Optimizing Empty Container Repositioning on a Liner Service Network Considering Foldable Containers

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This study considers the empty container repositioning problem of shipping companies that use standard and 3-in-1 foldable containers with more advanced designs. An algorithm optimizing empty container repositioning in multiple fixed liner shipping services considering vessel capacity limit was proposed, which can optimize the empty container flows considering the minimization of total repositioning time and vessel capacity limit. And a mathematical model is developed to compare the total management costs of container repositioning in different cargo shipping demand scenarios. Empty container repositioning analyses were conducted focusing on a liner shipping service network in the Pacific Islands where empty containers are likely to be present because of the imbalance between inbound and outbound flows of containers. Results indicate that the introduction of foldable containers can effectively reduce the congestion of container repositioning in some links and the transshipment of empty containers caused by the link congestion, and thus total shipping time of empty container repositioning can be reduced by repositioning containers in a most effective way. Moreover, it is also proved that container management cost for shipping companies can be reduced if foldable containers are introduced.

Key Words : *maritime container shipping, empty container repositioning, foldable containers, liner service network, Pacific Islands*

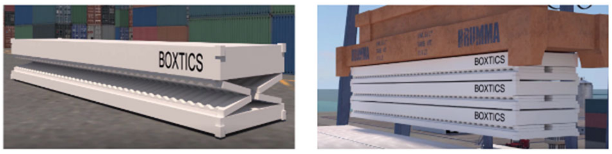
1. INTRODUCTION

In recent years, rapid economic growth and globalization have led to a substantial increase in container cargo shipping demand and growing trade imbalances between imports and exports among different regions, resulting in an imbalance between the inbound and outbound flows of full containers. Therefore, repositioning a large number of empty containers from the surplus to deficit areas is necessary. If the repositioned empty containers cannot temporally meet the required number at the ports in the deficit area, the leased containers would be offset by the shortage. However, the remaining empty containers that cannot be repositioned should be stored in the surplus area. The cost burden of remedying the excess or deficiency of empty containers has become a major pressure on container shipping companies, and it may affect the stable supply of container shipping services; therefore, repositioning empty containers has become an important issue in the management of shipping services1).

One of the difficulties of repositioning empty containers is that they require the same spaces for transport and storage as full containers. To alleviate this problem, introducing foldable containers is a possible solution. Fig. 1 shows the folding process of a foldable container. Less space is required if an empty container is folded, leading to multiple foldable containers being folded into the equivalent dimensions of a standard container. Therefore, containerships and the storage space can be used more efficiently, resulting in reduced transport costs, storage costs, and handling times of containers.

However, foldable containers have not yet been put into practical use, although their concept has already been established, because their merits have not yet been fully revealed. Designs of foldable containers, which affect the additional costs, including the costs of the folding and unfolding processes, manufacturing, maintenance, and repair, are key to their use[3]. A Japanese company has designed a 3-in-1 foldable container that can be folded and unfolded with just one button, which can save the cost and time of folding and unfolding, enabling the containers to be more economical and practical[2].

(a) Original state (b) Beginning of folding process



(c) End of folding process (d) bundling process

(e) Stacked on the container ship

Fig. 1 Folding, bundling, and stacking process of the foldable container. Source: Boxtics Inc.[2]

By comparing the management costs of empty container repositioning between cases where only standard containers are used, and where the 3-in-1 foldable containers are introduced, this study aims to determine the situations wherein foldable containers can be advantageous in empty container repositioning from an economic perspective. To solve this problem, we formulated an empty container repositioning problem concerning the transport of full containers, focused on liner shipping services in the Pacific Island countries (PICs). This implied that the introduction of foldable containers may reduce the total management cost of container repositioning in some situations, depending on the future growth rates of cargo shipping demand. The volume of containerized cargo generated at a port varies according to the shipping market conditions[4]. Therefore, considering different cargo shipping demands and analyzing various possible scenarios are necessary.

We focused on PICs because empty containers are likely to occur here, since the volume of import of full containers is much greater than that of export containers. Because PICs have few domestic industries aside from agriculture and fishery, they rely heavily on imports to meet the demand for basic goods, which are primarily transported through maritime shipping, including food, fuel and productive resources such as commercial machinery and appliances. In contrast, exports from PICs are typically lower in value and consist of a limited range of goods, often resulting in heavy imbalances in trade[5] Therefore, the imports far outweigh the exports in most PICs. The effect of introducing foldable containers to remedy the excess or deficiency of empty containers in PICs is expected.

The Pacific region consists of numerous islands dispersed across the southwest Pacific Ocean that are sometimes called “sea-locked countries”[6]. The region has suffered from high costs of participating in international trade, due to its remoteness from the world’s major markets. The dispersed nature of the region also leads to expensive transport costs, especially when connecting smaller remote islands. Empty containers are not only an issue in terms of transport efficiency, but also seriously undermine the profitability of the liner shipping companies (LSCs) operating in PICs. LSCs often receive subsidies from Pacific Island governments to maintain their operations in the region.

2. LITERATURE REVIEW

Several studies have explored the potential benefits of foldable containers in container repositioning. Konings[7] analyzed the economic and logistical viability of introducing foldable containers through a cost–benefit analysis, showing that the use of foldable containers could lead to substantial net benefits in the total chain of container transport. However, he also pointed out the additional costs of introducing foldable containers. Shintani et al.[3] modeled the entire empty container flow as an integer programming problem with different strategies in an empty container flow itinerary, and discovered the possibility of saving container fleet management costs by repositioning empty containers through the use of foldable containers. Shintani et al.[8] also proposed an integer programming model to determine which among the three container fleet configurations (i.e., foldable containers only, standard containers only, or a mix of foldable containers and standard containers) would minimize the shipping company’s container management costs, and they revealed that a mix of foldable containers and standard containers would provide the best solution. Moon et al.[9] compared the repositioning costs of foldable containers to those of standard containers, using mathematical models with heuristic algorithms to minimize the total relevant cost, including the folding/unfolding, inventory storage, container purchasing, and repositioning costs. Sensitivity analysis revealed 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. Myung and Moon10) addressed a multi-port and multi-period container planning problem for shipping companies considering both standard and foldable containers, using a network flow model which optimally allocated both foldable and standard containers to minimize the total purchasing, repositioning, and storage costs. They also pointed out the necessity of determining the rate of foldable containers within a defined period. Bandara et al.11) demonstrated, through a simulation for the port of Melbourne, that using foldable containers would reduce the total number of containers handled in the port, and then generate numerous benefits, such as reductions in capacity constraints at loading and storage centers, and a reduction in port infrastructure expansion costs. Therefore, foldable containers can contribute to the sustainability of the shipping industry. Moon and Hong12) developed a mathematical model for repositioning both standard and foldable empty containers, which minimizes the total costs for transportation, inventory holding, handling, folding/unfolding, container leasing, and installing facilities that accommodate foldable containers. Linear programming-based and hybrid genetic algorithms have been used to obtain satisfactory solutions for these problems. Wang et al.13) addressed the problem of ship-type decisions concerning empty container repositioning and foldable containers, which determines the capacity of ships deployed in a trans-Pacific shipping service route at a tactical level, and empty container repositioning between ports at an operational level. Optimal decisions of ship type can help the effective use of the vessel capacity, and thus promote the sustainability of the shipping industry. Zhang et al.14) developed a mixed-integer linear programming model to determine the optimal empty container repositioning with foldable containers on the intermodal transportation network related to China's Belt and Road Initiative. Goh15) investigated foldable containers from the shipper and sustainability perspectives. In particular, the viability of foldable containers as an instrument of carbon offsetting for the shipping industry was explored. Zhang et al.16) investigated the potential of foldable containers to improve empty container repositioning in river–sea intermodal transport along the Yangtze River in China, taking into consideration bridge height and water depth constraints. Their results showed that introducing foldable containers into empty container repositioning along a river could encourage companies to use vessel space more effectively and decrease the total cost for shipping companies, ensuring their sustainability. Lee and Moon17) proposed a robust formulation that requires only limited information about the distribution of demand to replicate real-world situations for the empty container repositioning problem between North America and Asia, considering foldable containers under demand uncertainty. Liang et al.18) developed a mathematical model to compare the total management costs of container repositioning of various patterns in different cargo shipping demand scenarios focusing on a liner shipping service in the Pacific Islands. They also considered the different patterns (i.e. random and biased demand) on consecutive monthly cargo shipping demand for a year. Moreover, earlier research demonstrated that foldable containers could help in reducing the carbon footprint of the shipping industry because the number of shipments could be reduced by folding and bundling the empty containers, which is an increasingly important global sustainability issue11),15),19),20).

