C_{ij} x_{ijt} + \sum_i \sum_t H_i I_{it} + \sum_i \sum_t P_i y_{it}$$

In the objective function, the first term is the repositioning cost, the second term stands for the storage cost, and the last term is the purchasing cost.

3.1.2. The constraints

3.1.2.1. Inventory balance. The container flows that go into and out of inventory at a port in a certain period are shown in Fig. 2. The inventory balance equations for containers can be represented as follows.

In the inventory at port i in period t,

- The number of empty containers going into the inventory includes the number of empty containers from the last period (period $t-1$), the number of empty containers that are supplied in period t, the number of containers that are repositioned from other ports in previous periods and arrive in period t, and the number of containers that are purchased in period t.
- The number of empty containers going out of the inventory consists of the number of empty containers that are transported to other ports and the demand at that port.

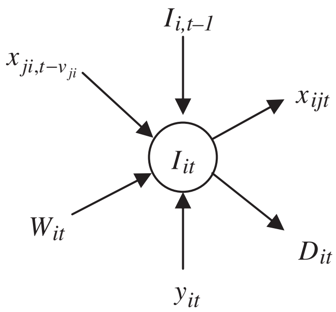

Fig. 2. Inventory balance.

Thus, the inventory balance constraint can be represented as follows:

$$I_{it} = I_{it-1} + \sum_{\{j:j\neq i,t>v_{ji}\}} x_{jit-v_{ji}} - \sum_{\{j:j\neq i,t\leqslant T-v_{ij}\}} x_{ijt} + y_{it} + W_{it} - D_{it} \quad \forall i,t \tag{1}$$

3.1.2.2. Repositioning capacity. The number of empty containers that are repositioned from one port to another port in a certain period cannot exceed the repositioning capacity.

$$x_{ijt} \leqslant K_{ijt} \quad \forall i,j \neq i,t \tag{2}$$

3.2. Model 2 – using foldable containers only

3.2.1. The objective function

The goal of the objective function is to minimize the total relevant cost, which involves the cost of repositioning empty containers, the storage cost, the purchasing cost, and the folding/unfolding cost.

The objective function can be expressed as follows:

$$\text{Min} \sum_i \sum_{j,j\neq i} \sum_t C_{ij}^F x_{ijt}^F + \sum_i \sum_t H_i^F I_{it}^F + \sum_i \sum_t P_i^F y_{it}^F + \sum_i \sum_t L_i^U \left[D_{it} - W_{it}^F\right]^+ + \sum_i \sum_t L_i^F \left[W_{it}^F - D_{it}\right]^+$$

where $[x]^+ = \text{Max}[x,0]$

Similar to the objective function of Model 1, the first three terms represent the repositioning cost, the storage cost, and the purchasing cost, respectively, while the last two terms indicate the unfolding and folding costs, respectively. At a certain port, if the number of supplied containers is greater than the demand, the remaining containers will be folded and kept in inventory or will be repositioned to other ports, which will incur folding costs. Conversely, when the number of supplied containers is less than the demand, some containers in the inventory must be unfolded to fulfill the demand, which will result in unfolding costs.

3.2.2. The constraints

3.2.2.1. Inventory balance. The inventory balance equations for containers can be represented as follows.

In the inventory at port i in period t,

- The number of empty containers going into the inventory includes the number of empty containers from the last period (period $t-1$), the number of empty containers that are received in period t, the number of containers that are repositioned from other ports in previous periods and arrive in period t, and the number of containers that are purchased in period t.
- The number of empty containers going out of the inventory consists of the number of empty containers that are transported to other ports and the demand at that port.

Thus, the inventory balance constraint can be described as follows:

$$I_{it}^F = I_{it-1}^F + \sum_{\{j:j\neq i,t>v_{ji}\}} x_{jit-v_{ji}}^F - \sum_{\{j:j\neq i,t\leqslant T-v_{ij}\}} x_{ijt}^F + y_{it}^F + W_{it}^F - D_{it} \quad \forall i,t \tag{3}$$

3.2.2.2. Repositioning capacity. The number of empty containers that are repositioned from one port to another port in a certain period cannot exceed the repositioning capacity.

$$\frac{x^F_{ijt}}{N} \leqslant K_{ijt} \quad \forall i, j \neq i, t \tag{4}$$

The two models described above are used to compare the repositioning costs of standard and foldable containers. Section 5 presents some numerical experiments in which these two models are applied.

3.3. Model 3 – using both standard and foldable containers

In this model, both standard and foldable containers are considered simultaneously. Several variables are added to this model:

Decision variables:

d_{it}	Number of standard containers to be used to satisfy a partial demand at port i in period t
d^F_{it}	Number of foldable containers to be used to satisfy a partial demand at port i in period t
z^F_{it}	Number of foldable containers to be folded at port i in period t
z^U_{it}	Number of foldable containers to be unfolded at port i in period t

3.3.1. The objective function

The goal of the objective function is to minimize the total relevant cost, which involves the cost of repositioning empty containers, the storage cost, the purchasing cost, and the folding/unfolding cost.

The objective function can be expressed as follows:

$$\text{Min} \sum_i \sum_{j, j \neq i} \sum_t \left(C_{ij} x_{ijt} + C^F_{ij} x^F_{ijt} \right) + \sum_i \sum_t \left(H_i I_{it} + H^F_i I^F_{it} \right) + \sum_i \sum_t \left(P_i y_{it} + P^F_i y^F_{it} \right) + \sum_i \sum_t \left(L^F_i z^F_{it} + L^U_i z^U_{it} \right)$$

In the objective function, the first term represents the total repositioning cost, the second term stands for the total storage cost, the third term is the total purchasing cost, and the last term is the total folding and unfolding costs.

