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Effects of Foldable Containers in Various Circumstances in Maritime Transport

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Abstract

This paper analyzes the effect of foldable containers in various circumstances. Recently, as a result of the COVID-19 pandemic, many unexpected situations have arisen in the shipping and logistics industries. In this study, we examine three key situations: shutdowns, demand fluctuations, and fleet size fluctuations. Furthermore, we developed an integer programming model to analyze through experiments the effect of foldable containers in each situation. The results show that foldable containers have proven to be more effective than standard containers in many situations, and they facilitate a faster recovery from container imbalances. However, the optimal number of foldable containers differs in each situation, and the cost of foldable containers is high. To address this, we propose implementing effective container usage through lease policies. Additionally, we explore management countermeasures from the perspective of each market participant to expand the foldable container market.

Keywords

freight systems, freight planning and logistics, freight container, freight innovations, marine, ports and channels, container

The shipping and logistics market continues to grow, and international container volume is also increasing. The RWI/ISL (Leibniz Institute for Economic Research and the Institute for Shipping Economics and Logistics) container throughput index, a representative container volume index, has also increased, despite the COVID-19 pandemic, as shown in Figure 1. Also, the number of container ships continues to increase, as borne out in a 2021 Statista Research Department report, which claimed: "The number of container ships in the global fleet increased from 4,966 ships in 2011 to 5,371 ships in 2020" (*1*).

However, despite this quantitative growth, shipping and maritime logistics are vulnerable to the disadvantages of slow speed and inflexibility. Such weaknesses have been revealed during the COVID-19 pandemic.

Although global trade volumes declined sharply in early 2020 as a result of the widespread COVID-19 pandemic, logistics demands had recovered rapidly by the end of the same year following the launch of vaccinations. Furthermore, as social and commerce-related transactions shift from traditional face-to-face interactions to remote interactions, people's consumption patterns are changing, resulting in an increase in global logistics volume. These unexpected increases in demand have exacerbated the chronic imbalance in trade volume between Asia and North America.

In Asia, an unfavorable situation arose in which empty containers were not readily available when needed. On the other hand, in North America, numerous surplus empty containers were left unused as no ships were available to transport them to Asia. The Shanghai Containerized Freight Index (SCFI), a representative index of container fares, continued to increase. The index started at 1,022.72 points in January 2020, rose to 2,870.34 points in January 2021, and finally reached 5,109.6 points in January 2022. However, as the supply of container ships increased and the COVID-19 situation subsided, the SCFI index plummeted to 972.45 points in

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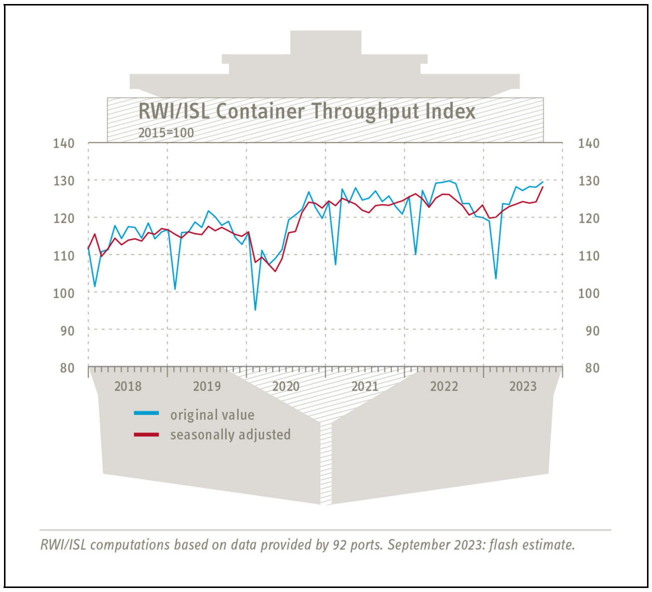

Figure 1. RWI/ISL container throughput index (2).
Note: RWI/ISL = Leibniz Institute for Economic Research and the Institute for Shipping Economics and Logistics.

May 2023. This uncertainty has further intensified container imbalances.

Previous Studies of Unexpected Situations

Various academic studies have been conducted to address unexpected situations. Before COVID-19, these studies primarily focused on changes in demand or port disruptions. Di Francesco et al. (*3*) solved the problem of repositioning empty containers by dividing the disruption of a given port into two disruptions and using multi-scenario optimization. Dong and Song (*4*) studied the container relocation and fleet size decisions of customer demand in uncertain and imbalanced situations. Lee and Moon (*5*) studied robust optimization for empty container repositioning problems by considering foldable containers. They proposed a multistage stochastic programming formulation. Tanaka et al. (*6*) researched demand fluctuation risk to formulate vessel assignment plans to account for inter-company competition. On the other hand, Du et al. (*7*) conducted a study to maximize the profits of each company in the empty container repositioning problem through cooperation by implementing slot sharing between liner shipping companies. After COVID-19, Notteboom et al. (*8*) analyzed and compared the impact it had had on the shipping logistics business with that of the 2008–2009 financial crisis. Koyuncu et al. (*9*) predicted a decrease in container throughput by performing time series analysis using data from the past and from the early days of the COVID-19 pandemic. Xiao et al. (*10*) developed a novel container throughput forecast model at ports by using a decomposition ensemble model.

Previous Studies of Foldable Containers

In this study, we conducted an analysis of the effects of using foldable containers in various circumstances, with particular emphasis on addressing the issue of container imbalances. Foldable containers are innovative containers and are now starting to be commercialized. These containers can be folded when empty, thereby reducing transportation and storage costs. However, their production costs are higher, and they need special handling equipment that still requires further commercialization. Konings and Thijs (*11*) and Konings (*12*) introduced and analyzed the basic advantages and disadvantages of exploiting foldable containers. Many other studies about the effects and advantages of foldable containers have been conducted Shintani et al. (*13*) analyzed the effect foldable containers had on fleet size management, while Wang et al. (*14*) studied ship type decisions that took into account foldable containers. Jeong and Kim (*15*) focused on the weak durability of foldable containers and conducted research on the impact of equipment failure. They noted that issues with the durability of foldable containers led to the conclusion that the complete replacement of standard containers to ensure reliability is not feasible. Similarly, Wang and Heo (*16*) studied the varying supply ratios of foldable containers and standard containers to determine the appropriate mixing levels.

