Original Article

Repositioning of empty containers using both standard and foldable containers

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Abstract Advanced technologies are expected to drive practical applications that can reduce transportation and storage costs via novel space-saving foldable containers. To use them efficiently, shipping companies need a systematic algorithm that will simultaneously reposition foldable containers along with standard ones currently in use. Moreover, ports with facilities for folding and unfolding containers must be selected. To address these issues, we have developed a mathematical model for repositioning both standard and foldable empty containers. We use the model to minimize total transportation costs, inventory holding, handling, folding and unfolding, container leasing, and installing facilities that accommodate foldable containers. In addition to the mathematical model, we develop linear programming-based and hybrid genetic algorithms to obtain satisfactory solutions for these complex problems within reasonable computation times. We conduct several experiments to demonstrate the performance of the proposed methods and analyze their sensitivities to the cost parameters related to foldable containers.

Maritime Economics & Logistics (2016) **18,** 61–77. doi:10.1057/mel.2015.18;

Keywords: empty container repositioning; foldable containers; hybrid genetic algorithm

Introduction

The transportation of goods using intermodal shipping containers has continuously increased worldwide, and overseas container traffic has expanded over the last 20 years, leading to large gaps between supply and demand in container traffic among regions and an imbalanced container inventory. In other words, when imports exceed exports for a given region, a surplus of empty containers results, and in the converse situation, a shortage of empty containers creates problems for shipping firms. Repositioning of empty containers solves this equity problem in storage access. In addition, foldable containers, introduced as a new alternative, can reduce costs related to transportation, inventory holding and handling via the folding and unfolding processes. However, high processing time and production cost of foldable containers have made shipping companies hesitant to adopt these units. Recently, advanced technologies reducing these drawbacks are expected to increase the practical use of foldable containers. Therefore, to deploy foldable containers more efficiently, the shipping industry requires a systematic algorithm for the simultaneous repositioning of empty standard containers currently in use and the new foldable containers.

Many of the previous studies on repositioning focused on the empty container management. Crainic *et al* (1989) developed a mathematical model for the distribution of empty containers. Li *et al* (2004) discussed the management of empty containers through an inventory policy in a port characterized by stochastic demand. Later, Li *et al* (2007) expanded this problem to cover multiple ports. Shintani *et al* (2007) studied container shipping network design by considering the repositioning of empty containers and suggested a heuristic solution approach based on a genetic algorithm (GA). Shen and Khoong (1995) proposed a decision support system for the repositioning of empty containers. In addition, Moon *et al* (2010) addressed the problems of leasing and purchasing costs in an attempt to reduce the imbalance of empty containers in port, and they developed both linear programming (LP)-based and hybrid GAs. Song and Dong (2011) proposed a repositioning model that considered flexible ports; they evaluated their model through simulation.

Few studies addressed the problem of empty container repositioning using foldable containers. Koning and Thijs (2001) and Koning (2005) analyzed the economic and logistical feasibility of foldable containers under several conditions, and their results revealed that foldable containers might be incorporated profitably. Shintani *et al* (2010) analyzed the effect of foldable containers in repositioning of empty containers in the hinterland. Moon *et al* (2013) provided mathematical models for comparing the use of both standard and foldable containers and claimed that both purchasing and transportation costs affect the use of foldable containers. However, this study simultaneously considers both standard and foldable containers in the repositioning of empty containers among ports. Our proposed model offers guidance to companies in decisions as to which ports to select for the installation of facilities for folding and unfolding containers.

Specifically, we propose a mathematical formulation and solution approach for the repositioning of standard and foldable containers at minimum costs. We consider in-port facilities for handling folding and unfolding processes as fixed costs.

The remainder of this article is organized as follows: The next section defines the problem of repositioning empty containers among ports and shows a mathematical model to address this problem. The LP-based and hybrid GAs are described in the section that follows. Next, we present the results of the computational experiments performed to evaluate the performances of the suggested algorithms and analyze their sensitivity to cost parameters. The last section provides conclusions.

Problem Definition

Shipping companies must reposition empty containers to balance the container supply and demand among ports. In areas with surplus empty containers, repositioning can reduce the costs of storing excess empty containers. In addition, shipping companies can satisfy shortages by receiving empty containers from other ports. Companies should consider standard and foldable containers when making repositioning decisions. Moreover, shipping companies must determine whether to invest in installation of the equipment required for handling the foldable containers in port.

Foldable and standard containers can be repositioned among ports as shown in Figure 1. The folded containers can be transported only if the loading and destination ports have the facilities for handling them.