3.3.2. The constraints

3.3.2.1. Inventory balance. The inventory balance equations for containers can be represented as follows.

3.3.2.1.1. For standard containers. In the inventory at port i in period t,

- The number of empty containers going into the inventory includes the number of empty containers from the last period (period $t-1$), the number of empty containers that are received in period t, the number of containers that are repositioned from other ports in previous periods and arrive in period t, and the number of containers that are purchased in period t.
- The number of empty containers going out of the inventory consists of the number of empty containers that are transported to other ports and the number of standard containers to be used to satisfy a partial demand at that port.

Thus, the inventory balance constraint for standard containers can be described as follows:

$$I_{it} = I_{it-1} + \sum_{\{j: j \neq i, t > v_{ji}\}} x_{jit-v_{ji}} - \sum_{\{j: j \neq i, t \leqslant T - v_{ij}\}} x_{ijt} + y_{it} + W_{it} - d_{it} \quad \forall i, t$$

3.3.2.1.2. For foldable containers. In the inventory at port i in period t,

- The number of empty containers going into the inventory includes the number of empty containers from the last period (period $t-1$), the number of empty containers that are received in period t, the number of containers that are repositioned from other ports in previous periods and arrive in period t, and the number of containers that are purchased in period t.
- The number of empty containers going out of the inventory consists of the number of empty containers that are transported to other ports and the number of foldable containers to be used to satisfy a partial demand at that port.

Thus, the inventory balance constraint for foldable containers can be described as follows:

$$I^F_{it} = I^F_{it-1} + \sum_{\{j: j \neq i, t > v_{ji}\}} x^F_{jit-v_{ji}} - \sum_{\{j: j \neq i, t \leqslant T - v_{ij}\}} x^F_{ijt} + y^F_{it} + W^F_{it} - d^F_{it} \quad \forall i, t$$

3.3.2.2. Satisfaction of demand. All of the demands should be satisfied.

$$d_{it} + d^F_{it} = D_{it} \quad \forall i, t$$

3.3.2.3. Repositioning capacity. The number of repositioned containers cannot exceed the repositioning capacity

$$x_{ijt} + \frac{x^F_{ijt}}{N} \leqslant K_{ijt} \quad \forall i, j, t$$

3.3.2.4. Number of folded/unfolded containers. If the number of supplied containers is greater than the demand, the remaining containers must be folded for storage in inventory or repositioned to other ports.

$$z^F_{it} \geqslant W^F_{it} - d^F_{it} \quad \forall i, t$$

If the number of supplied containers is less than the demand, the containers that are stored in inventory must be unfolded to satisfy the demand.

$$z^U_{it} \geqslant d^F_{it} - W^F_{it} \quad \forall i, t$$

Because the objective function needs to be minimized, if $W^F_{it} \geqslant d^F_{it}$, then $z^F_{it} = W^F_{it} - d^F_{it}$ and $z^U_{it} = 0$; otherwise, $z^F_{it} = 0$ and $z^U_{it} = d^F_{it} - W^F_{it}$

A summary of Model 3 is shown below.

$$\text{Min} \sum_{i,j,t} \left(C_{ij}x_{ijt} + C^F_{ij}x^F_{ijt} \right) + \sum_{i,t} \left(H_i I_{it} + H^F_i I^F_{it} \right) + \sum_{i,t} \left(P_i y_{it} + P^F_i y^F_{it} \right) + \sum_{i,t} \left(L^F_i z^F_{it} + L^U_i z^U_{it} \right)$$

S.t.

$$I_{it} = I_{it-1} + \sum_{\{j:j \neq i, t > v_{ji}\}} x_{jit-v_{ji}} - \sum_{\{j:j \neq i, t \leqslant T - v_{ij}\}} x_{ijt} + y_{it} + W_{it} - d_{it} \quad \forall i, t \tag{5a}$$

$$I^F_{it} = I^F_{it-1} + \sum_{\{j:j \neq i, t > v_{ji}\}} x^F_{jit-v_{ji}} - \sum_{\{j:j \neq i, t \leqslant T - v_{ij}\}} x^F_{ijt} + y^F_{it} + W^F_{it} - d^F_{it} \quad \forall i, t \tag{5b}$$

$$d_{it} + d^F_{it} = D_{it} \quad \forall i, t \tag{6}$$

$$x_{ijt} + \frac{x^F_{ijt}}{N} \leqslant K_{ijt} \quad \forall i, j, t \tag{7}$$

$$z^F_{it} \geqslant W^F_{it} - d^F_{it} \quad \forall i, t \tag{8a}$$

$$z^U_{it} \geqslant d^F_{it} - W^F_{it} \quad \forall i, t \tag{8b}$$

All variables are non-negative integers

4. Heuristic algorithms

All three models can be solved by optimization software such as LINGO. In our numerical experiments that are shown in the next section, LINGO can solve small problems (from 4 to 10 ports) very quickly. However, LINGO cannot handle large problems, i.e. where the number of ports varies from 100 to 200 ports. It can only solve 17 out of 60 large problems. When the size of the problem becomes larger, not only does it take more computation time, but the optimization software also requires more allocated memory than it can handle. One of the reasons why LINGO cannot solve large problems is that it runs out of memory. Moreover, the real problems are bigger than those conducted in the numerical experiment. Therefore, heuristic algorithms are needed to solve these mathematical models. The proposed algorithms will be shown in this section.

4.1. Heuristic algorithm for Models 1 and 2

Models 1 and 2 are very similar. Therefore, one heuristic algorithm is proposed to solve those models. The heuristic algorithm is described as follows. First, the inventory level at each port in a period is calculated by the inventory level of the last period, the number of supplied containers, and the demand during that period. After this step, two sets of ports are determined. In each period, there are some ports that have a surplus of containers (i.e., a positive inventory level). These ports are put into the set of surplus ports (A_t where t is a certain period). Similarly, for each period, there are some ports that have a deficit of containers (i.e., a negative inventory level). These ports are put into the set of deficit ports (B_t). Second, the number of containers to be repositioned from the ports in A_t to the ports in B_t is determined. Each port in B_t is considered (These will be called deficit ports.). The deficit port that has to pay the highest price for each container is assigned the highest priority. Empty containers will be repositioned from ports that have a surplus of empty containers (surplus ports) to deficit ports. A deficit port has a set of surplus ports that are candidates for repositioning. This set is named C_{it} where i is the deficit port and t is the period in which the deficit of containers occurs at port i. A surplus port that has a lower repositioning cost gets a higher priority to reposition empty containers. The procedure to determine the number of containers to be repositioned to a considered deficit port stops when the demand at that deficit port is fully satisfied or there are no other candidates for repositioning. This second step finishes when all ports in B_t have been considered. After the second step, there are several ports whose demands are not fully satisfied. Finally, the remaining demand at each port in a period is fulfilled by the purchase of containers.