As for the effect of foldable containers on the empty container repositioning network, Erdoğan and Kabadurmuş (*17*) compared the impacts of foldable containers, street-turn, depot-direct strategies, and their combinations on empty container repositioning. Kim et al. (*18*) showed, through mixed-integer programming (MIP), that with the introduction of foldable containers, the flow of empty container repositioning in the hinterland changes. Moreover, as for the additional restrictions resulting from foldable containers, Moon and Hong (*19*) researched the installation of the special equipment needed to operate foldable containers. Kim et al. (*20*) analyzed additional loading rules and effects when considering the characteristics of foldable containers. Jeong et al. (*21*) studied the impact of determining optimal devanning times, which is an important consideration when using foldable containers. However, most of the previous studies did not consider the mitigation of fluctuations that result from leveraging the advantageous characteristics of foldable containers. Similar to this study, Liang et al. (*22*) analyzed the trade-off between relocation costs and management costs given changes in the demand for foldable containers, but there is a limit

Table 1. Comparisons of Recent Papers Related to this Research

Authors	Considering Foldable Container	Changing Situation	Concepts
Konings and Thijs (*11*)	√	na	Introduce foldable containers to academia
Konings (*12*)	√	na	Basic advantages and disadvantages of foldable containers, which related to space saving
Dong and Song (*4*)	na	Demand	Fleet sizing and empty container repositioning problem in multiple vessels and ports
Shintani et al. (*13*)	√	na	Analysis of the effect of the foldable container according to the fleet size
Di Francesco et al. (*3*)	na	Shutdown	Repositioning of empty containers with port disruptions using single and multiple scenarios
Moon and Hong (*19*)	√	na	Installation of foldable container equipment and minimization of total repositioning cost
Wang et al. (*14*)	√	na	Ship type decision in liner shipping considering foldable containers
Erdoğan and Kabadurmuş (*17*)	√	na	Analysis of foldable containers, street-turn, and depot-direct strategies effects on empty container repositioning
Jeong et al. (*21*)	√	na	Determining the optimal devanning time according to the scenario in the container supply chain
Lee and Moon (*5*)	√	Demand	Propose robust formulation for the empty container repositioning problem, which considers foldable containers
Tanaka et al. (*6*)	na	Demand	Formulating vessel assignment plans
Du et al. (*7*)	na	na	Sharing slots and calculating appropriate lease prices through cooperation between shipping companies
Kim et al. (*18*)	√	na	Analysis of rules and cost distribution issues that arise when introducing foldable containers
Kim et al. (*18*)	√	na	Analysis of hinterland network changes when considering foldable containers
Koyuncu et al. (*9*)	na	na	Predicts the volume of containers after COVID-19 by using the SARIMA model
Liang et al. (*22*)	√	Demand	Use scenarios to analyze the effects of foldable containers on demand fluctuations
Notteboom et al. (*8*)	na	Throughout the shipping industry	Analysis of shipping industry disruptions after COVID-19 by comparing it with the 2008–2009 financial crisis
Wang and Hu (*16*)	√	na	An appropriate ratio of foldable and standard containers was studied using a mathematical model
Jeong and Kim (*15*)	√	na	Design a failure pattern and develop an integer programming model for the facility failure of foldable containers
Xiao et al. (*10*)	na	Container throughput	Integrates VMD algorithm, SARIMA technique, CNN method, LSTM approach
This paper	√	Shutdown, demand, fleet size	Analysis of effective use of foldable containers in various circumstances

Note: SARIMA = seasonal auto-regressive integrated moving average; VMD = variational mode decomposition; CNN = convolutional neural network; LSTM = long short-term memory; na = not applicable.

to considering demand changes alone. We provide a summary of the pertinent literature in Table 1.

The Increasing Use of Foldable Container in the Industrial Sector and the Purpose of this Study

Several companies and institutions are competing for the actual production and commercialization of foldable containers. This is especially the case with Holland Container Innovation (HCI) in the Netherlands and with Korea Railroad Research Institute (KRRI) in the Republic of Korea, which is working hard to standardize and fully commercialize foldable containers. The containers these companies have developed are shown in Figure 2.

As shown in Figure 2, the foldable container, the closest to commercialization to date, is a method of making one pack by folding all four containers. Many other

Figure 2. Developed foldable containers: (a) KRRI (*23*) © KRRI; and (b) HCI (*24*) © 4FOLD.
Note: KRRI = Korea Railroad Research Institute; HCI = Holland Container Innovation.

folding methods, such as folding five or six containers in one pack, have also been studied, but they failed in development for commercialization purposes. Therefore, owing to the current level of the technology, it can be considered that foldable containers generally have the effect of reducing four storage spaces into one.

Foldable containers offer significant effectiveness in reducing transportation and storage costs across various scenarios. Their adaptability—capability of being folded or unfolded based on the situation—enables swift responses to restrictions and fluctuations. This flexibility serves as a buffer in cases where container availability falls short. We believe that using foldable containers can enhance the efficiency of relocating empty containers compared with standard ones, even when faced with transport capacity limitations. Therefore, our study delves into how foldable containers effectively navigate crises in diverse circumstances. In addition to exploring their commonly recognized effects of reducing transportation and storage expenses, we aim to explore their efficacy in managing various changing situations, such as demand fluctuations. Furthermore, we hypothesize that these effects manifest more prominently when there is an imbalance between the supply and demand of foldable containers, a hypothesis we intend to validate through experimentation.

To analyze the impact of foldable containers, we developed a mathematical model and conducted experiments in three key situations: shutdowns, demand fluctuations, and fleet size fluctuations. Additionally, we examined the combined effects arising from the interplay of these situations. Moreover, we present managerial insights geared toward the efficient commercialization of foldable containers.

The remainder of this paper is organized as follows. We first describe the problem before explaining the mathematical model. We then show the computational results and provide managerial insights. We end with conclusions and suggestions for areas of further research.

Problem Description

In this paper, we want to analyze the effect that using foldable containers has on trading situation changes. Because many different situations can occur, we would like to analyze when foldable containers are effective and how many foldable containers are needed in each case. We assumed that there were several ports, of which each could only be traded through the sea. Each port may have the same export and import volumes of containers (ideal case), or each port may be different, as in the real world. We want to identify the problems in case of a shutdown situation, demand fluctuation, or fleet size fluctuation. We believe this is especially timely research. Many shutdowns, such as the closure of ports, occur. In addition, the lack of containers and container vessels continues to be a problem.

We studied how these problems disappear when foldable containers are used. Assumptions in this paper are as follows:

- Several ports are traded only by sea and the total number of containers is fixed.
- Container transport between ports by land is not considered.
- The set-up considers returned containers from customers on land, but does not consider backhauling.
- The storage of containers is only considered with respect to imported containers awaiting customs declaration (laden containers) and the storage of empty containers within designated depots for export.
- Unsatisfied demand is regarded as lost sales, which in turn is considered as a cumulative cost for a decline in reputation. Leases are not considered.
- Voyage time, import/export processing time, onshore transportation time, and delays caused by shutdowns are considered.