The inbound and outbound flows of empty containers at a port are illustrated in Figure 2.

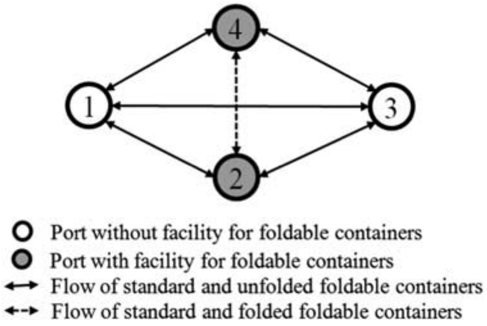

Figure 1: Repositioning flows of empty containers.

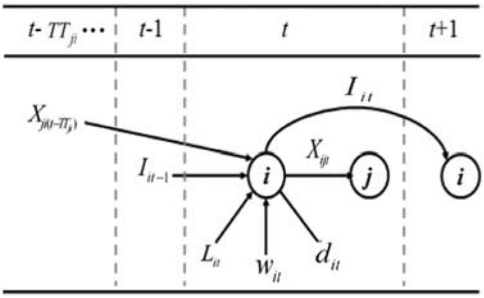

Figure 2: Inbound and outbound flows of empty containers.

The inbound container flows include the following:

- The number of empty containers received from customers in period t (w_{it})
- The number of repositioned empty containers received from other ports in period t ($X_{ji(t-tt_{ji})}$)
- The number of leased empty containers received from a leasing company when the inventory cannot satisfy the demand in period t (L_{it})
- The number of empty containers stored in period $t-1$ (I_{it-1})

The outbound container flows include the following:

- The demand for empty containers at port i in period t (d_{it})
- The number of empty containers to be repositioned from port i to port j in period t (X_{ijt})

The objective of this study is to minimize the total relevant costs associated with repositioning containers and the fixed costs incurred as a result of installing facilities for using foldable containers in port. We determine the quantities of repositioned, leased (both standard and foldable) containers and whether facilities for handling foldable containers exist in port. From a strategic viewpoint, this methodology offers guidelines for decisions with respect to investment in the fixed cost for foldable containers. At the operational level, this methodology supports repositioning and leasing of containers with consideration of predetermined fixed variables.

For this problem, the assumptions, some of which are standard in the literature, are as follows:

- The supply and demand for empty containers are independent at each port.
- The demand must be satisfied; no backlog is allowed.
- When there is a shortage of empty containers, empty containers must be leased.

- Containers are only leased as long term, and their return is not considered; that is, we assume that the lease-term does not expire in the planning horizon (Choong *et al*, 2002). The foldable container is leased in a folded state.
- Foldable containers received from customers are shipped to another port in a folded state. Four empty foldable containers are folded in the size of one standard container. This bundle of foldable containers stays aboard during shipping as well as after arriving at the port, leading to the potential for huge profits in repositioning empty containers (Shintani *et al*, 2010).

Mathematical Model

This section presents a mathematical model for repositioning empty containers using both standard and foldable containers. The notation used in this model is specified as indicated.

Indices:

t	Index for periods ($t=1, 2, \ldots, T$)
i, j	Index for ports ($i, j=1,2, \ldots, P$)
S	Index for standard empty containers
U	Index for unfolded containers
F	Index for folded containers

Parameters:

c_{ij}^{TS}	Unit transportation cost for a standard or unfolded container from port i to port j
c_{ij}^{TF}	Unit transportation cost for a folded container from port i to port j
f_i	Fixed cost for a port at which facilities for folding and unfolding processes are installed
c_i^{HS}	Unit handling cost for a standard or unfolded container at port i
c_i^{HF}	Unit handling cost for a folded container at port i
h_i^S	Unit inventory holding cost for a standard or unfolded container at port i
h_i^F	Unit inventory holding cost for a folded container at port i
b_i^S	Unit leasing cost for a standard container at port i
b_i^F	Unit leasing cost for a foldable container at port i
p_i^{fo}	Unit folding cost for a foldable container at port i
p_i^{un}	Unit unfolding cost for a foldable container at port i
d_{it}	Demand for empty containers at port i in period t
w_{it}^S	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
tt_{ij}	Transportation time from port i to port j

Decision variables:

S_{ijt}	Number of standard containers to be transported from port i to port j in period t
U_{ijt}	Number of unfolded containers to be transported from port i to port j in period t
F_{ijt}	Number of folded containers to be transported from port i to port j in period t
D_{it}^S	Partial demand that is satisfied with standard containers at port i in period t
D_{it}^U	Partial demand that is satisfied with unfolded containers at port i in period t
D_{it}^F	Partial demand that is satisfied with folded containers at port i in period t
L_{it}^S	Number of standard containers to be leased at port i in period t
L_{it}^F	Number of foldable containers to be leased at port i in period t
I_{it}^S	Inventory level of standard containers at port i in period t
I_{it}^U	Inventory level of unfolded containers at port i in period t
I_{it}^F	Inventory level of folded containers at port i in period t
G_{it}^{fo}	Number of foldable containers that require folding at port i in period t
G_{it}^{un}	Number of foldable containers that require unfolding at port i in period t
Y_i	1, if a facility for folding/unfolding processes is installed at port i; 0, otherwise

The mathematical model follows.

$$\begin{aligned}
\text{Min} \sum_{i=1}^{P} f_i Y_i &+ \sum_{t=1}^{T} \sum_{j=1, j \neq i}^{P} \sum_{i=1}^{P} c_{ij}^{TS} \left(S_{ijt} + U_{ijt}\right) + \sum_{t=1}^{T} \sum_{j=1, j \neq i}^{P} \sum_{i=1}^{P} c_{ij}^{TF} F_{ijt} \\
&+ \sum_{t=1}^{T} \sum_{j=1, j \neq i}^{P} \sum_{i=1}^{P} \left(c_i^{HS} + c_j^{HS}\right) \left(S_{ijt} + U_{ijt}\right) + \sum_{t=1}^{T} \sum_{j=1, j \neq i}^{P} \sum_{i=1}^{P} \left(c_i^{HF} + c_j^{HF}\right) F_{ijt} \\
&+ \sum_{t=1}^{T} \sum_{i=1}^{P} h_i^S \left(I_{it}^S + I_{it}^U\right) + \sum_{t=1}^{T} \sum_{i=1}^{P} h_i^F I_{it}^F + \sum_{t=1}^{T} \sum_{i=1}^{P} b_i^S L_{it}^S \\
&+ \sum_{t=1}^{T} \sum_{i=1}^{P} b_i^F L_{it}^F + \sum_{t=1}^{T} \sum_{i=1}^{P} p_i^{fo} G_{it}^{fo} + \sum_{t=1}^{T} \sum_{i=1}^{P} p_i^{un} G_{it}^{un} \qquad (1)
\end{aligned}$$

subject to

$$D_{it}^S + D_{it}^U + D_{it}^F = d_{it} \qquad \forall i, t \qquad (2)$$

$$I_{it}^{S} = I_{it-1}^{S} + \sum_{j=1,j\neq i}^{P} S_{ji(t-TT_{ji})} + L_{it}^{S} - \sum_{j=1,j\neq i}^{P} S_{ijt} + w_{it}^{S} - D_{it}^{S} \qquad \forall i,t \tag{3}$$

$$\begin{aligned} I_{it}^{U} + I_{it}^{F} = {} & I_{it-1}^{U} + I_{it-1}^{F} + \sum_{j=1,j\neq i}^{P} U_{ji(t-TT_{ji})} - \sum_{j=1,j\neq i}^{P} U_{ijt} + \sum_{j=1,j\neq i}^{P} F_{ji(t-TT_{ji})} \\ & - \sum_{j=1,j\neq i}^{P} F_{ijt} + L_{it}^{F} + w_{it}^{F} - D_{it}^{U} - D_{it}^{F} \qquad \forall i,t \end{aligned} \tag{4}$$

$$\sum_{j=1,i\neq j}^{P} F_{ijt} + \sum_{j=1,i\neq j}^{P} F_{ji(t-TT_{ji})} \leqslant MY_i \qquad \forall i,t \tag{5}$$

$$\left(w_{it}^{F} + \sum_{j=1,j\neq i}^{P} U_{ji(t-TT_{ji})} - \sum_{j=1,j\neq i}^{P} U_{ijt} - D_{it}^{U} - D_{it}^{F} \right) - G_{it}^{fo} \leqslant M(1-Y_i) \qquad \forall i,t \tag{6}$$

$$\left(D_{it}^{U} + D_{it}^{F} - w_{it}^{F} - \sum_{j=1,j\neq i}^{P} U_{ji(t-TT_{ji})} + \sum_{j=1,j\neq i}^{P} U_{ijt} \right) - G_{it}^{un} \leqslant M(1-Y_i) \qquad \forall i,t \tag{7}$$