These studies considered certain factors related to foldable containers in empty container repositioning and revealed the economic and environmental benefits of foldable containers. However, none of them have considered empty container repositioning optimization in multiple fixed liner shipping services considering vessel capacity limit.

Even in the context of studies on empty container repositioning management without foldable containers being introduced, only a few studies considered the problem with changeable demand, as summarized in Kuzmicz and Pesch21). Lam et al.22) demonstrated the application of a dynamic stochastic model for repositioning empty containers. They used the contracting value iteration algorithm to obtain the exact optimal average cost solution. Song and Zhang 23) applied a fluid flow model to determine the optimal empty container repositioning policy in a single-port system, with stochastic demand modeled using a two-state Markov process. They characterized the underlying dynamics and followed the dynamic programming approach to obtain a closed-form solution to the optimal control problem. Song and Dong 24) considered both fleet sizing and empty container repositioning under uncertain demand on a liner shipping system with a trans-Atlantic service. They considered three types of distributions (i.e., exponential, uniform, and normal distributions) for daily demands. Zhang et al.25) considered repositioning empty containers between multiple ports over multiple periods with stochastic demand and lost sales. Numerical examples were provided to illustrate the solution procedures, based on normal and uniform distributions. Dong and Song26) considered the joint container fleet sizing and the repositioning problem of empty containers in multi-vessel, multi-port, and multi-voyage shipping systems with dynamic, uncertain, and imbalanced customer demands, and they applied them to a trans-

Table 2 Summary of relevant studies.

Papers	Foldable Container	Demand Uncertainty	Focusing on Specific Region/Shipping Service	Container repositioning in multiple fixed services considering capacity limit
Research on foldable containers				
Konings[7]	√			
Shintani et al.[8]	√			
Moon et al.[9]	√			
Myung and Moon [10]	√			
Bandara et al.[11]	√		Melbourne port (Australia)	
Moon and Hong[12]	√			
Wang et al.[13]	√		Trans-Pacific shipping service	
Zhang et al.[14]	√			
Goh[15]	√			
Zhang et al.[16]	√		Yangtze River (China)	
Lam and Gu[17]	√			
Liang et al.[18]	√	√	PICs	
Hjortnaes et al.[19]	√			
Lee and Moon[20]	√	√	North America–Asia	
Research on empty container repositioning with demand uncertainty				
Lam et al. [22]		√		
Song and Zhang [23]		√		
Song and Dong [24]		√	Trans-Atlantic shipping service	
Zhang et al.[25]		√		
Dong and Song [26]		√	Trans-Pacific and Europe–Asia shipping service	
This study	√	√	PICs	√

Pacific shipping service and a Europe–Asia shipping service.

Table 2 summarizes the characteristics of the above studies. As shown in the table, to the best of our knowledge, no studies have considered empty container repositioning optimization and analyses in multiple fixed liner shipping services considering vessel capacity limit. This study aims to fill this research gap.

3. GMCSNS MODEL UPDATING

To analyze the empty container flow, the actual shipping volume of full containers for each liner service is necessary, but such data are generally not available from the outside. Therefore, the annual volume of containerized cargo transported between each port for each liner service is calculated using the global maritime container shipping network simulation (GMCSNS) model[27,28]. The GMCSNS model is a model in which the shipping route of each container is determined by the global interregional maritime container cargo shipping demand (OD volume) and maritime network factors, such as service frequency and vessel capacity. Congestion would also occur if the capacity of the container ship approached the upper limit. In the GMCSNS model, the liner shipping services operated by each container shipping company are treated as a separate network, as shown on the right side of Fig. 2.

(1) Input Data

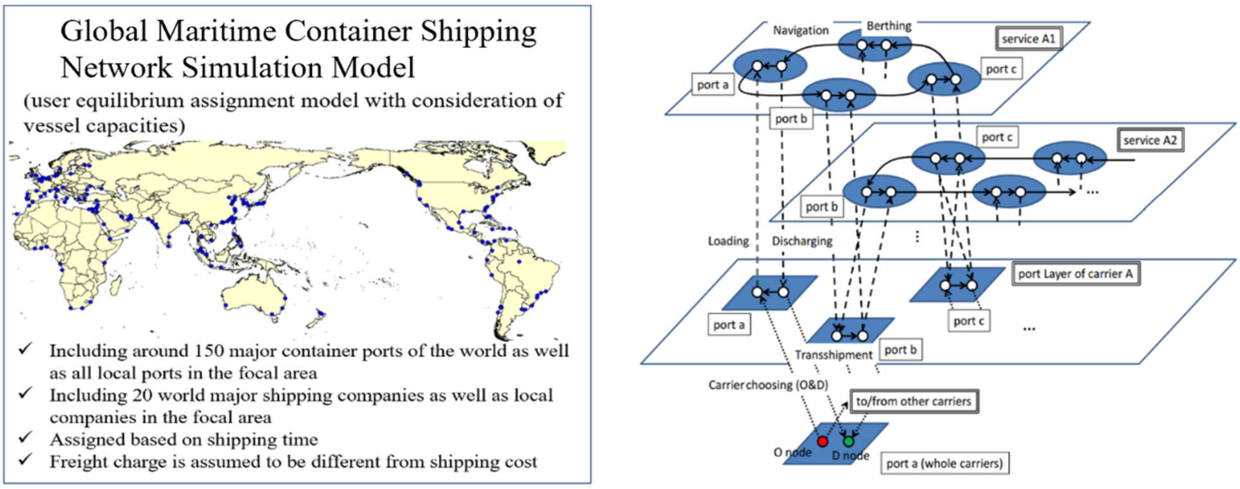
a) Ports and MCS networks

The model used in this section updates Riku et al.[6] based on 2018 data. Ports in the world with an annual container throughput of over 500,000 TEU are included in this model. To simulate container flows in more detail in the PICs, the model also includes all international ports in sovereign PIs (including the United States (US) and French territories) with at least one appearance in the MDS Containership Databank. As a result, 226 ports in the world are included in the model: 25 ports in PICs and 173 ports in other regions.

The MCS network in the GMCSNS model is constructed based on the MDS Containership Databank. It provides information for each containership such as vessel name, IMO number, name of service, (co-)operating and slot chartered companies, list of port to call and its order, service frequency (yearly basis), TEU Capacity, DWT, and vessel speed. The model in this study includes 38 liner shipping companies (LSCs): the top 30 of the largest LSCs in the world and 8 local LSCs that provide Liner Services (LSs) to the PICs. The model includes 1076 LSs, and the developed network consists of 407,600 links.

b) Container cargo shipping demand

The demand of container cargo shipping, q_{rs}, from



Global Maritime Container Shipping Network Simulation Model

(user equilibrium assignment model with consideration of vessel capacities)

- ✓ Including around 150 major container ports of the world as well as all local ports in the focal area
- ✓ Including 20 world major shipping companies as well as local companies in the focal area
- ✓ Assigned based on shipping time
- ✓ Freight charge is assumed to be different from shipping cost

Fig 2. Network structure of the maritime container shipping network model. Source: Shibasaki[27)]

ports r to s is estimated as follows. First, the shipping demand for container cargo (O-D matrix) between countries or regions on a TEU-basis is obtained from the data provided by IHS, Inc. (Global Trade Atlas Forecasting), which provides a container shipping demand for each year among all countries/regions of the world. The second step for estimating demand for container cargo shipping is dividing the aggregated O-D matrix above into a port-basis according to the port's share of the export and import container cargo throughput for the aggregated region. Then, the third step is to eliminate the containers shipped by companies which are not included in the model. This is necessary for the balanced calculation of the model between the vessel capacity and the number of containers shipped in each service. This is obtained by first subtracting the amount of shipping demand which is shipped by the carriers not considered in the model from the total amount, which is estimated based on the share by carriers of vessel capacity arriving at and departing from each port. Subsequently, the method proposed by Fratar[30)] is applied to adjust errors by inputting the total amount of shipping demand for each port for the carriers included in the model as given and the OD matrix estimated in the second step as initial inputs[28)].