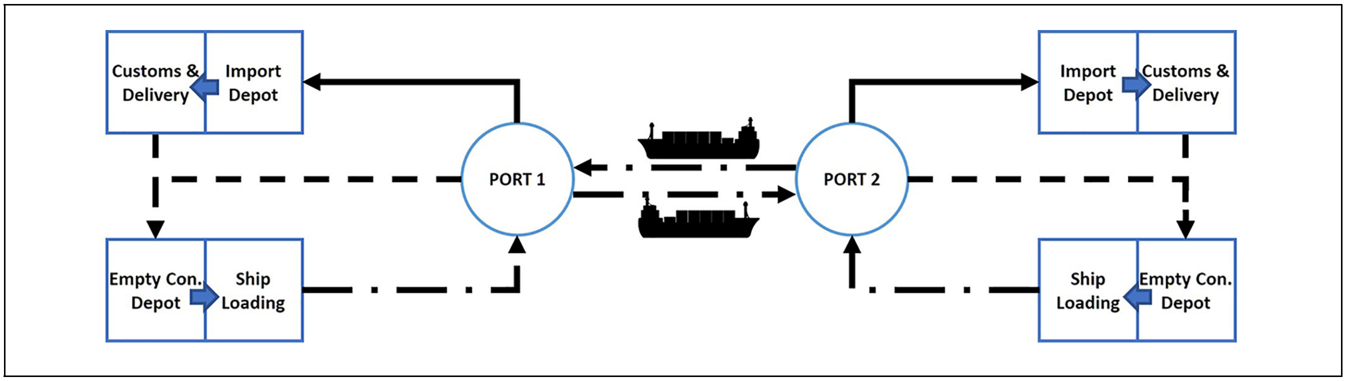

Figure 3. Network flow of containers in the case of two ports (laden container: solid line; empty container: dotted line).

- Only reduction costs, sea transportation costs, inventory costs, and accumulated lost sales costs are considered.
- Space limitations of container vessels are considered, but space limitations of depots are not considered.

The example of the network flow in the case of two ports reflecting the above assumptions is shown in Figure 3. Export and import processes are carried out at each port. Vessels are carrying laden and empty containers between each port. Because vessels have capacity limitations, the fluctuation of the vessels' capacities is expressed through the capacity of the given vessel's changes over time. When containers arrive at each port, laden containers move to the import depot and go through customs clearance. If a shutdown occurs, the customs process will be suspended. Containers delivered to the customer will be moved back to the empty container depot in an empty state. On the other hand, imported empty containers are moved directly to the empty container depot. If products are exported from each port, the empty container will be matched and transported to another port. When an excess of exported products surpasses the availability of empty containers, it leads to a situation of lost sales and a decline in reputation. In Figure 3, only two ports are cited to give a simple example, but the container flow can be expressed equally for numerous ports. Therefore, the mathematical model we develop in the next section is a generalized version that considers various ports.

Mathematical Model

In this section, we propose a mathematical model to solve the problem in the situation by reflecting on the assumptions and problematic situations described above. We develop a deterministic mathematical model that simulates situations through changes in parameters. The sets and parameters of the model used are listed in Table 2 and the variables in Table 3. For better understanding, important variables are shown in Figure 4.

Table 2. Sets and Parameters

P	Set of ports
T	Indices of time periods
C	Types of containers
R	Possible port-to-port routes
V_{ij}^{t}	Capacity of the vessel in period t, route (i,j)
D_{ij}^{t}	Demand route (i,j) in period t
IT_i	Import processing time in port i
LT_i	Onshore processing time in port i
ET_i	Export processing time in port i
ST_{ij}	Voyage time in route (i,j)
SC_{ij}	Voyage cost in route (i,j)
SP_{ij}	Voyage price in route (i,j)
W_i^t	Import process capacity in port i, period t
IC_i	Storage cost in port i
AC_{ij}	Accumulated lost sales cost in route (i,j)
FC_i	Folding/unfolding cost in port i
CF	Holding cost of foldable container
CS	Holding cost of standard container
NF	Number of total holding foldable containers
NS	Number of total holding standard containers

The constraints and objective functions are as follows:

$$\begin{aligned}
\boldsymbol{Max} \quad & \sum_{(i,j)\in R}\sum_{t\in T} SP_{ij}(x_{ijt}^{1} + x_{ijt}^{3}) \\
& - \sum_{(i,j)\in R}\sum_{t\in T} SC_{ij}(x_{ijt}^{1} + x_{ijt}^{2} + x_{ijt}^{3} + x_{ijt}^{4} + \frac{1}{4}x_{ijt}^{5}) \\
& - \sum_{i\in P}\sum_{t\in T} IC_i(iw_{it}^{1} + iw_{it}^{3} + ew_{it}^{2} + ew_{it}^{4} + \frac{1}{4}ew_{it}^{5}) \\
& - \sum_{t\in T}(CF \times NF + CS \times NS) \\
& - \sum_{(i,j)\in R}\sum_{t\in T} AC_{ij} \times al_{ijt} - \sum_{i\in P}\sum_{t\in T} FC_i(f_{it} + uf_{it})
\end{aligned} \tag{1}$$

Subject to

Table 3. Variables

x^c_{ijt}	Number of container type c transported from port i to port j in period t
im^c_{it}	Number of container type c transported from port i to depot in period t
l^c_{it}	Number of container type c transported from port i to onshore process in period t
e^c_{it}	Number of container type c transported from empty container depot to port i in period t
iw^c_{it}	Number of container type c in import container depot at port i in period t
ew^c_{it}	Number of container type c in empty container depot at port i in period t
al_{ijt}	Number of accumulated lost sales from port i to port j in period t
f_{it}	Number of folding processes at port i in period t
uf_{it}	Number of unfolding processes at port i in period t

$$\begin{aligned} NS = & \sum_{(i,j)\in R}\sum_{s=t-ST_{ij}+1\,|s>0}^{t}(x^1_{ijs}+x^2_{ijs}) \\ & + \sum_{i\in P}\sum_{s=t-IT_{ij}+1\,|s>0}^{t}(im^1_{is}+im^2_{is}) \\ & + \sum_{i\in P}\sum_{s=t-LT_{ij}+1\,|s>0}^{t}(l^1_{is}+l^2_{is}) \\ & + \sum_{i\in P}\sum_{s=t-ET_{ij}+1\,|s>0}^{t}(e^1_{is}+e^2_{is}) \\ & + \sum_{i\in P}(iw^1_{it}+iw^2_{it}) + \sum_{i\in P}(ew^1_{it}+ew^2_{it}) \quad t\in T \end{aligned} \tag{2}$$