However, the quality of the solution obtained from the above procedure may not be good. Some ports have to purchase containers, while their candidates still have containers available. This shortfall is caused by the repositioning capacity, which does not allow a surplus port to reposition as many containers as it can. Therefore, a local search algorithm is applied to improve the quality of the obtained solution. In the local search algorithm, containers are considered to be repositioned in advance to satisfy the future demand at a deficit port. The procedure of the heuristic algorithm for Models 1 and 2 is shown below.

Step 1. Calculate the inventory level at each port in the current period.

$$I_{it} = I_{it-1} + W_{it} - D_{it} \quad \forall i, t$$

Step 2. For each period, create a set of surplus ports, namely $A_t = \{i|I_{it} > 0\}$. For each period, create a set of deficit ports, namely $B_t = \{i|I_{it} < 0\}$.

Step 3. In period t

Step 3.1. In B_t, select port i that has the highest purchasing price of a container.

Step 3.2. Create a set of ports that are available for repositioning to port i, namely $C_{it} = \{j|j \in A_{t-v_{ji}}\}$.

Step 3.3. If $C_{it} \neq \emptyset$, select port j that has the smallest repositioning cost to port i; otherwise, go to step 3.7.

Step 3.4. Assign the number of containers that are repositioned from port j to port i in period $t - v_{ji}$ as many as possible.

$$x_{jit-v_{ji}} = \min(I_{jt-v_{ji}}, -I_{it}, K_{jit-v_{ji}})$$

where K_{ijt} is defined as the available capacity for repositioning from port i to port j in period t.

Step 3.5. Update the inventory level and repositioning capacity.

$$I_{it} = I_{it} + x_{jit-v_{ji}}$$

$$I_{jt-v_{ji}} = I_{jt-v_{ji}} - x_{jit-v_{ji}}$$

If $I_{jt-v_{ji}} = 0$, then remove j from set $A_{t'}$ where $t' \leqslant t - v_{ji}$.

$$K_{jit-v_{ji}} = K_{jit-v_{ji}} - x_{jit-v_{ji}}$$

Step 3.6. If $I_{it} = 0$, remove i from set B_t and go to step 3.8; otherwise, remove j from set C_{it} and go back to step 3.3.

Step 3.7. Assign the number of purchased containers and update inventory level.

$$y_{it} = -I_{it}$$
$$I_{it} = 0$$

remove i from set B_t.

Step 3.8. If $B_t = \emptyset$, go to step 4; otherwise, go back to step 3.1.

Step 4. Increase t by 1. If $t > T$, then go to step 5. Otherwise, go back to step 3.

Step 5. Execute the local search algorithm to improve the solution.

4.2. Heuristic algorithm for Model 3

In Model 3, both standard and foldable containers are used simultaneously. Therefore, the procedure to determine the number of repositioned containers is different from that of the previous algorithm. Obviously, the repositioning and storage costs of a standard container are higher than those of a foldable container. Hence, the standard containers have higher priority to satisfy the demand. The foldable containers will have higher priority to be repositioned to other ports or to be stored in the inventory. The procedure to solve this model can also be divided into two phases, similar to the algorithm for Models 1 and 2. The first phase is used to find a feasible solution, while the second phase improves that obtained solution for Models 1 and 2. The procedure of the first phase is described as follows. First, the inventory level at each port in each period is calculated. The difference between this algorithm and the heuristic algorithm for Models 1 and 2 is that the available standard containers have a higher priority to meet the demand. After this step, the sets A_t, and B_t are determined. Second, the number of repositioned containers is determined. In this step, the foldable containers have a higher priority to be repositioned. Finally, the number of purchased containers is determined. The procedure of the second phase is also based on the local search algorithm. The procedure of the heuristic algorithm for Model 3 is as follows.

Step 1: Calculate the inventory level at each port in the current period.

$$I_{it} = \text{Max}(I_{it-1} + W_{it} - D_{it}, 0) \quad \forall i, t$$

$$I^F_{it} = \text{Max}\left\{I^F_{it-1} + W^F_{it} - \text{Max}[D_{it} - (I_{it-1} + W_{it}), 0], 0\right\} \quad \forall i, t$$

$$R_{it} = \text{Max}\left[D_{it} - (I_{it-1} + W_{it}) - \left(I^F_{it-1} + W^F_{it}\right), 0\right] \quad \forall i, t$$

where R_{it} is the remaining demand of port i in period t.

Step 2: For each period, create a set of surplus ports, namely $A_t = \{i|I_{it} > 0\}$ and $A^F_t = \left\{i|I^F_{it} > 0\right\}$. For each period, create a set of deficit ports, namely $B_t = \{i|R_{it} > 0\}$.

Step 3: In period t

Step 3.1. In B_t, select port i that has the highest purchasing price of a container.

Step 3.2. Create a set of ports that are available for repositioning to port i, namely, $C_{it} = \{j|j \in A_{t-v_{ji}}\}$ and $C^F_{it} = \left\{j|j \in A^F_{t-v_{ji}}\right\}$.

Step 3.3. If $C^F_{it} \neq \emptyset$, select port j that has the smallest repositioning cost to port i; otherwise, go to step 3.7.