(2) Model Output

The reproducibility of GMCSNS model in terms of the container cargo throughput for export and import at ports in the PICs is shown in Fig. 3. As shown in the figure, container cargo throughput for export/import is reproduced well by the GMCSNS model at most of Ports in the PICs, except for some ports such as Suva port. Therefore, we can use the results of GMCSNS model to conduct analyses on empty container repositioning.

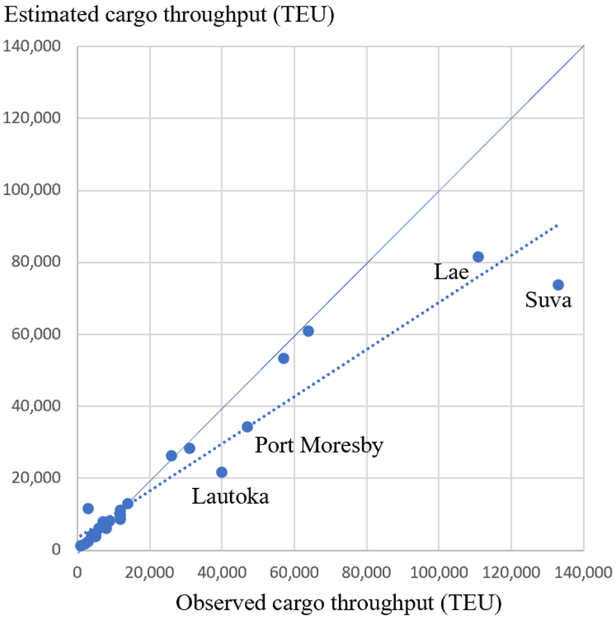


Fig. 3 The reproducibility of GMCSNS model in terms of the container cargo throughput for export and import at ports in the PICs ports

4. PROBLEM DESCRIPTION AND SOLUTION ALGORITHM

(1) Problem Description

This section focused on four liner shipping services in the PICs (see Fig. 4), which are provided by Kyowa Shipping and call at 27 ports. We calculated the deficit or surplus of empty containers in ports, based on the number of containers loaded and discharged at each port calculated from the GMCSNS model as shown in Table 3. In this section, an algorithm is developed for solving empty container repositioning problem based on them. Further, the effect of introducing foldable container for empty container repositioning is discussed, including shipping time saving and management cost saving.

This section conducts simulations of empty container repositioning optimization and compares the container management costs of different introduction rates of foldable containers at different demand increasing rates. When considering empty container repositioning in multiple services, containers can be repositioned through different paths, and it would be most effective if empty containers are transported by the path of shortest shipping time to minimize container management cost because each service is fixed and thus maritime shipping cost is fixed. However, if congestion occurs in some links, containers will be transported through other paths. Therefore, transshipment between different shipping services is occurred.

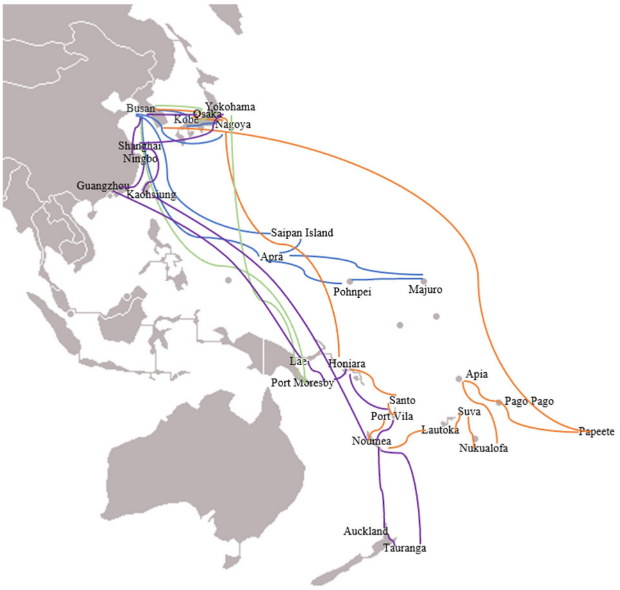


Fig. 4 Shipping services provided by Kyowa Shipping.

Table 3 Surplus or deficit of empty containers at each port.

Port	Surplus (TEU)	Port	Deficit (TEU)
Busan	812	Yokohama	1106
Shanghai	1280	Nagoya	56
Kaohsiung	164	Osaka	259
Auckland	124	Kobe	52
Tauranga	874	Ningbo	200
Majuro	472	Guangzhou	402
Lae	507	Apra	19
Santo	333	Pohnpei	1070
Lautoka	30	Port Moresby	251
Noumea	131	Honiara	1185
Apia	29	Port Vila	332
Nukualofa	193	Suva	71
Papeete	64	Pago Pago	10
Total	5013	Total	5013

(2) Solution Algorithm

a) Algorithm for empty container repositioning optimization

In this study, we assume the shipping cost of each vessel is fixed because the level of service in each liner shipping such as vessel size, frequency, speed, and schedule is fixed. Therefore, the optimization of empty container repositioning only considers the minimization of total shipping time of empty containers to minimize container management cost. In addition, vessel capacity limit should be considered. We assume that the demand for empty container repositioning should be met by the remaining space of the containership, after satisfying the shipping demand for full containers. Fig. 5 shows the algorithm for optimization of empty container repositioning.

In Step 1, the problem can be regarded as a production and sales balance transportation problem that minimizes the total shipping time of the system without considering capacity constraint. By inputting the data of surplus and deficit of empty containers at each port, empty containers are repositioned through the shortest path time between ports, which is calculated based on the link shipping time. As the results, the initial O-D demand of empty containers between ports $\boldsymbol{t}^{(0)}$ is calculated without considering the capacity constraint.

In Step 2, considering the vessel capacity constraint, O-D demand between ports is assigned to each link in the network based on User Equilibrium (UE) principle by the Frank-Wolfe algorithm. As the results, the empty container flow $\boldsymbol{f}^{(0)}$ and shipping time $\boldsymbol{c}^{(0)}$ by link are calcuated, and then the total shipping time of the system $TC^{(0)}$ is calculated. In this step, congestion may occur in some links because of capacity constraint.

In Step 3, let k =1, calculate the shortest path time between the ports based on the previous link shipping time $\boldsymbol{c}^{(k-1)}$. In Step 4, based on the shortest path time between the ports updated in Step 3, the empty container repositioning problem need to be recalculated, and the optimal repositioning solution $\mathrm{t}^{(k)}$ may be updated. In Step 5, the O-D demand between ports updated in Step 4 is reassigned to each link in the network, and the container flow $\boldsymbol{f}^{(k)}$ and shipping time $\boldsymbol{c}^{(k)}$ by link and the total shipping time $TC^{(k)}$ are calculated.