$$\begin{aligned} NF = & \sum_{(i,j)\in R}\sum_{s=t-ST_{ij}+1\,|s>0}^{t}(x^3_{ijs}+x^4_{ijs}+x^5_{ijs}) \\ & + \sum_{i\in P}\sum_{s=t-IT_{ij}+1\,|s>0}^{t}(im^3_{is}+im^4_{is}+im^5_{is}) \\ & + \sum_{i\in P}\sum_{s=t-LT_{ij}+1\,|s>0}^{t}(l^3_{is}+l^4_{is}+l^5_{is}) \\ & + \sum_{i\in P}\sum_{s=t-ET_{ij}+1\,|s>0}^{t}(e^3_{is}+e^4_{is}+e^5_{is}) \\ & + \sum_{i\in P}(iw^3_{it}+iw^4_{it}+iw^5_{it}) \\ & + \sum_{i\in P}(ew^3_{it}+ew^4_{it}+ew^5_{it}) \quad t\in T \end{aligned} \tag{3}$$

$$\sum_{i\in P} x^c_{ij(t-ST_{ij})} = im^c_{jt}\ \forall\, j\in P,\ t\in T,\ c\in C \tag{4}$$

$$im^c_{i(t-IT_i)} + iw^c_{i(t-1)} = iw^c_{it} + l^c_{it}\ \forall\, i\in P,\ t\in T,\ c\in\{1,3\},\ t>IT_i \tag{5}$$

$$l^1_{it} + l^3_{it} \leqslant W_i^{t-1}\ 1\ i\in P,\ t\in T,\ t>1 \tag{6}$$

$$l^1_{i(t-LT_i)} + im^2_{i(t-IT_i)} + ew^2_{i(t-1)} = ew^2_{it} + e^1_{it} + e^2_{it}\ \forall\, i\in P,\ t\in T,\ t>IT_i,\ t>LT_i \tag{7}$$

$$\begin{aligned} & l^3_{i(t-LT_i)} + im^4_{i(t-IT_i)} + ew^4_{i(t-1)} + uf_{i(t-1)} - f_{i(t-1)} \\ & = ew^4_{it} + e^3_{it} + e^4_{it}\ \forall\, i\in P,\ t\in T,\ t>IT_i,\ t>LT_i \end{aligned} \tag{8}$$

$$im^5_{i(t-IT_i)} + ew^5_{i(t-1)} - uf_{i(t-1)} + f_{i(t-1)} = ew^5_{it} + e^5_{it}\ \forall\, i\in P,\ t\in T,\ t>IT_i \tag{9}$$

$$e^c_{i(t-ET_i)} = \sum_{j\in P} x^c_{ijt}\ \forall\, i\in P,\ c\in C,\ t\in T,\ t>ET_i \tag{10}$$

$$x^1_{ijt} + x^3_{ijt} \leqslant D^t_{ij}\ \forall\, (i,j)\in R,\ t\in T \tag{11}$$

$$al_{ijt} = al_{ijt-1} + D^t_{ij} - x^1_{ijt} - x^3_{ijt}\ \forall\, (i,j)\in R,\ t\in T,\ t>1 \tag{12}$$

$$x^1_{ijt} + x^2_{ijt} + x^3_{ijt} + x^4_{ijt} + {}^1\!/_4 x^5_{ijt} \leqslant V^t_{ij}\ \forall\, (i,j)\in R,\ t\in T \tag{13}$$

$$x^c_{ijt} = 0\ \forall 0(i,j)\notin R,\ c\in C,\ t\in T \tag{14}$$

$$\begin{aligned} & l^2_{it} = l^4_{it} = l^5_{it} = ew^1_{it} = ew^3_{it} = iw^2_{it} = iw^4_{it} = iw^5_{it} \\ & = 0\ \forall 0 i\in P,\ t\in T \end{aligned} \tag{15}$$

$$x^c_{ijt}, al_{ijt} \in \mathbb{Z}_+\ \forall\, (i,j)\in R,\ c\in C,\ t\in T \tag{16}$$

$$im^c_{it},\ l^c_{it},\ e^c_{it},\ iw^c_{it},\ ew^c_{it}, f_{it}, uf_{it} \in \mathbb{Z}_+\ \forall\, i\in P,\ c\in C,\ t\in T \tag{17}$$

$${}^1\!/_4 x^5_{ijt} \in \mathbb{Z}_+\ \forall\, (i,j)\in R,\ c\in C,\ t\in T \tag{18}$$

$${}^1\!/_4 e^5_{it},\ {}^1\!/_4 ew^5_{it},\ {}^1\!/_4 im^5_{it} \in \mathbb{Z}_+\ \forall\, i\in P,\ t\in T \tag{19}$$

The objective function (1) maximizes the total profits based on the revenue obtained from transporting freight, deducting container transportation costs (including empty repositioning), storage costs, container holding costs, accumulated lost sales costs, folding costs, and unfolding costs. In variables, type c expresses types of containers. If c is 1 or 2, it means standard laden containers and standard empty containers, respectively, and when c is 3, it means foldable laden containers. In addition, c being 4 or 5 means unfolded and folded states of foldable empty containers, respectively. Constraints (2) and (3) specify that the quantity of both standard and foldable containers remains constant in each period, determined by the total sum of containers in transit and storage. Constraint (4) is the balance equation of import containers, and Constraint (5) is the balance equation of import depots for laden containers. Constraint (6) expresses the processing capacity at customs because all import containers have to go through the import

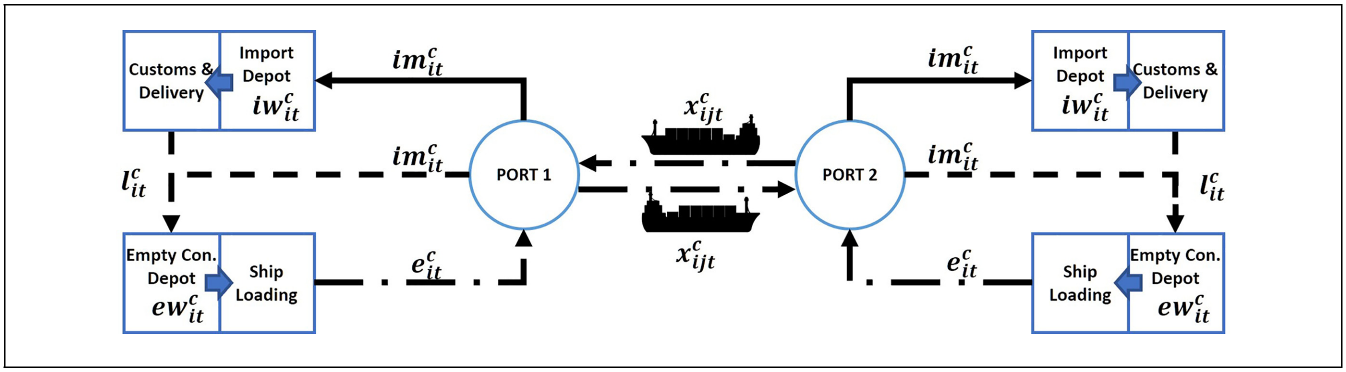

Figure 4. The main variables as listed in Table 3.

process. Constraints (7), (8), and (9) are the balance equation of standard containers, unfolded states of foldable containers, and folded states of foldable containers in empty container depots, respectively. Constraint (10) is the balance equation of export containers. Constraints (11), (12), and (13) are demand constraints, accumulated lost sales, and vessel capacity constraints, respectively. We put zeros on variables that should not have a value in Constraints (14) and (15). Constraints (16) and (17) show that variables are integers, and Constraints (18) and (19) express that foldable packs have to be a multiple of four.