Step 3.4. Assign the number of containers that are repositioned from port j to port i in period $t - v_{ji}$ as many as possible.

$$x^F_{jit-v_{ji}} = \min\left(I^F_{jt-v_{ji}}, R_{it}, K_{jit-v_{ji}} * N\right)$$

where K_{ijt} is defined as the available capacity for repositioning from port i to port j in period t and N is the number of foldable containers that can be packed in the size of a standard container.

Step 3.5. Update the inventory level and repositioning capacity.

$$R_{it} = R_{it} + x^F_{jit-v_{ji}}$$
$$I^F_{jit-v_{ji}} = I^F_{jit-v_{ji}} - x^F_{jit-v_{ji}}$$

If $I^F_{jit-v_{ji}} = 0$, remove j from set $A^F_{t'}$, where $t' \leqslant t - v_{ji}$.

$$K_{jit-v_{ji}} = K_{jit-v_{ji}} - \frac{x^F_{jit-v_{ji}}}{N}$$

Step 3.6. If $R_{it} = 0$, remove i from set B_t and go to step 3.12; otherwise, remove j from set C^F_{it} and go back to step 3.3.

Step 3.7. If $C_{it} \neq \emptyset$, select port j that has the smallest repositioning cost to port i; otherwise, go to step 3.11.

Step 3.8. Assign the number of containers that are repositioned from port j to port i in period $t - v_{ji}$ as many as possible.

$$x_{jit-v_{ji}} = \min(I_{jt-v_{ji}}, R_{it}, K_{jit-v_{ji}})$$

Step 3.9. Update the inventory level and repositioning capacity.

$$R_{it} = R_{it} + x_{jit-v_{ji}}$$
$$I_{jit-v_{ji}} = I_{jit-v_{ji}} - x_{jit-v_{ji}}$$

If $I_{jit-v_{ji}} = 0$, remove j from set $A_{t'}$, where $t' \leqslant t - v_{ji}$.

$$K_{jit-v_{ji}} = K_{jit-v_{ji}} - x_{jit-v_{ji}}$$

Step 3.10. If $R_{it} = 0$, remove i from set B_t and go to step 3.12; otherwise, remove j from set C_{it} and go back to step 3.7.

Step 3.11. Assign the number of purchased containers and update the inventory level.

$$y_{it} = R_{it}$$
$$R_{it} = 0$$

remove i from set B_t.

Step 3.12. If $B_t = \emptyset$, go to step 4; otherwise, go back to step 3.1.

Step 4. Increase t by 1. If t > T, go to step 5; otherwise, go back to step 3.

Step 5. Execute the local search algorithm to improve the solution.

A small case study is provided in the appendix where the values of parameters, the optimal solution, and the solution from the heuristic algorithm are shown.

5. Numerical experiments

5.1. Performance of the two heuristic algorithms

To evaluate the performance of the two heuristic algorithms, 120 problems are randomly generated. These problems are categorized into small problems and large problems. In small problems, the number of ports varies from 4 to 10, while there are more than 100 ports in large problems. We considered the weekly period. The planning horizon is randomly generated in four values, 13, 26, 39, and 52 periods. The range of demand at a port in a period is between 200 and 500 containers. The range of containers to be supplied at a port in a period is between 200 and 500 containers for Models 1 and 2. For Model 3, the range of standard containers and foldable containers to be supplied to a port in a period is from 100 to 250 containers. The transportation time from one port to another is from 1 to 3 periods. The transportation cost is proportional to the transportation time. The initial inventory at a port is randomly generated from 0 to 50 containers. The repositioning capacity varies from 150 to 200 containers. There are 30 small problems for Models 1 and 2, 30 small problems for Model 3, 30 large problems for Models 1 and 2, and 30 large problems for Model 3. These problems were solved using LINGO (optimization software) and two heuristic algorithms. The comparison between the optimal solutions and the solutions obtained from the heuristic algorithms are summarized in Tables 1 and 2 below. The ratio of the objective value is calculated using the following formula

$$\text{Ratio of the objective value} = \frac{\text{Objective value obtained from the heuristic algorithm}}{\text{Objective value obtained from the mathematical program}}$$

The heuristic algorithms for Models 1 and 2 can find an optimal solution, while the heuristic algorithm for Model 3 cannot find an optimal solution. However, the error is very small. For large problems, there are 15 problems of Models 1 and 2 and 7 problems of Model 3 for which LINGO found an optimal solution. Therefore, the statistics presented in Tables 1 and 2 are based on the number of problems with optimal solutions. Not only is the objective value considered, but the necessary computation time is also an important factor of the overall performance. For small problems, both LINGO and the heuristic algorithm produce solutions quickly. LINGO can solve all small problems within a second (one second is the minimum time unit of LINGO), while the computation time of the proposed algorithm is less than 0.02 s. However, the proposed algorithm can solve large problems very quickly, while LINGO cannot. The computational time is less than one second for both of the heuristic algorithms. The statistics of the computation time for large problems are shown in Table 3.

5.2. Sensitivity analysis

For the sensitivity analysis, the purchasing price of a foldable container is assumed to be twice as much as that of a standard container. Four foldable containers take up as much space as a standard container when folded and packed together. The folding and unfolding costs are the same; they are assumed to be approximately 50USD per handling. A weekly period is considered, and the planning horizon is a year. Only 40-ft containers are considered. The handling cost is approximately 50USD per standard container at a port. The transportation cost, representing the sailing cost, is approximately 20USD per

Table 1
Results of the mathematical program and the heuristic algorithms for Models 1 and 2.

	Ratio of the objective value	
	Small problems	Large problems
Min	1.000	1.004
Max	1.151	1.125
Average	1.039	1.074
Standard deviation	0.034	0.027
Num_opt	2	0

*Num_opt: the number of problems in which the heuristic algorithm found an optimal solution.

Table 2
Results of the mathematical program and the heuristic algorithm for Model 3.

	Ratio of the objective value	
	Small problems	Large problems
Min	1.005	1.020
Max	1.160	1.155
Average	1.028	1.077
Standard deviation	0.041	0.056
Num_opt	0	0

Table 3
Computation time necessary for solving large problems using the mathematical program and the heuristic algorithms (in seconds).