In Step 6, iterative calculation is judged to stop based on the relative change between successive solutions, $TC^{(k)}$ and $TC^{(k-1)}$. Namely, if

$$|TC^{(k)} - TC^{(k-1)}|/TC^{(k-1)} \leq \varepsilon \qquad (1)$$

then stop, where ε is a predetermined tolerance. Else, let k = k +1 and go to Step 3.

b) Empty container repositioning problem without capacity constraint

As described above, the container repositioning

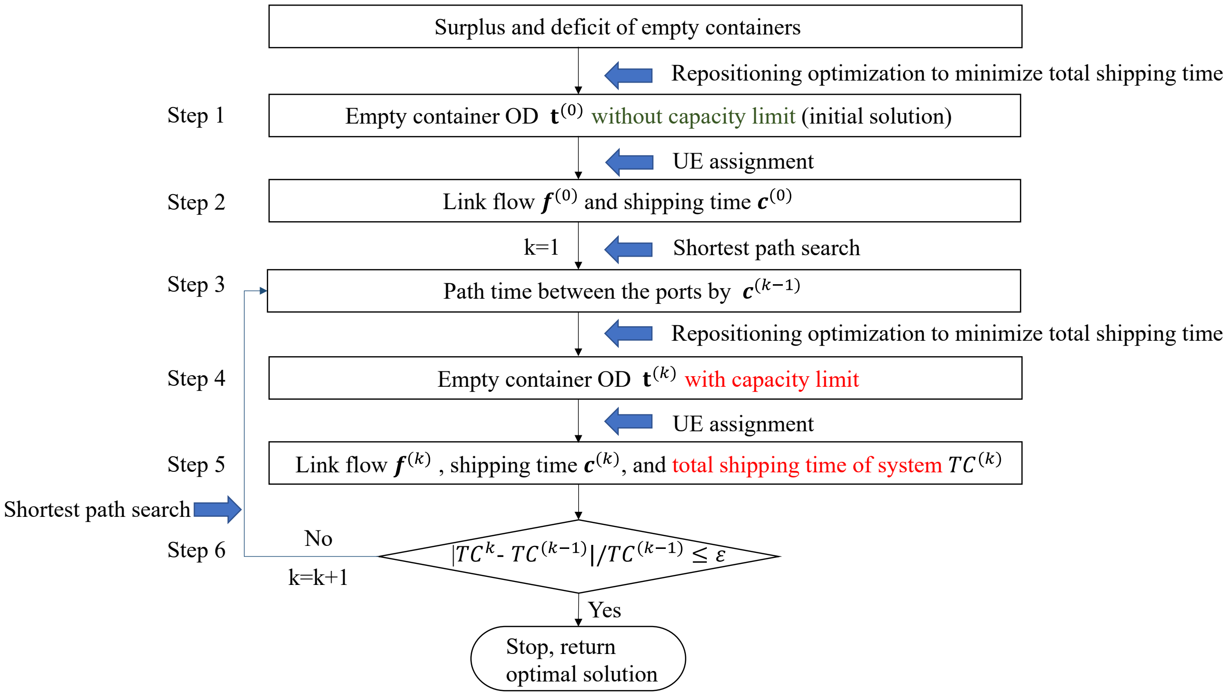


Fig. 5 Algorithm for optimization of empty container repositioning.

problem without considering capacity constraint can be regarded as a production and sales balance transportation problem that minimizes the total shipping time of the system. Transportation problem originally means the problem of transporting/shipping the commodities from the industry to the destinations with the least possible cost while satisfying the supply and demand limits. It is a special class of linear programming technique that was designed for models with linear objective and constraint functions. The application of transportation problem can be extended to the empty container repositioning problem, it works in a way of minimizing the cost function. In this study, the cost function is the shipping time spent on empty container repositioning from surplus (supply) ports to deficit (demand) ports. Therefore, the empty container repositioning problem without considering capacity constraint are formulated as a linear function that minimize shipping time cost without any compromise in supply and demand.

The empty container repositioning problem without considering capacity constraint may be formulated as follows.

$$\min Z(q) = \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}q_{ij} \tag{2}$$

$$s.t. \quad \sum_{j=1}^{n} q_{ij} = S_i, \ \text{i=1,2,…,m} \tag{3}$$

$$\sum_{i=1}^{m} q_{ij} = D_j, \ \text{j=1,2,…,n} \tag{4}$$

$$\sum_{i=1}^{m} S_i = \sum_{j=1}^{n} D_j \tag{5}$$

$$\text{q}_{ij} \ge 0, \ \text{i=1,2,…,m; j=1,2,…,n} \tag{6}$$

where Z is the objective function, m is the number of surplus ports, n is the number of deficit ports, c_{ij} is the unit time cost of empty container repositioning from port i to port j, q_{ij} is the number of empty containers repositioned from port i to port j, S_i is the surplus of empty containers at port i, and D_j is the deficit of empty containers at port j.

The objective function (2) is the minimization of the total time cost of empty container repositioning,. Equation (3) guarantees that the number of empty containers generated at port i equals to the total number of empty containers repositioned from port i to all deficit ports. Equation (4) ensures that the number of empty containers demanded at port j equal to the total number of empty containers repositioned from all surplus ports to port j. Equation (5) implies that the surplus of empty containers equals to the deficit in the system. Constraint (6) is non-negative constraints.

c) Empty container assignment problem with capacity constraint

A route is chosen for each empty container to minimize total transit time from the surplus port to the deficit port. Since vessels of each service have their own capacities, and the space for repositioning empty containers would become less after loading full containers, there is diseconomy of scale by concentrating the cargo onto a specific path. Therefore, the congestion of the link is considered and a user equilibrium (UE) assignment is applied as network assignment methodology based on Wardrop's first principle.

$$\min y(x) = \sum_{a\in A} \int_0^{x_a} t_a(x_a)dx \tag{7}$$

$$s.t.\ x_a = \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{p\in P^{ij}} \delta^{ij}_{a,p} \cdot f^{ij}_{p},\ \forall \mathrm{a} \tag{8}$$

$$\sum_{p\in P^{ij}} f^{ij}_{p} - q^{ij} = 0,\ \forall i, j \tag{9}$$

$$f^{ij}_{p} \geq 0,\ \forall p, i, j \tag{10}$$

where y is the objective function, a is the link, A is the set of links, x_a is the flow of the link a, t_a is the cost function of the link a, p is the path, P^{ij} is the set of path for OD pair ij, δ^{ij}_{ap} is the Kronecker delta, and f^{ij}_{p} is the flow on the path p. Kronecker delta, $\delta^{ij}_{a,p}$, is written as

$$\delta^{ij}_{a,p} = 1,\ \text{if a} \in \text{p};{=}0,\ \text{if a} \notin \text{p} \tag{11}$$

The definition of time cost function is described below.

$$t_a(x_a) = \tau^{0}_{a} \left\{ 1 + \alpha \left(\frac{x_a}{C_a}\right)^{\beta} \right\} \tag{12}$$

where τ^0_a is the free flow shipping time, C_a is the link capacity, α and β are the parameters related to congestion.

The UE problem defined in Equation (7) is solved through the Frank-Wolfe algorithm, as introduced by Sheffi[31)].

(3) Formulation for total management cost

The algorithm described above can calculate the optimal repositioning solution that minimize total repositioning time. Because the objective of this study is to verify whether foldable containers can reduce management costs, we need to calculate the management cost based on the results of repositioning time. The total management cost of containers is expressed in equation (13), which consists of container purchase cost, maintenance cost, and transshipment cost. Because the level of service in each liner shipping such as vessel size, frequency, speed, and schedule are fixed, the total voyage cost of each vessel is fixed regardless of whether foldable containers are used or not. Therefore, voyage cost is not included in total management cost. The 3-in-1 foldable container used in this study can be folded and unfolded with just one button, thus folding and unfolding cost is also not considered. In addition, because there are multiple services for repositioning, we assumed that all containers can be repositioned in this period, the storage cost caused by accumulation of empty containers are not considered.

$$C = SD \cdot CS + FD \cdot CF + CFO + CM \cdot (SD + FD) + TS \cdot HD \tag{13}$$

where SD is the number of standard containers, CS is the purchase cost (US\$/TEU) of standard containers, FD is the number of foldable containers, CF is the purchase cost (US\$/TEU) of foldable containers, CFO is the fixed cost (US\$) for introducing foldable containers, CM is the maintenance cost (US\$/TEU) of containers, TS is the transshipment volume (TEU) of containers, HD is the handling cost (US\$/TEU) of containers.