$$I_{it}^{U} \leqslant M(1-Y_i) \qquad \forall i,t \tag{8}$$

$$I_{it}^{F} \leqslant MY_i \qquad \forall i,t \tag{9}$$

$$D_{it}^{U} \leqslant M(1-Y_i) \qquad \forall i,t \tag{10}$$

$$D_{it}^{F} \leqslant MY_i \qquad \forall i,t \tag{11}$$

$$I_{it}^{S},\, I_{it}^{U},\, I_{it}^{F},\, D_{it}^{S},\, D_{it}^{U},\, D_{it}^{F},\, G_{it}^{fo},\, G_{it}^{un} \geqslant 0 \qquad \forall i,t \tag{12}$$

$$Y_i = \{1,0\} \qquad \forall i \tag{13}$$

The objective function (1) estimates the total relevant costs when repositioning empty containers among ports and installing facilities for foldable containers. The total cost involves the fixed cost for installing foldable facilities at a port as well as the costs of repositioning empty containers, handling a container when it is loaded and unloaded to and from a vessel, inventory holding, leasing, and folding and unfolding processes. Constraint (2) ensures that all demand must be satisfied. Constraints (3) and (4) are inventory balance equations for standard and foldable containers, respectively. For instance, in Constraint (4), the number of foldable containers going into inventory in period *t* depends upon the inventory quantity in the prior period (*t*–1), the number of repositioned containers shipped from other ports in previous periods and arriving in period *t*, the number of leased containers and the number of supplied containers in period t. The number of foldable containers removed from inventory in period t includes those repositioned to ship to other ports in period t and the partial demand of that port. Constraint (5) stipulates that folded containers only be shipped to ports equipped with facilities for the folding and unfolding processes where M is a sufficiently large number. Constraints (6) and (7) define the number of folding and unfolding processes. The supplied and repositioned foldable containers remaining after satisfying partial demand of a port should be folded and stored on site. On the other hand, the shortage of foldable containers should be fulfilled from inventory or leased ones that must be unfolded. Constraints (8) and (9) define the state of the foldable containers when they are stored in inventory. When a folding and unfolding facility is installed at a port, foldable containers are stored in a folded state; otherwise, they are stored in an unfolded state. Constraints (10) and (11) determine partial demand for foldable containers according to whether a facility for folding and unfolding processes is installed. Thus, Constraints (9) and (11) relate to ports with a folding–unfolding facility installed, and the other constraints relate to the ports without these capabilities.

LP-based and Hybrid GAs

In general, the mathematical model guarantees optimal solutions, although it becomes more difficult to find them as the problem size increases. In this section, we propose alternative methods, namely, LP-based and hybrid GAs, to obtain satisfactory solutions for large problems within a limited time.

LP-based GA

The proposed mathematical model is a Mixed Integer Programming (MIP) model in which several variables are required to take on integer values, and others are allowed to take on either integer or non-integer values. As the size of a problem increases, an MIP problem is much harder to solve than an LP problem. However, an MIP problem can be relaxed by omitting the binary decision variable (Y_i). Hence, we suggest the use of an LP-based GA in which a set of values, determined by omitting the binary decision variables, is generated by a GA.

As shown in Figure 3, a chromosome is coded as a one-dimensional array with n columns, where n is the number of ports. The example in Figure 3 indicates that facilities for the folding and unfolding processes are installed at Ports 2, 4 and 6.

Port index	1	2	3	4	5	6
Y_i	0	1	0	1	0	1

Figure 3: Chromosome representation.

The procedure for the LP-based GA is as follows:

Step 1: Generate the initial population
Chromosomes are generated for the first generation. A value is randomly assigned to each gene in each chromosome.

Step 2: Calculate the fitness value
First, the fixed cost of each chromosome is calculated based on the values of the genes. Second, the total relevant costs except for the fixed cost are evaluated by the objective function of the relaxed LP model. Consequently, the objective function value of chromosome a (Z_a) equals the fixed cost plus the total relevant costs found by the LP model. Thus, the fitness value of chromosome a is calculated by the following formula:

Fitness function $= ((1/Z_a))/(\sum_{a=1}^{a=A}(1/Z_a))$, where A is a population size.

Step 3: Update the solution and terminate
Solutions in the population, or a set of chromosomes, are arranged in descending order of their fitness values. The current best chromosome is compared with the best chromosome that has been found so far. If the new solution is better than the former one, the solution is updated.

The procedure is terminated when the number of generations has reached the maximum number or any solution is not updated for consecutive generations.