	Models 1 and 2		Model 3	
	Mathematical program	Heuristic algorithm	Mathematical program	Heuristic algorithm
Min	92	0.047	225	0.047
Max	231	0.594	2049	0.656
Average	126.67	0.227	1008.71	0.285
Standard deviation	34.90	0.145	816.28	0.173

day. Three ports are selected, one each from East Asia, the US, and Europe. The supply and demand for containers are in the range from 200 to 700 containers per week based on raw data collected from a maritime shipping company. The demand at the East Asian port is higher than that of either the European or the US port. Conversely, the supply at the East Asian port is the lowest. We assume that the transportation time is symmetric. The transportation times are 1–3 weeks for the links between East Asia–US, US–Europe, and East Asia–Europe, respectively. The initial inventory level and the capacity of repositioning are randomly generated from 0 to 50 and from 150 to 200, respectively. The storage cost is estimated to be approximately 8USD per standard container in a period. The purchasing price of a standard container, which is amortized for a year, is 946USD per container for a shipping company while that price of a foldable container is 1,892USD per container.

5.2.1. Experiments on Models 1 and 2

Experiments are conducted to compare the cost of using standard containers with that of using foldable containers. First, an increase in demand for containerized cargo transport is considered. When the world economy recovers from the economic crisis that has set in from 2008 the demand for container transport rise again, and this also affects the imbalance in container flows. Second, the purchasing price of a foldable container has the potential to decrease. Currently, foldable containers with lower production costs have been designed in several studies. Moreover, when foldable containers can be produced on a large scale, their purchasing cost can fall. It is expected that foldable containers will be less expensive in the future. Third, an experiment has been conducted on the transportation cost. Unless a new source of energy is developed, oil is the only fuel to operate maritime vessels. This resource (crude oil) is nonrenewable and is expected to run out eventually. As a result, the transportation cost is assumed to increase. Finally, the cost of folding/unfolding a foldable container is considered. As it is likely that the production cost of a foldable container can be reduced, one may also expect that the folding/unfolding process can be faster and less costly in the future due to technological developments.

5.2.1.1. Standard containers vs. foldable containers when demand for containerized cargo transport increases. There are five scenarios for the changes in demand, corresponding to increases of 10%, 15%, 20%, 25%, and 30%. The container flows from Asia to the US and Europe increase year by year as reported by the UNCTAD Review of Maritime Transport. This growth of cargo flows also involves increasing imbalances between Asia–US and Asia–Europe (source: http://people.hofstra.edu/geotrans/eng/ch3en/conc3en/worldcontainerflows.html). Hence, more empty containers need to be repositioned. In that situation cost savings in repositioning empty containers can be larger when foldable containers are operated. The results are presented in Table 4.

In Table 4, the second and third columns indicate the total cost of using standard containers and foldable containers. The last column presents the percentage difference between the total cost of using standard containers and that of using foldable containers. A positive percentage indicates that using foldable containers is more expensive. From Table 4, it is evident that an increase in demand does not affect the preference to use standard containers over foldable containers. As mentioned above, when the demand increases, more empty containers will be repositioned. Therefore, the repositioning cost also increases, and the repositioning cost is higher when standard containers are used. However, because of increasing demand, more containers are purchased, and the purchasing cost rises. It is clear that the purchasing cost is higher when foldable containers are used. Hence, standard containers are used despite the increase in demand.

Table 4
Experiment on the increase in demand.

	Standard container	Foldable container	% Difference
Original result	1,963,064	2,223,166	13.25
+10%	2,175,830	2,478,813	13.92
+15%	2,278,826	2,598,145	14.01
+20%	2,384,100	2,726,711	14.37
+25%	2,483,394	2,839,550	14.34
+30%	2,593,146	2,974,307	14.70

Table 5
Experiment on the decrease in the purchasing price of foldable containers.

	Standard container	Foldable container	% Difference
Original result	1,963,064	2,223,166	13.25
−5%		2,167,330	10.41
−10%		2,110,900	7.53
−15%		2,055,064	4.69
−20%		1,998,634	1.81
−25%		1,942,204	−1.06
−30%		1,886,368	−3.91

Table 6
Experiment on the increase in the transportation cost.

	Standard container	Foldable container	% Difference
Original result	1,963,064	2,223,166	13.25
+10%	2,045,244	2,245,429	9.79
+20%	2,127,424	2,264,256	6.43
+30%	2,209,604	2,286,519	3.48
+40%	2,291,784	2,305,346	0.59
+50%	2,373,964	2,327,609	−1.95

Table 7
Experiment on the decrease in the folding/unfolding cost.

	Standard container	Foldable container	% Difference
Original result	1,963,064	2,223,166	13.25
−5%		2,193,358	11.73
−10%		2,148,646	9.45
−20%		2,074,126	5.66
−30%		1,999,606	1.86
−40%		1,925,086	−1.93

5.2.1.2. Standard containers vs. foldable containers when the purchasing price of foldable containers decreases. There are six scenarios for the changes in the purchasing price of foldable containers, corresponding to decreases of 5%, 10%, 15%, 20%, 25%, and 30%. The results are presented in Table 5.

The columns in Table 5 are equivalent to those in Table 4. A positive percentage indicates that the use of foldable containers is more expensive. From Table 5, it is evident that if the purchasing price of foldable containers decreases, the cost performance of foldable containers improves compared to standard containers. When the purchasing price decreases by 25% or more, using foldable containers becomes cheaper. If the purchasing price of a foldable container is 50% higher than that of a standard one, the use of foldable containers will be profitable (Note: we assumed that the original purchasing price of a foldable container is assumed to be twice as much as that of a standard container. Therefore, a 25% decrease in the purchasing price of a foldable container means that the purchasing price of a foldable container is 50% higher than that of a standard one.) Several studies on foldable design have been conducted, and the purchasing price of a foldable container is expected to be approximately 10–15% higher than that of a standard one (LOG.india, 2008). In that situation, using foldable containers would be very promising.