In this study, we assume that the purchase cost of a standard container is 2000 US\$/TEU with 10 years' lifespan (i.e., $CF = 200$); the purchase cost of a foldable container is 5000 US\$/TEU with 10 years' lifespan (i.e., $CF = 500$); the fixed cost for introducing foldable containers is 1,200,000 US\$ with 10 years' lifespan (i.e., $CFO = 120{,}000$); container maintenance cost per month per container is 300 US\$ (i.e., $CM = 300$); and the handling cost is 200 US\$/TEU (i.e., $CF = 200$), based on the previous studies[18)].

Based on the equation (13), it is necessary to calculate the number of containers that the shipping companies need to possess for analyzing the total management cost of containers. The number of containers that the shipping companies need to possess is represented by equation (14):

$$CN = \sum_{i} \sum_{j} Q_{ij} / YD / (d_{fij} + w_{ij}) + q_{ij} / YD / (d_{eij} + w_{ij}) \tag{14}$$

where CN is the number of containers, Q_{ij} is the annual shipping demand (TEU) of full containers from port i to port j, q_{ij} is the annual shipping demand (TEU) of empty containers repositioned from port i to port j, YD is a constant for conversion from one year to days (52 (weeks/year) x 7(days/week) = 364 (days/year)), d_{fij} is shipping time (Days) of full containers transported from port i to port j, d_{eij} is the shipping time (Days) of empty containers repositioned from port i to port j, w_{ij} is the land transport time (Days) of containers including vanning and devanning at the both ends of ports i and j.

The term $YD/\left(d_{fij} + w_{ij}\right)$ represents the volume of cargo that a container can transport from port i to port j per year, the term $YD/\left(d_{eij} + w_{ij}\right)$ is the times that a container needs to be repositioned from port i to port j per year. Therefore, the sum of the first and second terms in the equation is the number of containers required for each OD pair, thus the sum of the value of each OD pair is the total number of containers that the local LSC has to possess to satisfy cargo shipping demand.

$$w_{ij} = \frac{1}{2} \cdot \frac{YD}{freq} \tag{15}$$

where the term $(YD/freq)$ represents the duration in days for each vessel of the service. Because this study focus on maritime shipping, for simplicity, the land transport time is assumed to be half of that value.

5. CALCULATION RESULTS AND SIMULATIONS

(1) Results of empty container repositioning optimization

Table 4 shows the optimal repositioning solution without capacity constraint in the current cargo shipping demand. The total shipping time of empty containers is minimized without any compromise in supply and demand under this solution. The optimal repositioning solution do not change even consider vessel capacity constraint as shown in Table 5. In other words, in the current cargo shipping demand, all empty containers can be repositioned in a way of minimizing total shipping time, thus it is better not to introduce foldable containers because there is enough space on the containership to reposition empty containers, owing to the small shipping volume of full and empty containers.

If cargo shipping demand increases by 100%, the optimal repositioning solution without capacity constraint is shown in Table 6, whereas the optimal repositioning solution with considering the vessel capacity constraint changes, if only standard containers

Table 4 Optimal repositioning solution *without* capacity constraint in the current cargo shipping demand.

	Yokohama	Nagoya	Osaka	Kobe	Ningbo	Guangzhou	Apra	Pohnpei	Port Moresby	Honiara	Port Vila	Suva	Pago Pago	Total
Busan	0	0	0	0	0	195	19	598	0	0	0	0	0	812
Shanghai	0	0	112	0	32	207	0	0	0	929	0	0	0	1280
Kaohsiung	17	0	147	0	0	0	0	0	0	0	0	0	0	164
Auckland	124	0	0	0	0	0	0	0	0	0	0	0	0	124
Tauranga	665	0	0	0	168	0	0	0	0	0	0	41	0	874
Majuro	0	0	0	0	0	0	0	472	0	0	0	0	0	472
Lae	0	0	0	0	0	0	0	0	251	256	0	0	0	507
Santo	1	0	0	0	0	0	0	0	0	0	332	0	0	333
Lautoka	0	0	0	0	0	0	0	0	0	0	0	30	0	30
Noumea	131	0	0	0	0	0	0	0	0	0	0	0	0	131
Apia	0	0	0	29	0	0	0	0	0	0	0	0	0	29
Nukualofa	168	0	0	15	0	0	0	0	0	0	0	0	10	193
Papeete	0	56	0	8	0	0	0	0	0	0	0	0	0	64
Total	1106	56	259	52	200	402	19	1070	251	1185	332	71	10	5013

Table 5 Optimal repositioning solution *with* capacity constraint in the current cargo shipping demand.

	Yokohama	Nagoya	Osaka	Kobe	Ningbo	Guangzhou	Apra	Pohnpei	Port Moresby	Honiara	Port Vila	Suva	Pago Pago	Total
Busan	0	0	0	0	0	195	19	598	0	0	0	0	0	812
Shanghai	0	0	112	0	32	207	0	0	0	929	0	0	0	1280
Kaohsiung	17	0	147	0	0	0	0	0	0	0	0	0	0	164
Auckland	124	0	0	0	0	0	0	0	0	0	0	0	0	124
Tauranga	665	0	0	0	168	0	0	0	0	0	0	41	0	874
Majuro	0	0	0	0	0	0	0	472	0	0	0	0	0	472
Lae	0	0	0	0	0	0	0	0	251	256	0	0	0	507
Santo	1	0	0	0	0	0	0	0	0	0	332	0	0	333
Lautoka	0	0	0	0	0	0	0	0	0	0	0	30	0	30
Noumea	131	0	0	0	0	0	0	0	0	0	0	0	0	131
Apia	0	0	0	29	0	0	0	0	0	0	0	0	0	29
Nukualofa	168	0	0	15	0	0	0	0	0	0	0	0	10	193
Papeete	0	56	0	8	0	0	0	0	0	0	0	0	0	64
Total	1106	56	259	52	200	402	19	1070	251	1185	332	71	10	5013

Table 6 Optimal repositioning solution *without* capacity constraint if cargo shipping demand increases by 100%.

	Yokohama	Nagoya	Osaka	Kobe	Ningbo	Guangzhou	Apra	Pohnpei	Port Moresby	Honiara	Port Vila	Suva	Pago Pago	Total
Busan	0	0	0	0	0	390	38	1196	0	0	0	0	0	1624
Shanghai	0	0	224	0	64	414	0	0	0	1858	0	0	0	2560
Kaohsiung	34	0	294	0	0	0	0	0	0	0	0	0	0	328
Auckland	248	0	0	0	0	0	0	0	0	0	0	0	0	248
Tauranga	1330	0	0	0	336	0	0	0	0	0	0	82	0	1748
Majuro	0	0	0	0	0	0	0	944	0	0	0	0	0	944
Lae	0	0	0	0	0	0	0	0	502	512	0	0	0	1014
Santo	2	0	0	0	0	0	0	0	0	0	664	0	0	666
Lautoka	0	0	0	0	0	0	0	0	0	0	0	60	0	60
Noumea	262	0	0	0	0	0	0	0	0	0	0	0	0	262
Apia	0	0	0	58	0	0	0	0	0	0	0	0	0	58
Nukualofa	336	0	0	30	0	0	0	0	0	0	0	0	20	386
Papeete	0	112	0	16	0	0	0	0	0	0	0	0	0	128
Total	2212	112	518	104	400	804	38	2140	502	2370	664	142	20	10026

Table 7 Optimal repositioning solution *with* capacity constraint if cargo shipping demand increases by 100%.