Computational Experiments

Overview

We analyzed the effect that using foldable containers had when situations occurred in a given network flow. Total considered periods were set to 13 weeks. Voyage time between the ports was assigned to two weeks. The time required for the import process, onshore process, and export process at each port was set to one week each. In general, container ships traveling between Asia and the United States require two to four weeks for transportation, and customs clearance in the United States typically takes about a week. Moreover, overland transportation times can vary based on circumstances, usually estimated to take less than a week. Therefore, our assumptions align closely with reality. We analyzed 10 different situations, which included shutdowns, demand fluctuations, fleet size fluctuations, and a combination of each situation. The shutdown was described as a situation in which one port is closed for one week out of every four, during which time the import process was halted.

When fleet size and demand fluctuations occur together, the vessel capacity is designed to increase (or decrease) after an increase (or decrease) in demand, reflecting that demand is a leading indicator of vessel capacity. This can be expressed as the capacity of the vessel fluctuation after one to four weeks depending on the change in demand.

We also take into account the balance between imports and exports at each port, the total number of containers used, and the ratio of standard to foldable containers. The rationale behind considering balanced scenarios is to compare and analyze the efficacy of foldable containers in ideal situations against their performance in real-world situations (unbalanced situations). This approach was anticipated to provide a clearer view of the effectiveness of foldable containers in practical contexts.

Experiments were conducted on 9,020 situations and included the following inputs described in Table 4. The parameters for the various situations are detailed in the Appendix, and the cost data used in the experiments is presented in Table 5. In the time frame of 2022 to 2023, the average freight rate for containers between South Korea and the western United States ranged from \$2,000 to \$9,000 (based on 1 forty foot equivalent unit [FEU]), forming the basis for price and cost calculations. Additionally, factoring in the necessity of two to three personnel and specialized equipment, the assumed cost for folding/unfolding is estimated as being between \$100 and \$150, accounting for regional labor costs. However, it is important to note that a multitude of factors can cause actual costs to vary, causing prices to fluctuate over time. The models were implemented using XPRESS-IVE 8.6 with the Xpress-MP mathematical programming solver. Experiments were conducted with an Intel® Core™ i5-37400 CPU 3.0 GHz with 8.0 GB of RAM in Windows 10.

Experiment Results

The results of the experiment are summarized briefly in Figures 5 to 8. There were 41 cases related to the number of containers, but there were too many to be expressed in figures. Therefore, we chose two cases as graphs to analyze the shape. A sampling of 900 and 1,100

Table 4. The Types of Situation Considered

Import and export balances (2 cases)	- balanced: 100 FEU (port 1→port 2), 100 FEU (port 2→port 1) per week - imbalanced: 60 FEU (port 1→port 2), 100 FEU (port 2→port 1) per week
Various situations (10 cases)	1. normal 2. shutdown 3. fleet size decrease and increase 4. fleet size increase and decrease 5. demand decrease and increase 6. demand increase and decrease 7. fleet size and demand decrease and increase 8. fleet size and demand increase and decrease 9. shutdown, fleet size, and demand decrease and increase 10. shutdown, fleet size, and demand increase and decrease
Number of containers (41 cases)	800–1,600 (balanced case), 640–1,440 (imbalanced case), gap: 20
Proportion of standard container (11 cases)	0~1 (gap: 0.1)

Note: FEU = forty foot equivalent unit.

containers was selected in a balanced situation, and a sampling of 740 and 940 containers was selected in an imbalanced situation, which is shown in Figures 5, 6, 7, and 8, respectively. The horizontal axis is the proportion of standard containers, and the vertical axis is the total profit attained.

The experiments illustrated in Figures 5 and 6 showed that foldable containers have no effect and only reduce profit in many balanced cases, in which the container proportion is 1 (using only standard containers). Because standard containers are sufficient to handle each situation, an increase in the proportion of foldable containers only increases operating costs. However, Figures 7 and 8 show that foldable containers were meaningful in many cases. This circumstance was so because foldable containers are transported faster to areas with a shortage when there are many empty containers left on one side.

We found a peak proportion when a foldable container shows the best effect in some cases because there is a trade-off to reducing shortages and increasing operating costs in the use of foldable containers. We summarize the peak in each case in the Appendix. In a balanced situation, foldable containers have limited effects. Even if several imbalance situations occur, seldom is there a shortage of containers. Foldable containers were effective only in cases 2, 8, and 10, when the shutdown occurred, or when the demand and fleet size were increased first and decreased after. Otherwise, in the imbalanced situation, foldable containers were required in all cases.

Foldable containers were introduced to solve the imbalance of containers quickly. Therefore, we can check that the foldable container is effective even in case 1, which is the normal case. When various circumstances were considered, more complex situations occurred. First, fewer foldable containers are required in a shutdown (case 2) than in case 1. This is because when processing delays occur as a result of shutdowns, containers

Table 5. Cost data (per week, FEU)

	Port 1	Port 2
Voyage prices/costs	\$2,500/\$1,000 (to Port 2)	\$3,000/\$1,000 (to Port 1)
Accumulated lost sales costs	\$1,250 (to Port 2)	\$1,500 (to Port 1)
Storage costs	\$12	\$10
Folding/unfolding costs	\$150	\$100
Container holding costs	\$20 (standard), \$30 (foldable)	

Note: FEU = forty foot equivalent unit.

loaded with goods are waiting at the import port. This reduces the time spent in an empty container state, where the advantages of the foldable container are applicable.