5.2.1.3. Standard containers vs. foldable containers when the transportation cost increases. There are five scenarios for the changes in the transportation cost, ranging from a 10% to 50% increase in costs. The results are presented in Table 6.

When the transportation cost increases, the rate of increase in the repositioning cost will be lower if foldable containers are used. For this reason, in the last column of Table 6, the percentage difference in cost continues to be smaller. When the transportation cost increases, the cost performance of foldable containers relatively improves compared to standard containers. Using foldable containers will be more profitable when the available capacity for repositioning becomes large. Although the oil price fluctuates occasionally, the price level exhibits a rising trend. Hence, foldable containers show significant commercial viability.

5.2.1.4. Standard containers vs. foldable containers when the folding/unfolding cost decreases. There are five scenarios in which the folding/unfolding cost decreases by 5–40%. The results are presented in Table 7.

It is clear that when the folding/unfolding cost decreases, the conditions for using foldable containers improve. As observed from Table 7, when the folding/unfolding cost drops, the gap between the total cost of using standard containers

Table 8
Experiment on the increase in demand for Model 3.

Scenarios	Costs for standard containers				Costs for foldable containers				
	Repositioning	Storage	Purchasing	Total	Repositioning	Storage	Purchasing	F/UF	Total
Original result	0	74,680	551,518	626,198	300,127	33,630	0	392,900	726,657
+10%	0	81,952	625,306	707,258	329,538	37,416	0	431,550	798,504
+15%	0	85,576	659,362	744,938	345,868	38,418	0	451,400	835,686
+20%	0	89,552	694,364	783,916	361,029	39,780	0	470,250	871,059
+25%	0	92,760	721,798	814,558	376,738	40,968	0	490,200	907,906
+30%	0	96,888	763,422	860,310	391,821	42,362	0	508,900	943,083

and that of using foldable containers also narrows, confirming that foldable containers can become more favorable to use if the folding/unfolding cost can be reduced by more than 40%.

5.2.2. Experiments on Model 3

In this model, both standard and foldable containers are considered simultaneously. Two cases are investigated. In Case 1, the supplies of standard and foldable containers are the same at each port in every period; only standard containers are supplied in Case 2. The containers are supplied from different origins, such as from consignees after freights are unloaded or from planned purchase. The first case provides insight into the trade-off in using foldable containers vs. standard containers, while the second case reveals scenarios in which standard containers should be replaced by foldable containers.

5.2.2.1. The supplies of standard and foldable containers are equal. To conduct the experiments for this case, three situations are considered: an increase in demand, an increase in the transportation cost, and a decrease in the folding/unfolding cost. In each situation, several scenarios are considered.

5.2.2.1.1. An increase in demand. There are five scenarios for changes in demand: increases of 10%, 15%, 20%, 25%, and 30%, respectively. These results are presented in Table 8.

In all of the scenarios, foldable containers are used for repositioning. The largest cost of using standard containers is their purchasing cost, while the repositioning and folding/unfolding contribute the most to the cost of using foldable containers. This difference indicates that using foldable containers is useful in repositioning activities.

5.2.2.1.2. An increase in the transportation cost. There are five scenarios for changes in the transportation cost: increases of 10%, 20%, 30%, 40%, and 50%. These results are presented in Table 9.

Similar to Section 5.2.2.1.1, in this situation (viz. Section 5.2.2.1.2), foldable containers are used for repositioning. Only foldable containers are repositioned, while the number of standard containers that are purchased is unchanged, showing that standard containers are purchased because they have a lower purchasing cost, but foldable containers are more appropriate for repositioning.

Table 9
Experiment on the increase in transportation cost for Model 3.

Scenarios	Costs for standard containers				Costs for foldable containers				
	Repositioning	Storage	Purchasing	Total	Repositioning	Storage	Purchasing	F/UF	Total
Original result	0	74,680	551,518	626,198	300,127	33,630	0	392,900	726,657
+10%	0	74,680	551,518	626,198	321,950	33,630	0	392,900	748,480
+20%	0	74,680	551,518	626,198	340,356	33,630	0	392,900	766,886
+30%	0	74,680	551,518	626,198	362,179	33,630	0	392,900	788,709
+40%	0	74,680	551,518	626,198	380,585	33,630	0	392,900	807,115
+50%	0	74,680	551,518	626,198	402,408	33,630	0	392,900	828,938

Table 10
Experiment on the decrease in folding/unfolding cost for Model 3.

Scenarios	Costs for standard containers				Costs for foldable containers				
	Repositioning	Storage	Purchasing	Total	Repositioning	Storage	Purchasing	F/UF	Total
Original result	0	74,680	551,518	626,198	300,127	33,630	0	392,900	726,657
−5%	0	74,680	551,518	626,198	300,127	33,630	0	377,184	710,941
−10%	0	74,680	551,518	626,198	300,127	33,630	0	353,610	687,367
−20%	0	68,408	551,518	619,926	300,127	35,198	0	318,800	654,125
−30%	0	60,344	551,518	611,862	300,127	37,214	0	284,830	622,171
−40%	0	60,344	551,518	611,862	300,127	37,214	0	244,140	581,481

Table 11
Experiments for Model 3 when only standard containers are available at the beginning.