	Yokohama	Nagoya	Osaka	Kobe	Ningbo	Guangzhou	Apra	Pohnpei	Port Moresby	Honiara	Port Vila	Suva	Pago Pago	Total
Busan	0	0	0	0	0	390	38	1196	0	0	0	0	0	1624
Shanghai	0	0	224	0	64	414	0	0	104	1754	0	0	0	2560
Kaohsiung	34	0	294	0	0	0	0	0	0	0	0	0	0	328
Auckland	248	0	0	0	0	0	0	0	0	0	0	0	0	248
Tauranga	1666	0	0	0	0	0	0	0	0	0	0	82	0	1748
Majuro	0	0	0	0	0	0	0	944	0	0	0	0	0	944
Lae	0	0	0	0	0	0	0	0	398	616	0	0	0	1014
Santo	2	0	0	0	0	0	0	0	0	0	664	0	0	666
Lautoka	0	0	0	0	0	0	0	0	0	0	0	60	0	60
Noumea	262	0	0	0	0	0	0	0	0	0	0	0	0	262
Apia	0	0	0	58	0	0	0	0	0	0	0	0	0	58
Nukualofa	0	0	0	30	336	0	0	0	0	0	0	0	20	386
Papeete	0	112	0	16	0	0	0	0	0	0	0	0	0	128
Total	2212	112	518	104	400	804	38	2140	502	2370	664	142	20	10026

are used, as shown in Table 7. The results imply that some links are congested and thus some empty containers have to be repositioned to other ports. By adjusting the repositioning solution, the congestion in some links is reduced, which can avoid exceeding the capacity limit.

(2) Impacts of introducing foldable containers

Based on the result of surplus or deficit of empty containers, optimization simulations of empty container repositioning in different scenarios on foldable containers are conducted, including the calculations of the transshipment volume, total repositioning time, and total management cost. In the following analyses, we compare the effect of introducing foldable containers by different scenarios, including the comparisons between (1) the case that only standard containers are used and the case that only foldable containers are used, and (2) the case that foldable containers are equally allocated to all ports and the case that they are mainly allocated to congested ports.

If we assume the full replacement with foldable containers, the optimal repositioning solution with capacity constraint shown in Table 8 is the same as the repositioning solution without considering capacity constraint that is shown in Table 6. It is because that less space is required if an empty container is folded; therefore, the congestion in some links can be reduced and all empty containers can be repositioned in a most effective way.

With the similar demand increasing rate, if assuming that 60% foldable containers are introduced and that they are equally allocated to all surplus ports, the optimal repositioning solution is shown in Table 9. Meanwhile, if foldable containers are mainly allocated to Busan and Shanghai ports, where generated a large number of empty containers and occur congestion, the optimal repositioning solution would change as shown in Table 10. This indicates that the geographical distribution of foldable containers may affect the container repositioning.

Fig. 6 shows the transshipment volume of empty containers at different introduction scenarios on foldable containers if the cargo shipping demand

Table 8 Optimal repositioning solution with capacity constraint by introducing *100% foldable containers* if cargo shipping demand increases by 100%.

	Yokohama	Nagoya	Osaka	Kobe	Ningbo	Guangzhou	Apra	Pohnpei	Port Moresby	Honiara	Port Vila	Suva	Pago Pago	Total
Busan	0	0	0	0	0	390	38	1196	0	0	0	0	0	1624
Shanghai	0	0	224	0	64	414	0	0	0	1858	0	0	0	2560
Kaohsiung	34	0	294	0	0	0	0	0	0	0	0	0	0	328
Auckland	248	0	0	0	0	0	0	0	0	0	0	0	0	248
Tauranga	1330	0	0	0	336	0	0	0	0	0	0	82	0	1748
Majuro	0	0	0	0	0	0	0	944	0	0	0	0	0	944
Lae	0	0	0	0	0	0	0	0	502	512	0	0	0	1014
Santo	2	0	0	0	0	0	0	0	0	0	664	0	0	666
Lautoka	0	0	0	0	0	0	0	0	0	0	0	60	0	60
Noumea	262	0	0	0	0	0	0	0	0	0	0	0	0	262
Apia	0	0	0	58	0	0	0	0	0	0	0	0	0	58
Nukualofa	336	0	0	30	0	0	0	0	0	0	0	0	20	386
Papeete	0	112	0	16	0	0	0	0	0	0	0	0	0	128
Total	2212	112	518	104	400	804	38	2140	502	2370	664	142	20	10026

Table 9 Optimal repositioning solution with capacity constraint in the case that *60% foldable containers are equally allocated to all ports* if cargo shipping demand increases by 100%.

	Yokohama	Nagoya	Osaka	Kobe	Ningbo	Guangzhou	Apra	Pohnpei	Port Moresby	Honiara	Port Vila	Suva	Pago Pago	Total
Busan	0	0	0	0	0	390	38	1196	0	0	0	0	0	1624
Shanghai	0	0	224	0	64	414	0	0	38	1820	0	0	0	2560
Kaohsiung	34	0	294	0	0	0	0	0	0	0	0	0	0	328
Auckland	248	0	0	0	0	0	0	0	0	0	0	0	0	248
Tauranga	1432	0	0	0	234	0	0	0	0	0	0	82	0	1748
Majuro	0	0	0	0	0	0	0	944	0	0	0	0	0	944
Lae	0	0	0	0	0	0	0	0	464	550	0	0	0	1014
Santo	2	0	0	0	0	0	0	0	0	0	664	0	0	666
Lautoka	0	0	0	0	0	0	0	0	0	0	0	60	0	60
Noumea	262	0	0	0	0	0	0	0	0	0	0	0	0	262
Apia	0	0	0	58	0	0	0	0	0	0	0	0	0	58
Nukualofa	234	0	0	30	102	0	0	0	0	0	0	0	20	386
Papeete	0	112	0	16	0	0	0	0	0	0	0	0	0	128
Total	2212	112	518	104	400	804	38	2140	502	2370	664	142	20	10026

Table 10 Optimal repositioning solution with capacity constraint in the case that *60% foldable containers are mainly allocated to Busan and Shanghai ports* if cargo shipping demand increases by 100%.

	Yokohama	Nagoya	Osaka	Kobe	Ningbo	Guangzhou	Apra	Pohnpei	Port Moresby	Honiara	Port Vila	Suva	Pago Pago	Total
Busan	0	0	0	0	0	390	38	1196	0	0	0	0	0	1624
Shanghai	0	0	224	0	64	414	0	0	0	1858	0	0	0	2560
Kaohsiung	34	0	294	0	0	0	0	0	0	0	0	0	0	328
Auckland	248	0	0	0	0	0	0	0	0	0	0	0	0	248
Tauranga	1480	0	0	0	186	0	0	0	0	0	0	82	0	1748
Majuro	0	0	0	0	0	0	0	944	0	0	0	0	0	944
Lae	0	0	0	0	0	0	0	0	502	512	0	0	0	1014
Santo	2	0	0	0	0	0	0	0	0	0	664	0	0	666
Lautoka	0	0	0	0	0	0	0	0	0	0	0	60	0	60
Noumea	262	0	0	0	0	0	0	0	0	0	0	0	0	262
Apia	0	0	0	58	0	0	0	0	0	0	0	0	0	58
Nukualofa	186	0	0	30	150	0	0	0	0	0	0	0	20	386
Papeete	0	112	0	16	0	0	0	0	0	0	0	0	0	128
Total	2212	112	518	104	400	804	38	2140	502	2370	664	142	20	10026

increases by 100%. As shown in the figure, the transshipment volume is significantly reduced with the introduction of foldable containers.

Fig. 7 shows the total shipping time of empty container repositioning for each scenario, indicating that the total shipping time is also reduced by introducing foldable containers. Similarly, Fig. 8 shows the total number of containers that a company has to possess for each scenario, indicating the number of containers needed can be reduced by introducing foldable containers. They are because the introduction of foldable containers can effectively reduce the congestion in container repositioning in some links and enable empty containers to be repositioned through the shortest path without congestion, reducing the transshipment volume of empty containers, and thus a shipping company can effectively reduce the total repositioning time of empty containers and satisfy cargo shipping demand with less containers. Fig. 9 also shows the estimated total management cost of containers for each scenario based on the results of container repositioning optimization, indicating that management cost can be reduced with the introduction of foldable containers.