Step 4: Evolve a new generation
The elitism method with roulette-wheel selection is used as the selection operator. Thus, the best chromosome is selected and is copied into the new population. All of the chromosomes except for the best one are subsequently selected by roulette-wheel selection. A two point crossover operator is applied in which two points are randomly selected on two chromosomes. Next, a mutation operation is conducted to prevent convergence on a local solution. The value of any two randomly chosen genes is changed from 1 to 0 or from 0 to 1. The process is repeated starting at Step 2.

Hybrid GA

The LP-based GA is able to solve problems faster than the MIP model while offering near optimal solutions. Unfortunately, an LP problem must be solved for each chromosome, which becomes a time-consuming task for large problems. We thus propose a heuristic method combined with a GA to generate a satisfactory solution within a reasonable computation time.

The concept of the hybrid GA comes from the results of the MIP model that indicate that foldable containers are almost as economical to reposition as empty containers because the lower transportation and inventory holding costs of foldable containers, despite the expense of folding and unfolding, reduce the total relevant costs. In other words, foldable containers are preferable to standard containers for repositioning and inventory except where the savings from the use of foldable containers cannot offset the high fixed cost of installing the folding and unfolding facilities. In addition, the availability of foldable containers depends on whether the facilities for the folding and unfolding processes are installed or not. Therefore, in the hybrid GA, we focus on the binary decision variable related to fixed cost. Thus, this model contains the same chromosome representation as that of the LP-based GA. Moreover, using this methodology we can look at foldable containers assigned for repositioning and storage as often as possible.

The procedure of the hybrid GA follows the steps of the LP-based GA except in the calculation of the objective function. To define the decision variables aside from the binary decision variable determined by a chromosome, this model exploits the simple rule that foldable containers are preferred for repositioning over empty containers. Although use of foldable containers incurs costs for the folding and unfolding processes, the costs for transportation and inventory holding is less. Therefore, as container traffic increases, the total relevant costs decrease accordingly. Consequently, a solution is generated to enable the repositioning and storage of foldable containers to the greatest extent possible, and the constraints in the mathematical model must be met. Figure 4 illustrates the flowchart for calculation of the objective function in the hybrid GA.

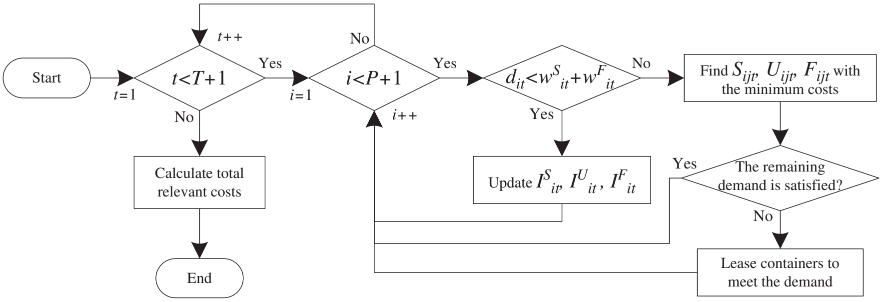

Figure 4: Flowchart for calculation of the objective function in the hybrid GA.

A solution is determined in periodic order. In a given period, a solution for each port is determined in a randomly chosen port order. At each port, demand is first satisfied with the supplied or stored standard containers. If demand remains, foldable containers are supplied to this port. Otherwise, the remaining foldable containers are stored as inventory. Subsequently, further demand can be fulfilled by the repositioning of containers as determined by the transportation costs and times between ports. At this time, foldable containers are prioritized over standard containers. Finally, leasing of empty containers satisfies any unsatisfied demand.

Computational Experiments

In this section, the performances of the developed LP-based GA and the hybrid GA are compared with that of the MIP model in several examples. We demonstrate the impact of incorporating foldable containers by showing results of sensitivity analyses conducted on the supply rate and related costs. All of the experiments were solved in JAVA in Windows 7 on an Intel(R) Core(TM) i5-2467 MHz CPU with 4GB RAM. CPLEX was used to solve the MIP and LP problems. The GA parameters are reported as the average values from 20 experiments with varying parameter values, as listed in Table 1.

We randomly generated 45 problems based on the number of ports and the periods showing imbalance between container imports and exports. The data used in the experiments are shown in Table 2. The objective function values and computation times obtained by the MIP, the LP-based GA, and the hybrid GA are listed in Table 3.

The objective function values of the LP-based GA are close to the optimal solutions, and the computation times of the MIP are much longer than those for the LP-based GA, especially for large problems. For large problems, the MIP is unable to find optimal solutions. The differences in the values of the objective function are less than 1 per cent. For all of the problems, the hybrid GA yields a shorter computation time than the MIP and produces satisfactory solutions.