Scenarios	Costs for standard containers				Costs for foldable containers				
	Repositioning	Storage	Purchasing	Total	Repositioning	Storage	Purchasing	F/UF	Total
Original result	1,205,100	196,040	561,924	1,963,064	0	0	0	0	0
Increase in demand									
+10%	1,324,920	216,144	634,766	2,175,830	0	0	0	0	0
+15%	1,386,240	225,656	666,930	2,278,826	0	0	0	0	0
+20%	1,444,300	235,976	703,824	2,384,100	0	0	0	0	0
+25%	1,505,660	244,584	733,150	2,483,394	0	0	0	0	0
+30%	1,565,480	254,784	772,882	2,593,146	0	0	0	0	0
Decrease in the purchasing price of foldable containers									
−10%	1,205,100	196,040	561,924	1,963,064	0	0	0	0	0
−20%	1,205,100	196,040	561,924	1,963,064	0	0	0	0	0
−30%	1,205,100	196,040	561,924	1,963,064	0	0	0	0	0
−40%	1,205,100	196,040	561,924	1,963,064	0	0	0	0	0
−50%	1,205,100	196,040	561,924	1,963,064	0	0	0	0	0
−55%	1,205,100	196,040	0	1,401,140	0	0	506,088	29,700	535,788

Table 12
Experiments for Model 3 when only standard containers are available at the beginning (continued).

Scenarios	Costs for standard containers				Costs for foldable containers				
	Repositioning	Storage	Purchasing	Total	Repositioning	Storage	Purchasing	F/UF	Total
Original result	1,205,100	196,040	561,924	1,963,064	0	0	0	0	0
Increase in the transportation cost									
+5%	1,287,280	196,040	561,924	2,045,244	0	0	0	0	0
+10%	1,369,460	196,040	561,924	2,127,424	0	0	0	0	0
+15%	1,451,640	196,040	561,924	2,209,604	0	0	0	0	0
+20%	1,533,820	196,040	561,924	2,291,784	0	0	0	0	0
+25%	1,616,000	196,040	561,924	2,373,964	0	0	0	0	0
Decrease in the folding/unfolding cost									
−5%	1,205,100	196,040	561,924	1,963,064	0	0	0	0	0
−10%	1,205,100	196,040	561,924	1,963,064	0	0	0	0	0
−20%	1,205,100	196,040	561,924	1,963,064	0	0	0	0	0
−30%	1,205,100	196,040	561,924	1,963,064	0	0	0	0	0
−40%	1,205,100	196,040	561,924	1,963,064	0	0	0	0	0

5.2.2.1.3. A decrease in the folding/unfolding cost. There are five scenarios for changes in the folding/unfolding cost: decreases of 5%, 10%, 20%, 30%, and 40%. These results are presented in Table 10.

Table 10 shows that the folding/unfolding cost affects the use of foldable containers in terms of cost. Because the foldable containers are utilized for repositioning, the total cost will be reduced if the folding/unfolding cost is reduced.

5.2.2.2. Only standard containers are supplied. Currently, only standard containers are in use, and through the experiments, using foldable containers turns out to be more costly. Hence, it is necessary to determine the conditions in which standard containers should be replaced by foldable containers. Similar to the experiments for Models 1 and 2, four situations will be considered: an increase in demand, a decrease in the purchasing price, an increase in the transportation cost, and a decrease in the folding/unfolding cost. These results are shown in Tables 11 and 12.

These experiments show that the high purchasing price of foldable containers prevents them from being widely used. It is suggested that more research should be done into the design of foldable containers to reduce their manufacturing cost as much as possible so that they can be put into practice in the near future.

6. Conclusions

In this study, the cost of foldable containers is compared to that of standard containers in the case of empty container repositioning. The contribution of this paper to the empty container repositioning issue is the development of mathematical models which point out the potential cost savings in using foldable containers in ocean transportation. Three mathematical models were developed for the comparison, and two heuristic algorithms were proposed to solve the three mathematical models. Several experiments were conducted using different conditions within the models. The results showed that there are some conditions in which it would be wise to replace standard containers with foldable containers. Currently, foldable containers cannot be widely used because of their high production cost, high maintenance cost, and vulnerability to damage. However, foldable containers are expected to become cheaper based on the current efforts to improve their design. These efforts and the rapid rise of oil prices will hopefully enable foldable containers to replace standard containers in the future. These experiments demonstrate that a decrease in the production cost of foldable containers and an increase in transportation costs play a key role in the use of foldable containers. In our future research, we will investigate the maintenance aspect of foldable containers. We may extend our research to the case of spot-leasing and may also investigate the impact of developing dedicated facilities in ports for folding/unfolding operations.

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Appendix A

A small case study for Model 1 is randomly generated using three ports and a ten period planning horizon. The data are shown in the following tables.

Port	Initial inventory	Storage cost (per container)	Purchasing price (per container)
1	32	40	3000
2	48	40	3000
3	13	40	3000

Transportation time and unit repositioning cost.

From–to	Transportation time (periods)	Repositioning cost (per container)
Port 1–Port 2	3	436
Port 1–Port 3	1	156
Port 2–Port 3	1	156

Repositioning capacity (containers).

From–to	Period									
	1	2	3	4	5	6	7	8	9	10
P1–P2	159	186	156	179	154	158	178	156	157	159
P1–P3	158	182	197	156	181	182	159	194	158	194
P2–P1	194	200	175	176	159	189	157	186	171	195
P2–P3	179	167	155	165	162	150	164	170	156	195
P3–P1	158	185	157	162	165	197	189	178	198	176
P3–P2	186	195	189	189	154	182	161	181	157	191

Demand at each port in each period (containers).

Port	Period									
	1	2	3	4	5	6	7	8	9	10
1	390	498	289	266	364	284	326	239	252	424
2	489	200	348	334	320	392	341	293	473	489
3	471	212	382	213	414	431	270	345	415	254

Number of supplied containers at each port in each period (containers).

Port	Period									
	1	2	3	4	5	6	7	8	9	10
1	256	461	207	258	456	400	383	492	376	427
2	365	252	416	269	210	342	408	431	390	403
3	373	389	319	345	298	205	389	271	500	499

The objective value, repositioning cost, storage cost, and purchasing cost of an optimal solution obtained from LINGO and the heuristic algorithm are shown in the table below. The objective value obtained from the heuristic algorithm is 0.02% higher than the optimal objective value.