The fluctuations in fleet size and demand are fundamentally similar. However, compared with case 1, there are scenarios where a greater or lesser number of foldable containers are required. This difference arises from the variability in scenarios where the foldable container can offer effectiveness, contingent on the capacity available for transporting empty containers. In instances of high demand or small fleet sizes, where the laden container occupies the entire vessel space, the foldable container simply results in increased costs. When facing low demand or larger fleet sizes, performance varies as a result of factors such as storage/transportation costs and management/purchase costs. Nonetheless, between these scenarios, when there is available space for empty containers, but that space is not enough to accommodate only standard containers, the foldable containers' rapid responsiveness maximizes efficiency. Foldable containers also proved effective in scenarios of insufficient total container numbers. Conversely, if the number of

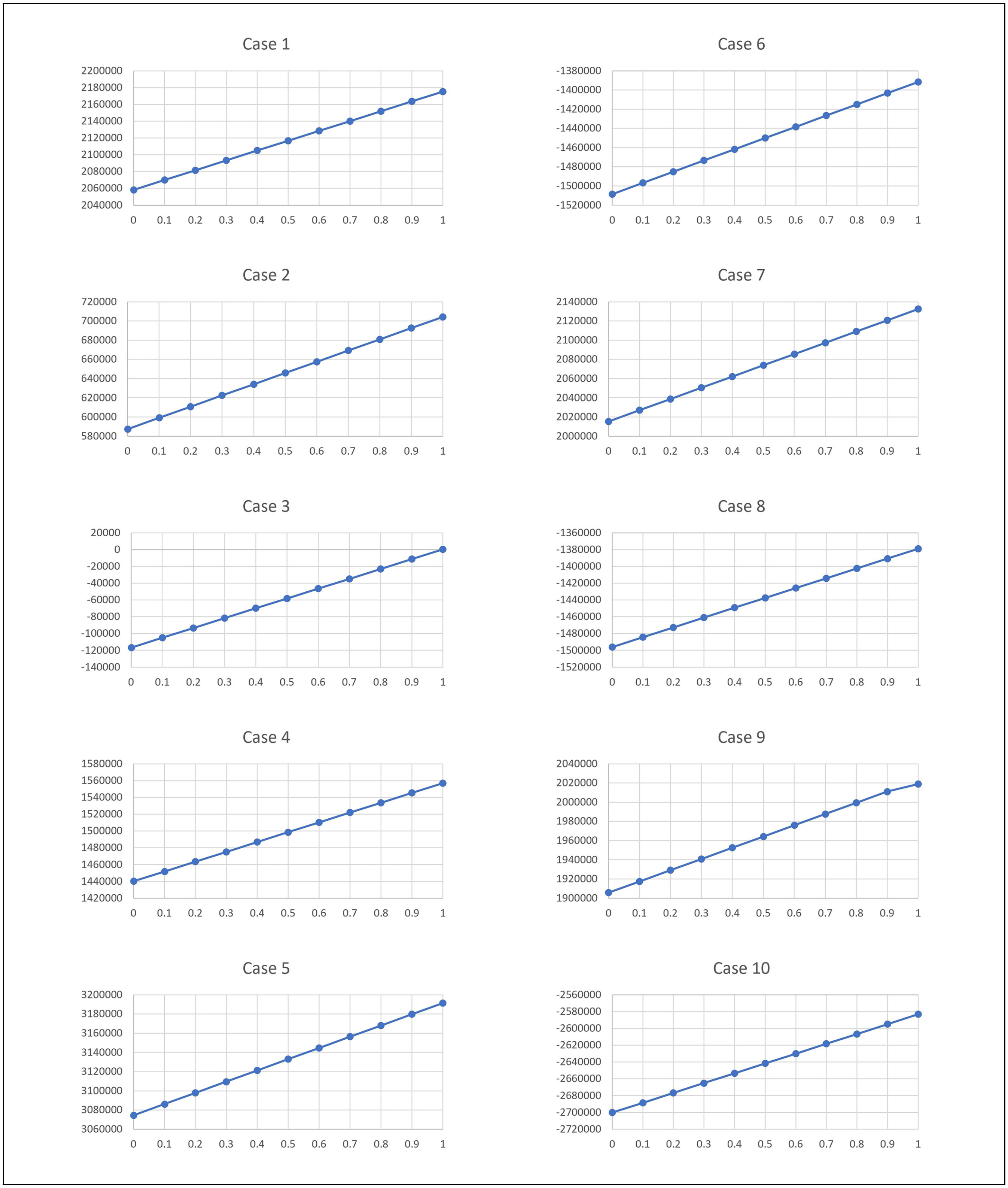

Figure 5. 900 containers in a balanced situation. (X-axis: ratio of standard container; Y-axis: profit).