Table 1: GA parameters used in the experiments

Parameters	*LP-based GA*	*Hybrid GA*
Population size	100	100
Generation number	100	150
Crossover probability	0.5	0.7
Mutation probability	0.02	0.05

Table 2: Data for relevant costs

Transportation cost	US$140/FEU[a]/week (SC[b]) $28/FEU/week (FC[c]) (Konings and Thijs, 2001)
Handling cost	$50/FEU/handling (SC) $13/FEU/handling (FC) (Shintani *et al*, 2010)
Inventory holding cost	$40/FEU/week (SC) $10/FEU/week (FC)
Folding and unfolding cost	$20/FEU/handling
Long-term leasing cost	480 USD/FEU(SC)
960 USD/FEU(FC)	
Fixed cost	$28 010/year

[a] FEU (forty-foot equivalent unit).
[b] SC (standard container).
[c] FC (foldable container).

The differences in the values of the objective function for the MIP and the hybrid GA range from 0.7 to 5.9 per cent. The computation time for the hybrid GA is less than 1 min regardless of problem size. Therefore, the LP-based and the hybrid GAs are capable of solving large problems while providing satisfactory solutions at reasonable computation times.

Furthermore, we performed sensitivity analyses on the ratio of supplied foldable containers (as shown in Table 4), the cost of installing folding and unfolding facilities, and the cost of the folding and unfolding processes.

The ratio of number of foldable containers supplied to number of standard containers is a measure of how much those containers are used in a given shipping company. The greater the extent to which the company exploits the foldable containers, the higher the ratio of foldable containers returned from customers. Figure 5 shows that as the ratio of supplied foldable containers is increased, the value of the objective function decreases. Thus, the cost-benefit of the foldable containers offsets the additional fixed costs for handling them and the costs of the folding and unfolding processes. Moreover, as foldable containers are increasingly utilized in the field, revenues to shipping lines increase. These results should encourage shipping companies to further commercialize foldable containers.

We also performed experiments with increasing or decreasing fixed costs for a specific problem. The fixed costs were varied from −50 to +80 per cent. Figure 6 illustrates that as the fixed costs are increased, the total relevant costs increase and the number of ports that handle foldable containers decreases. Conversely, as the fixed costs are reduced, the opposite situation emerges. As the number of ports for foldable container increases, the costs for transportation, handling and holding containers in inventory are reduced with the use of foldable containers even while the costs of folding and unfolding processes rise.