	Objective value	Repositioning cost	Storage cost	Purchasing cost
Mathematical program	1,663,464	27,144	139,320	1,497,000
Heuristic algorithm	1,663,792	14,352	152,440	1,497,000

The solutions obtained from the mathematical program (optimal solution) and the heuristic algorithm are presented as follows.

Number of containers in the inventory at each port in each period.

Mathematical program.

Port	Period									
	1	2	3	4	5	6	7	8	9	10
1	0	0	0	0	0	116	173	426	550	553
2	0	52	120	55	0	0	67	205	122	36
3	0	***95***	***32***	***164***	***48***	0	119	45	130	375

Heuristic algorithm.

Port	Period									
	1	2	3	4	5	6	7	8	9	10
1	0	0	0	0	0	116	173	426	550	553
2	0	52	120	55	0	0	67	205	122	36
3	0	***177***	***114***	***246***	***130***	0	119	45	130	375

Number of repositioned containers in each period.

Mathematical program.

From–to	Period									
	1	2	3	4	5	6	7	8	9	10
P1–P2	0	0	0	0	0	0	0	0	0	0
P1–P3	0	0	0	0	92	0	0	0	0	0
P2–P1	0	0	0	0	0	0	0	0	0	0
P2–P3	0	0	0	0	0	0	0	0	0	0
P3–P1	0	***82***	0	0	0	0	0	0	0	0
P3–P2	0	0	0	0	0	0	0	0	0	0

Heuristic algorithm.

From–to	Period									
	1	2	3	4	5	6	7	8	9	10
P1–P2	0	0	0	0	0	0	0	0	0	0
P1–P3	0	0	0	0	92	0	0	0	0	0
P2–P1	0	0	0	0	0	0	0	0	0	0
P2–P3	0	0	0	0	0	0	0	0	0	0
P3–P1	0	***0***	0	0	0	0	0	0	0	0
P3–P2	0	0	0	0	0	0	0	0	0	0

Number of purchased containers at each port in each period.
Mathematical program.

Port	Period									
	1	2	3	4	5	6	7	8	9	10
1	102	37	***0***	8	0	0	0	0	0	0
2	76	0	0	0	55	50	0	0	0	0
3	85	0	0	0	0	***86***	0	0	0	0

Heuristic algorithm.

Port	Period									
	1	2	3	4	5	6	7	8	9	10
1	102	37	***82***	8	0	0	0	0	0	0
2	76	0	0	0	55	50	0	0	0	0
3	85	0	0	0	0	***4***	0	0	0	0

The differences between the two solutions are shown in bold and italic. In the solution of the heuristic algorithm, there is no repositioned container from port 3 to port 1 in period two, while 82 containers are repositioned from port 3 to port 1 in period 2 in the optimal solution because the heuristic algorithm considers the future demands of the original port when deciding on the number of repositioned containers. In the 6th period, there is a deficit of 4 containers at port 3. Thus, there is no repositioned container from port 3 to port 1 in the 2nd period creating the differences between the two solutions.

References

Crainic, T.G., Dejax, P., Delorme, L., 1989. Models for multimode multicommodity location problems with interdepot balancing requirements. Annals of Operations Research 18, 279–302.

Crainic, T.G., Delorme, L., 1993. Dual-ascent procedures for multicommodity location-allocation problems with balancing requirements. Transportation Science 27, 90–101.

Crainic, T.G., Gendreau, M., Soriano, P., Toulouse, M., 1993a. A Tabu search procedure for multicommodity location/allocation with balancing requirements. Annals of Operations Research 41, 359–383.

Crainic, T.G., Gendreau, M., Dejax, P., 1993b. Dynamic and stochastic models for the allocation of empty containers. Operations Research 41, 102–126.

Dong, J.X., Song, D.P., 2009. Container fleet sizing and empty repositioning in liner shipping systems. Transportation Research Part E 45, 860–877.

Gendron, B., Crainic, T.G., 1997. A parallel branch-and-bound algorithm for multicommodity location with balancing requirements. Computers and Operations Research 24, 829–847.

Gendron, B., Potvin, J.Y., Soriano, P., 2003. A Tabu search with slope scaling for the multicommodity capacitated location problem with balancing requirements. Annals of Operations Research 122, 193–217.

Konings, R., Thijs, R., 2001. Foldable containers: a new perspective on reducing container-repositioning costs. European Journal of Transport and Infrastructure Research 1 (4), 333–352.

Konings, R., 2005. Foldable containers to reduce the costs of empty transport? A cost-benefit analysis from a chain and multi-actor perspective. Maritime Economics and Logistics 7 (3), 223–249.

Li, J.A., Liu, K., Leung, S.C.H., Lai, K.K., 2004. Empty container management in a port with long-run average criterion. Mathematical and Computer Modelling 40, 85–100.

Li, J.A., Leung, S.C.H., Wu, Y., Liu, K., 2007. Allocation of empty containers between multi-ports. European Journal of Operational Research 182, 400–412.

LOG.india: Containing Space – Four in a Box, June 2008. <www.log-india.com>.

Moon, I.K., Do Ngoc, A.D., Hur, Y.S., 2010. Positioning empty containers among multiple ports with leasing and purchasing consideration. OR Spectrum 32, 765–786.

Shen, W.S., Khoong, C.M., 1995. A DSS for empty container distribution planning. Decision Support Systems 15, 75–82.

Shintani, K., Konings, R., Imai, A., 2010. The impact of foldable containers on container fleet management costs in hinterland transport. Transportation Research Part E 46, 750–763.

Song, D.P., Dong, J.X., 2010. Effectiveness of an empty container repositioning policy with flexible destination ports. Transport Policy 18, 92–101.

Song, D.P., Dong, J.X., 2011. Flow balancing-based empty container repositioning in typical shipping service routes. Maritimes Economics and Logistics 13, 61–77. http://dx.doi.org/10.1057/mel.2010.18.

Song, D.P., Zhang, Q., 2010. A fluid flow model for empty container repositioning policy with a single port and stochastic demand. Siam Journal on Control and Optimization 48 (5), 3623–3642.