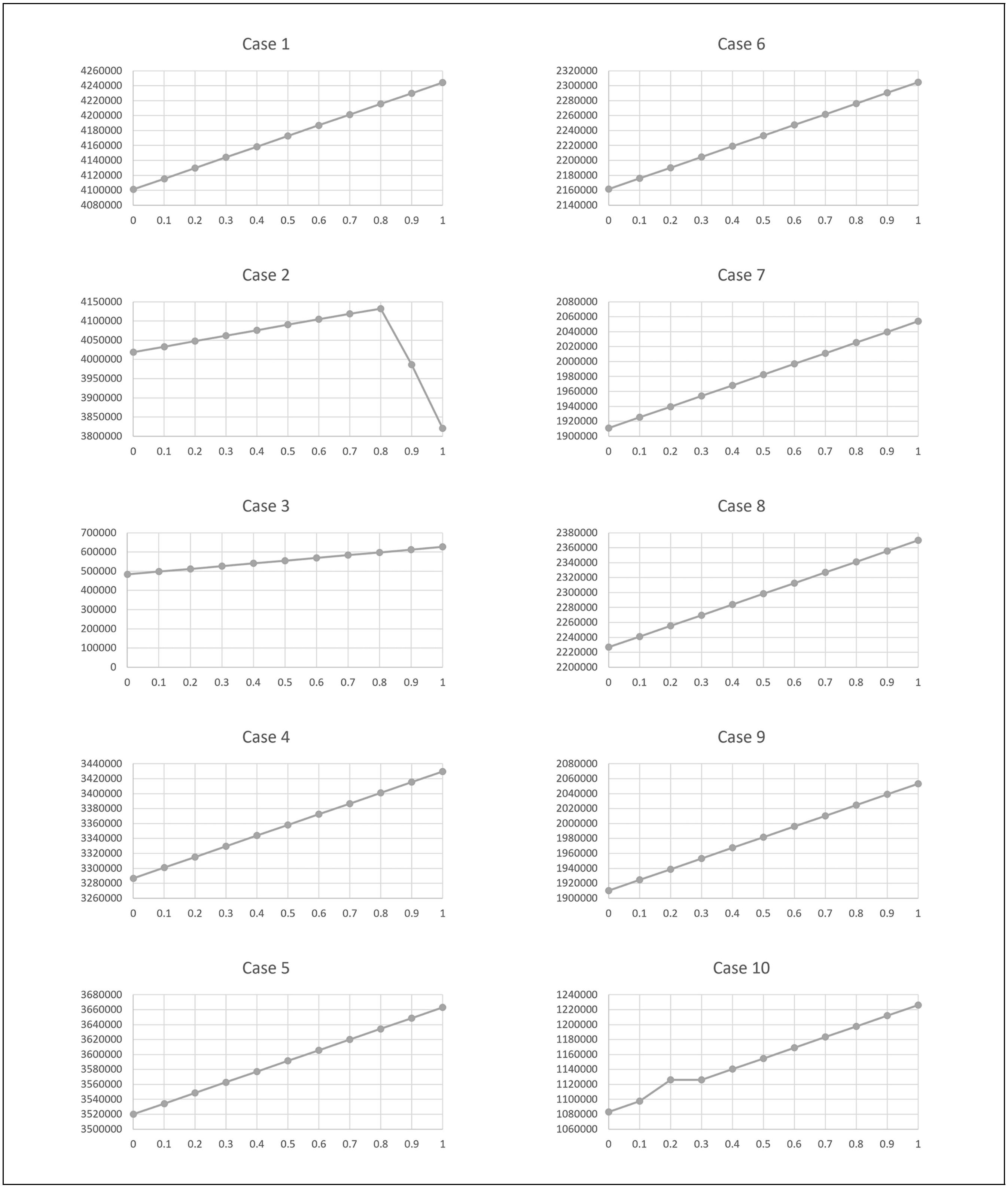

Figure 6. 1,100 containers in a balanced situation. (X-axis: ratio of standard container; Y-axis: profit).

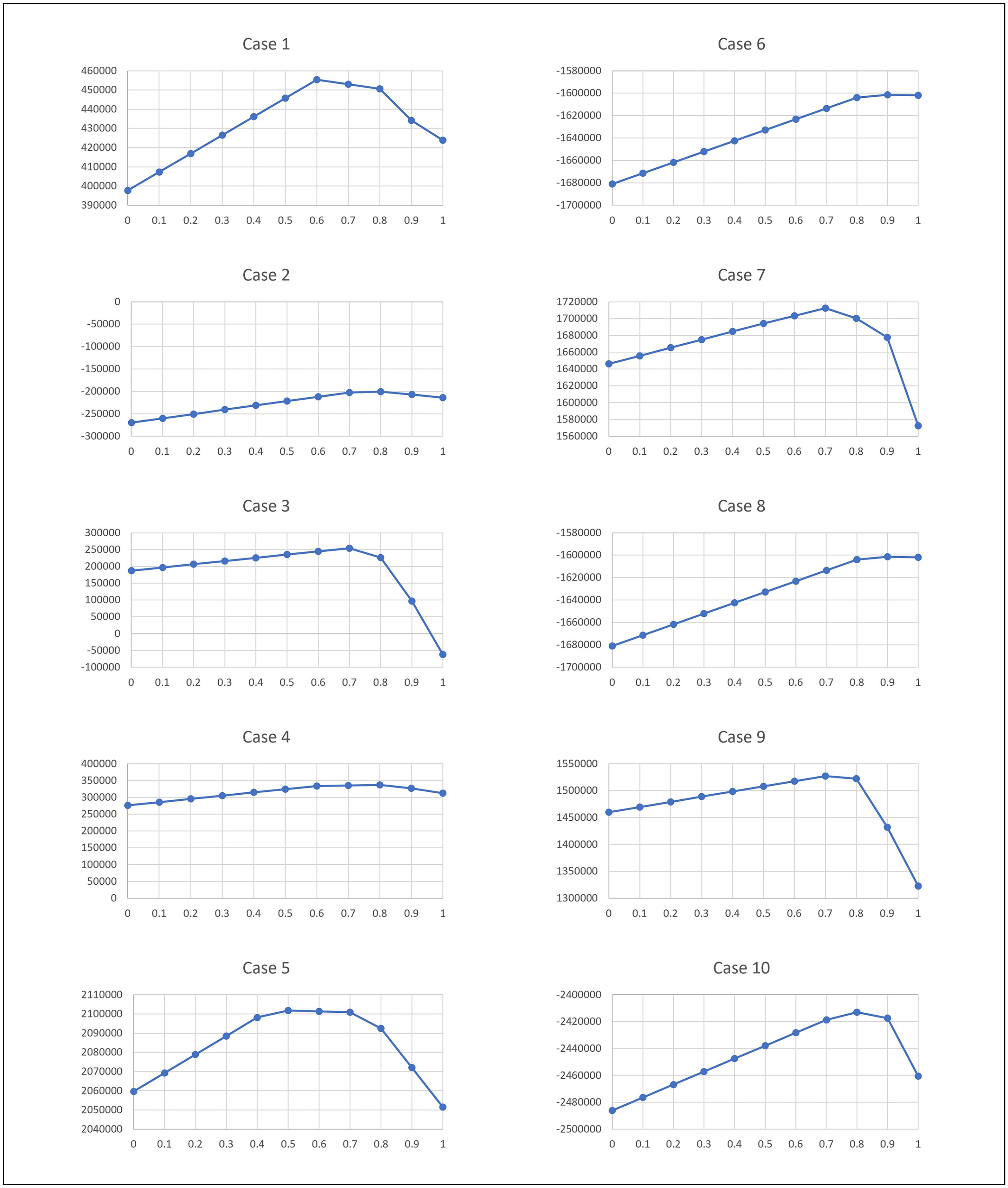

Figure 7. 740 containers in an imbalanced situation. (X-axis: ratio of standard container; Y-axis: profit).