Table 3: Comparison of MIP, hybrid GA and LP-based GA

No.	*Size*[a]	*Objective function value ($)*					*Computation time (seconds)*		
		MIP(A)	*Hybrid GA (B)*	*LP-based GA(C)*	*RatioAB*[b] *(%)*	*Ratio AC*[b] *(%)*	*MIP*	*LP-based GA*	*Hybrid GA*
1	5–30	1 943 739	1 959 784	1 943 759	0.8	0.0	2.7	9.0	2.8
2	5–50	2 895 650	2 917 135	2 895 650	0.7	0.0	3.8	14.6	3.3
3	8–40	5 671 529	5 737 178	5 671 549	1.2	0.0	24.4	24.7	10.0
4	8–50	7 937 256	8 016 046	7 937 286	1.0	0.0	31.6	32.2	11.0
5	9–30	3 466 983	3 587 488	3 467 003	3.5	0.0	15.0	22.8	10.1
6	9–40	4 929 501	5 117 899	4 929 521	3.8	0.0	26.0	30.6	11.2
7	9–50	6 471 192	6 693 846	6 471 222	3.4	0.0	61.0	39.1	11.0
8	10–30	3 445 164	3 573 475	3 445 164	3.7	0.0	14.1	26.5	10.6
9	10–40	4 897 854	5 096 438	4 897 954	4.1	0.0	41.5	36.4	12.5
10	10–50	6 435 094	6 668 817	6 435 094	3.6	0.0	37.8	49.9	14.6
11	11–30	4 419 360	4 504 392	4 419 360	1.9	0.0	10.9	31.7	11.4
12	11–40	6 480 592	6 585 595	6 480 592	1.6	0.0	24.4	45.7	13.8
13	11–50	8 847 443	8 981 362	8 847 443	1.5	0.0	26.7	69.1	16.7
14	12–40	5 878 328	5 988 710	5 878 328	1.9	0.0	36.5	59.5	15.7
15	13–30	4 949 504	5 039 666	4 949 504	1.8	0.0	14.8	42.0	14.1
16	14–40	7 327 285	7 440 429	7 327 285	1.5	0.0	53.4	82.7	18.4
17	14–50	9 924 990	10 067 964	9 924 990	1.4	0.0	89.3	111.4	22.3
18	15–30	4 720 849	4 956 372	4 720 849	5.0	0.0	39.4	56.8	17.1
19	15–40	6 581 925	6 858 057	6 581 925	4.2	0.0	88.3	93.6	20.8
20	15–50	8 596 852	8 949 677	8 596 852	4.1	0.0	249.5	118.8	26.1
21	16–30	5 656 202	5 759 104	5 656 202	1.8	0.0	58.4	69.7	19.1
22	16–40	8 228 453	8 353 693	8 228 453	1.5	0.0	138.9	110.7	22.3
23	17–30	5 770 287	5 878 952	5 770 287	1.9	0.0	155.4	76.4	20.6
24	17–50	11 316 678	11 487 987	11 316 678	1.5	0.0	563.5	164.2	30.8
25	18–40	7 662 198	7 940 642	7 662 198	3.6	0.0	673.7	139.2	28.4
26	18–50	10 032 490	10 372 125	10 032 490	3.4	0.0	645.1	177.8	33.9
27	19–30	6 346 342	6 490 268	6 346 342	2.3	0.0	381.6	100.2	24.2
28	19–40	9 097 367	9 275 015	9 097 367	2.0	0.0	699.9	151.2	30.4
29	20–30	6 044 477	6 251 009	6 044 477	3.4	0.0	368.8	104.3	26.4
30	20–40	8 715 627	8 854 411	8 715 627	1.6	0.0	978.1	185.2	32.3
31	21–30	6 192 581	6 437 396	6 192 592	4.0	0.0	897.1	107.0	28.6
32	21–40	8 132 672	8 433 787	8 133 343	3.7	0.0	923.4	168.6	37.4
33	21–50	10 198 026	10 666 103	10 198 427	4.6	0.0	4845.6	248.4	41.5
34	22–30	6 244 823	6 615 489	6 278 309	5.9	0.5	2484.0	114.7	31.2
35	22–40	8 557 271	8 960 279	8 557 431	4.7	0.0	3989.8	186.8	39.7
36	22–50	11 097 807	11 579 119	11 098 287	4.3	0.0	5513.8	298.0	44.4
37	23–30	6 645 874	6 974 888	6 676 526	5.0	0.5	4111.8	127.5	32.8
38	23–40	9 236 166	9 596 548	9 236 496	3.9	0.0	12 318.8	210.3	42.9
39	23–50	12 109 464	12 539 329	12 109 982	3.5	0.0	9536.8	392.6	48.5
40	24–30	7 607 304	7 877 396	7 617 813	3.6	0.1	10 695.8	148.1	35.6
41	24–40	10 870 086	11 191 401	10 875 059	3.0	0.0	7465.8	236.3	45.2
42	24–50	14 660 987	15 042 490	14 661 461	2.6	0.0	9096.9	425.3	51.5
43	25–30	—	7 751 034	7 195 665	—	—	—	152.5	38.0
44	25–40	—	10 454 444	9 912 423	—	—	—	239.2	49.8
45	25–50	—	13 761 010	12 957 175	—	—	—	435.3	55.3
		Average value			2.9	0.0	1843.0	128.1	25.9
		Minimum value			0.7	0.0	2.7	9.0	2.8
		Maximum value			5.9	0.5	12 318.8	435.3	55.3

[a] Number of ports – Number of periods.

[b] Ratio AB = (B–A)*100/A and Ratio AC = (C–A)*100/A

Table 4: Ratios of foldable containers supplied at a port

Standard (%)	*Foldable (%)*
100	0
80	20
60	40
40	60
20	80
0	100

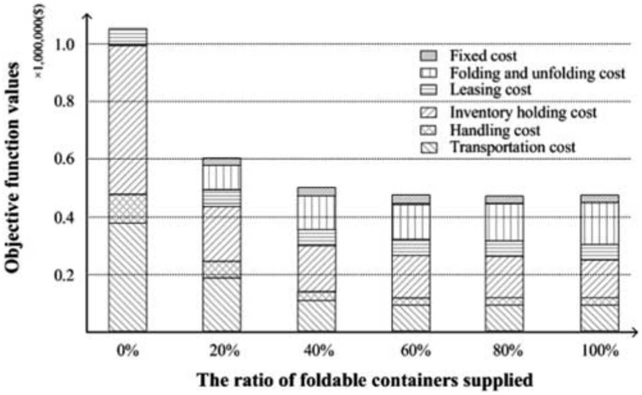

Figure 5: Objective function values and the number of ports for foldable containers according to the ratio of supplied foldable containers.