The results also imply that the reduction effect on transshipment volume and total shipping time in the case of intensive allocation of foldable containers to the congested ports is greater than the case of their equal allocation to all ports. It is because foldable containers can be more effectively used if they are allocated to these congested ports.

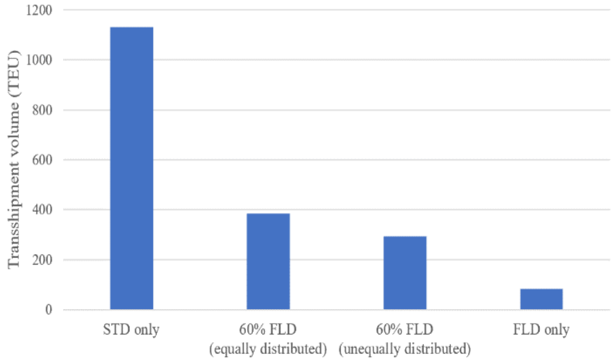


Fig. 6 Empty container transshipment volume by foldable container scenario with 100% increase in cargo shipping demand.

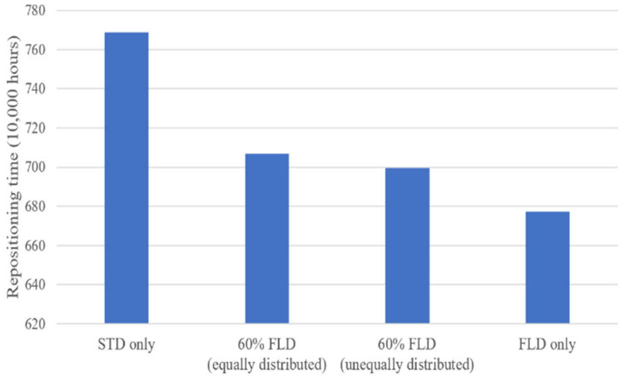


Fig. 7 Container repositioning time by foldable container scenario with 100% increase in cargo shipping demand.

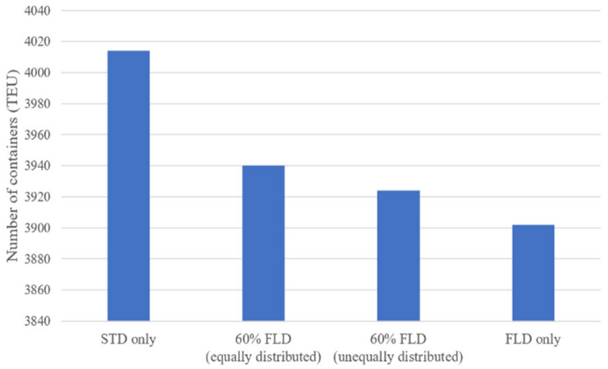


Fig. 8 Total number of containers that a company has to possess by foldable container scenario with 100% increase in cargo shipping demand.

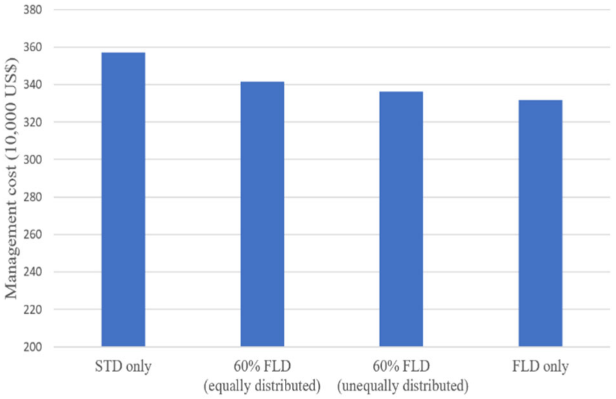


Fig. 9 Total management cost of containers by foldable container scenario with 100% increase in cargo shipping demand.

(3) Difference in results by demand increasing rate and foldable containers introduction rate

In this subsection, we consider the optimization results by different demand increasing rate with different introduction rate of foldable containers. Fig. 10 shows the total management cost of containers by different introduction rate of foldable containers at different demand increasing rate. As shown in the figure, at the current cargo shipping demand or with a demand increase from the current demand of less than 40%, the total management costs of empty container repositioning are the cheapest if only standard containers are used (S0). In other words, it is better not to introduce foldable containers. If the cargo shipping demand increases by 60% from the current demand, in case that an introduction rate of foldable containers (S3) is 60%, the total management costs would be minimized. Moreover, even in the other introduction rates of foldable containers, the management costs are smaller compared to S0. This implies that foldable containers may be effective in reducing the cost of managing empty containers. If cargo shipping demand increases by 80% and 100% from the current demand, the case that an introduction rate of foldable

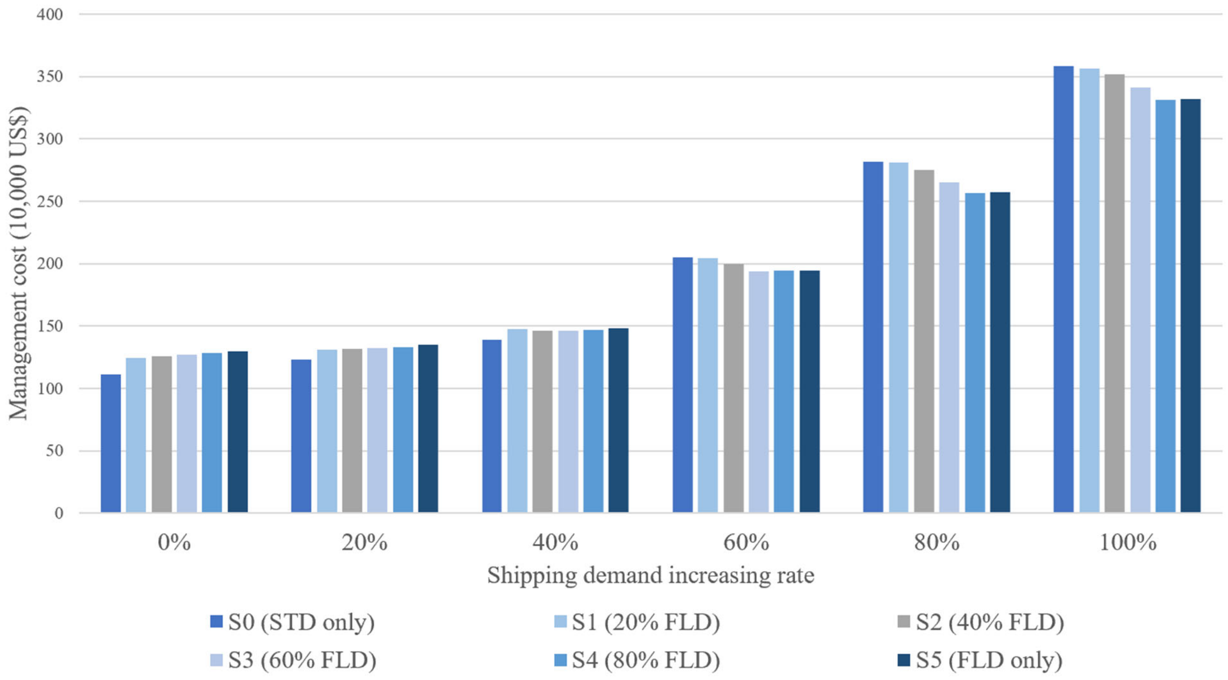


Fig. 10 Total container management cost by different introduction rate of foldable containers at different demand increasing rate.

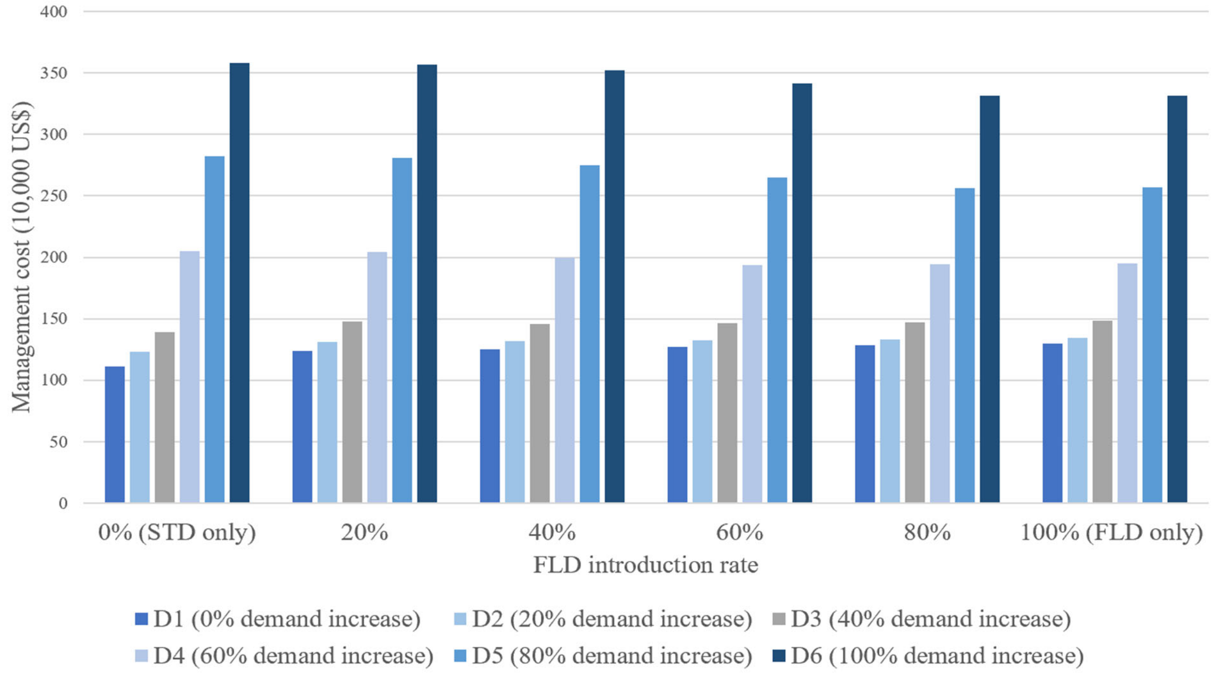


Fig. 11 Total container management cost by different demand increasing rate at different introduction rate of foldable containers.

containers is 80% (S4) has the greatest effect on cost reduction. However, with the full replacement with foldable containers (S5), the total management cost is higher than S4, which implies that introducing too many foldable containers would increase management costs.

Fig. 11 shows the total management cost of containers by different demand increasing rate at different introduction rate of foldable containers. As shown in the figure, the total management cost would increase as cargo shipping demand increases. Introducing foldable containers can mitigate the fluctuations in management cost caused by the shipping demand fluctuation. Moreover, the higher the introduction rate, the smaller the management cost fluctuation. Therefore, the introduction of foldable container enables management cost to be more stable.

Fig. 12 shows a breakdown of the total management cost of containers by different introduction rate

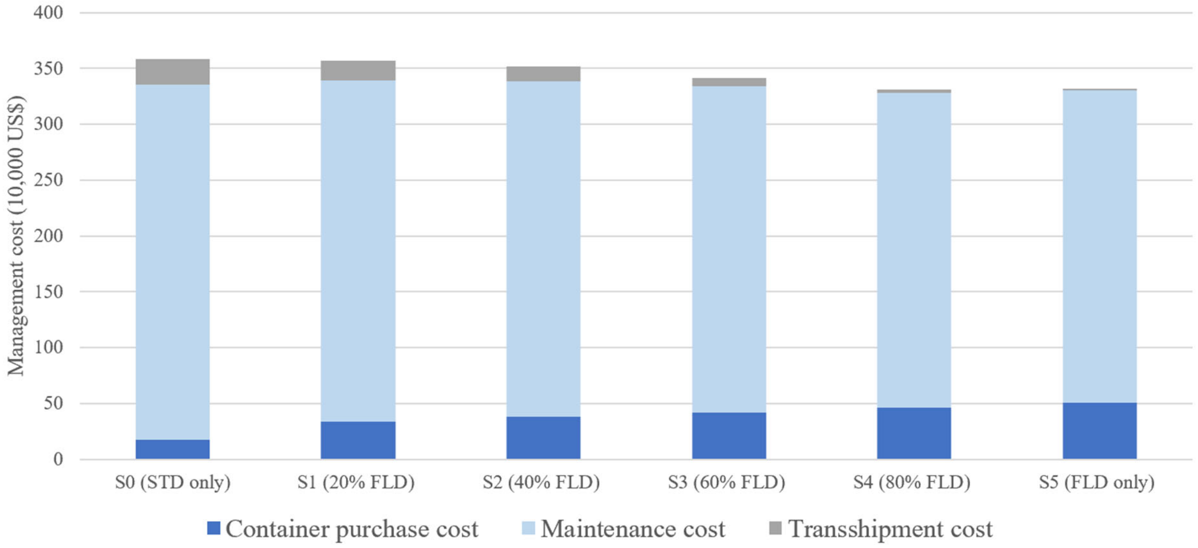


Fig. 12 Breakdown of total container management cost by different introduction rate of foldable containers if cargo shipping demand increases by 100%.

of foldable containers if the cargo shipping demand increases by 100%. The results imply that though the foldable container leads to an increase in container purchase cost, it enables a shipping company to reduce the total number of containers that it has to possess, and thus to reduce the container maintenance cost. Moreover, foldable containers could also help in reducing the transshipment volume of empty containers, which would lead to additional handling costs.

6. CONCLUSIONS

In recent years, rapid economic growth and globalization have increased the trade imbalance between Asia and the Pacific region, which has led to a serious problem of repositioning empty containers. One of the measures to alleviate this problem is to introduce foldable containers, which have not yet been put into practical use. Therefore, to analyze whether foldable containers can be advantageous in empty container repositioning from an economic perspective, we compared the management costs of empty container repositioning if using only standard containers and introducing foldable containers.

Particularly, focusing on a liner shipping service network between East Asia and Oceania, we developed a solution algorithm for optimizing empty container repositioning in multiple liner shipping services considering vessel capacity constraint, which can optimize the empty container flows to minimize the total repositioning time. Moreover, we conducted empty container repositioning analyses and confirmed the effect of empty container repositioning in multiple shipping services by introducing foldable containers, including shipping time and management cost saving.

Based on the results of scenario simulation analyses, the following conclusions are acquired First, the total shipping time of empty container repositioning can be reduced by introducing foldable containers. This is because the introduction of foldable containers can effectively reduce the congestion of container repositioning in some links and the transshipment of empty containers caused by the congestion, thus enable empty containers to be repositioned through the shortest path. Second, with the introduction of foldable containers, the number of containers that a shipping company has to possess can be reduced compared to the scenario if using only standard containers. The reason is that the containers can be reused more efficiently by transporting the empty containers in a most effective way by introducing foldable containers, and thus a shipping company can satisfy cargo shipping demand with less containers. Third, the total container management cost for a shipping company can be reduced with the introduction of foldable containers. Even though the introduction of foldable containers leads to an increase in the purchase cost per container, the number of containers it has to possess can be reduced, and the transshipment volume of empty containers can be also reduced, which would lead to additional handling costs of empty containers. Therefore, introducing foldable containers contributes to the decrease of total container management cost. Moreover, the cost reduction effect in the case that foldable containers are unequally allocated to the congestion port is greater than if they are equally allocated to all ports. Finally, introducing foldable containers can mitigate the fluctuations in management cost caused by the shipping demand fluctuation, which implies that the introduction of foldable container enable management cost to be more stable.

In summary, this study provided evidence for the economic feasibility of foldable containers for empty container repositioning in the multiple liner services. However, we did not consider cargo shipping demand fluctuation as the previous study[18)] focusing on a single liner shipping service. Moreover, we will apply the model developed in this study to global maritime container shipping network including many liner shipping companies. In future research, we will discuss above issues in depth.

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