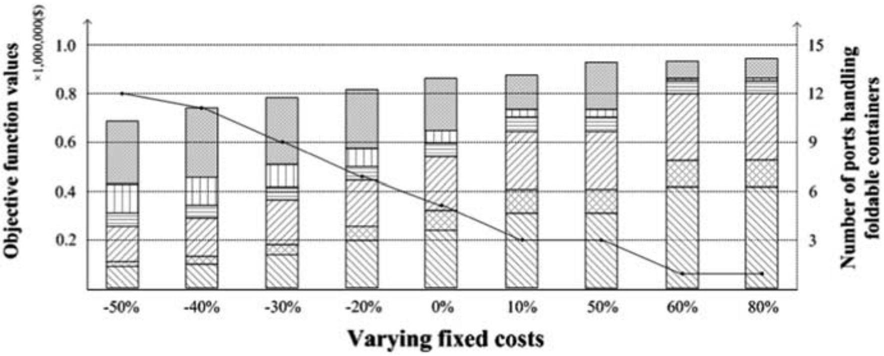

Figure 6: Objective function values and the number of ports handling foldable containers with varying fixed costs.

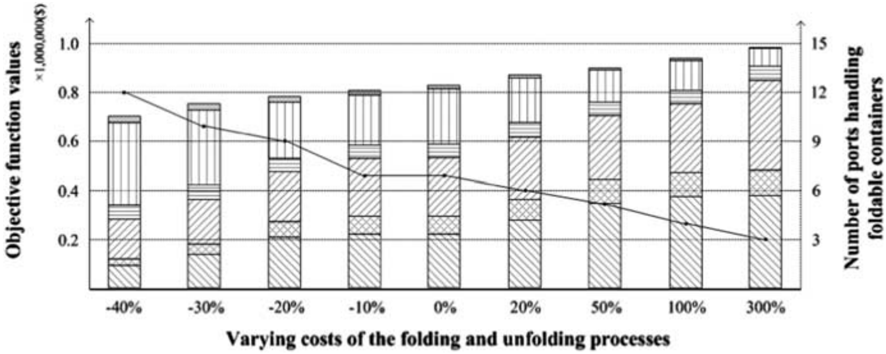

Figure 7: Objective function values and the number of ports handling foldable containers with varying costs of the folding and unfolding processes.

Hence, when a company decides to use foldable containers, the proposed methods suggest an appropriate fixed cost for investing in folding and unfolding facilities in port.

Figure 7 illustrates the effect of varying the cost of the folding and unfolding processes. The results show that as the cost of the folding and unfolding processes is steadily decreased, the value of the objective function is similarly decreased, and the number of ports with facilities able to handle foldable containers increases. In particular, the drop in the costs for folding and unfolding of containers results in a rise in the use of foldable containers, which leads to a reduction of the costs to reposition, store and handle containers. Thus, this model can aid decision makers in determining if the use of foldable containers is profitable according to the on-site folding and unfolding costs at a specific port.

Conclusions

Because of the great potential for the exploitation of foldable containers in commercial shipping, companies require a method for incorporating foldable containers into the real world. In particular, while some research focused on analyzing the economic effects of foldable containers, few studies addressed efficient utilization of foldable containers from a practical view point. Therefore, we investigated the repositioning of empty containers using both standard and foldable containers as well as considered the fixed costs of installing folding and unfolding facilities in port. We formulated an MIP model to minimize the total costs for transportation, inventory, handling, folding and unfolding processes, container leasing, and installation of facilities for folding and unfolding processes. In addition, we also proposed LP-based and hybrid GAs that yield satisfactory solutions in a short time. The results of the experiments show that the LP-based and hybrid GAs can solve large problems within a reasonable time. In particular, the LP-based GA offers near-optimal solutions in a suitable time, in contrast with the MIP model which requires impractical computation time. Moreover, the results of the sensitivity analyses on the supply rate and costs related to foldable containers should inspire companies to utilize these containers, and the proposed solution approaches provide guidelines for decisions related to their use.

We did not consider the return of leasing containers, which is a weak point of this research. In practice, we can utilize both long-term and short-term leasing along with a purchasing option. A better approach would be to study both long-term and short-term leasing with returns, and this will be the subject of further research.

Acknowledgements

The authors are grateful to the useful comments from the guest editor and two anonymous referees. This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (2010-0025714).

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