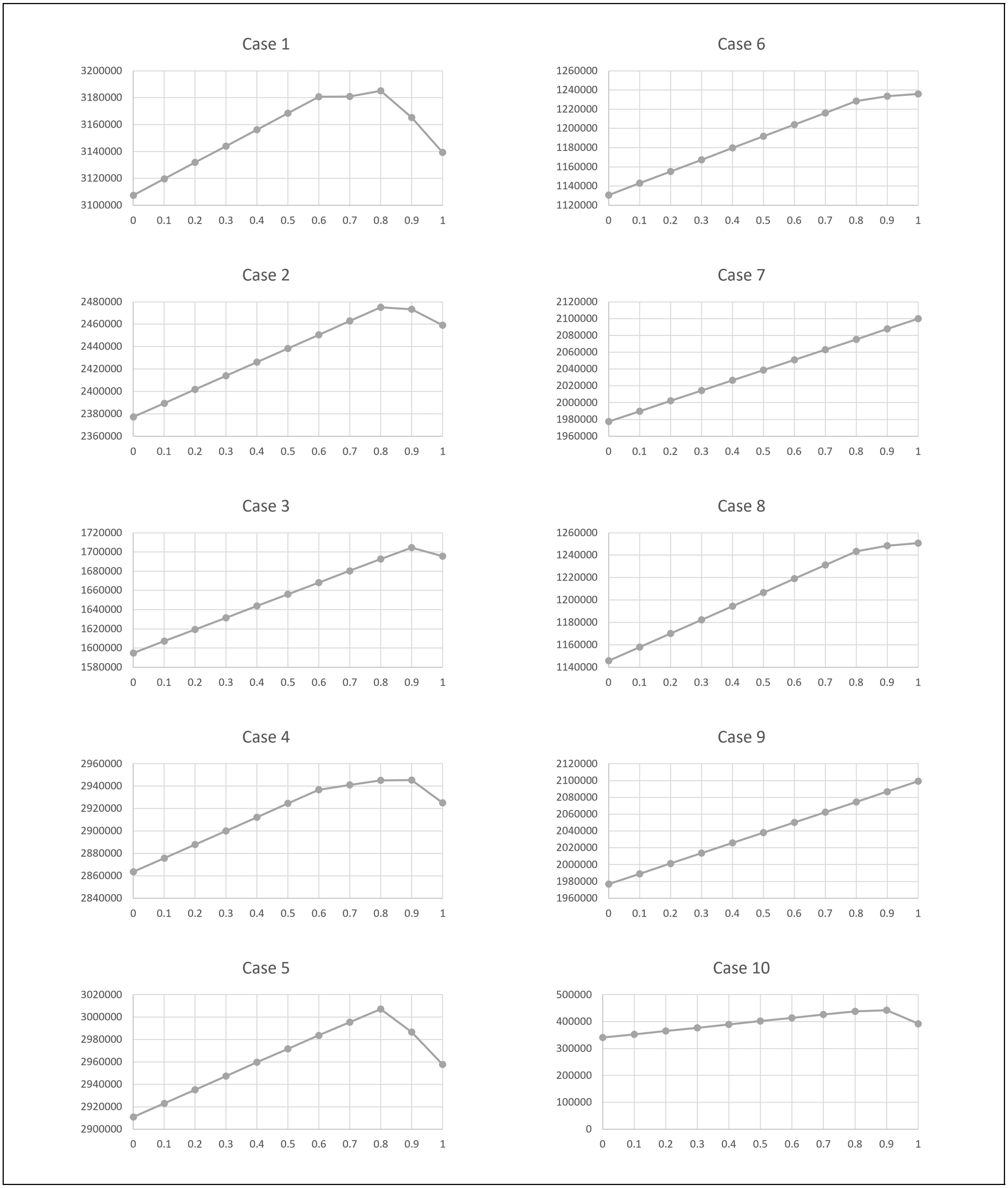

Figure 8. 940 containers in an imbalanced situation. (X-axis: ratio of standard container; Y-axis: profit).

Table 6. Profits in a Different Shutdown Situation (940 Containers in Imbalanced Situation)

Standard container proportion	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0
Every 6 weeks	2,761,080	2,767,046	2,766,940	2,758,720	2,752,500	2,740,280	2,728,060	2,715,840	2,703,620	2,691,400	2,679,180
Every 4 weeks	2,459,100	2,473,164	2,475,020	2,462,800	2,450,580	2,438,360	2,426,140	2,413,920	2,401,700	2,389,480	2,377,260
Every 3 weeks	1,937,180	1,989,228	2,003,200	2,000,980	1,998,760	1,986,540	1,974,320	1,962,100	1,949,880	1,937,660	1,925,440

containers was adequate, standard containers alone sufficed. Consequently, we concluded that the optimal ratio of foldable containers varies based on shutdown situations, demand and fleet size fluctuations, and the total number of containers available.

Effects of Shutdowns

We confirmed through experiments that foldable containers show effective profit growth in several situations. Our experiments are meaningful because foldable containers are effective in many cases. However, we observed that the peak proportions are different in each situation. To check the changes in the same case, additional experiments were conducted by changing the period of the shutdown situation. In the existing situation, shutdown occurred once every four weeks, but we performed additional experiments in which shutdown occurred once every three weeks and once every six weeks. In the case where the total number of containers was 940 in an imbalanced situation, the changes in profits caused by changes in the proportion of standard containers are summarized as shown in Table 6.

The experimental results showed that the more frequently shutdowns occur, the lower the total profit. This is clear because more shutdowns trigger delays in cargo transport. In addition, we observed that the need for foldable containers increased as the number of shutdowns increased. When the shutdown occurred once every six weeks, the peak standard container proportion was 0.9, but when the shutdown occurred every three to four weeks, the peak standard container proportion was 0.8. In this way we found that the more shutdowns occur, the more influential the foldable container is.

Managerial Insights

We found through experiments that the number of the most efficient foldable containers differed across different cases. Although foldable containers can reduce costs in various situations when used effectively, their high purchase and maintenance costs pose limitations that may hinder the commercialization of foldable containers.

To overcome these limitations, we suggest implementing a leasing system for foldable containers. By implementing a leasing system where available containers can act as buffers, it would be possible to resolve the container imbalance issue more effectively compared with when using standard containers. Each shipping company can develop a short-term foldable container lease strategy to leverage the benefits of using foldable containers in situations such as the COVID-19 pandemic. By accurately predicting various scenarios and determining the optimal lease quantity, shipping companies can pursue higher profitability.

Moreover, the manufacturing companies of foldable containers should install publicly accessible equipment and repair facilities at each port to promote the lease market for foldable containers. The leasing companies can effectively address the different demands from shipping companies by centralizing foldable containers and getting more significant benefits than they currently do through the leasing of standard containers.

On the government side, container imbalances impede logistics flow and can cause damage to the national economy. To address this issue, many countries have implemented policies to handle container imbalances. Because we have shown that foldable containers are effective in rectifying the disproportionate issue caused by uncertain situations, governments can encourage the supply of foldable containers through subsidies and other means.

Conclusions

In this paper, we observed that foldable containers have a significant impact on rapidly recovering supply chain imbalances in various circumstances. This is a result of foldable containers acting as buffers and solving situations of delayed transportation caused by ship capacity constraints. Foldable containers can be transported in a folded state, allowing for faster resolution of container imbalances. In particular, the use of foldable containers proved to be more effective when there was a disproportionate balance between exports and imports, which is a common occurrence in the real world. Thus, foldable containers offer great effectiveness in reality. Moreover, our experiments revealed that the optimal proportion of foldable containers varies depending on the situation. As a result, we propose a container lease system having considered managerial insights from the perspective of various institutions. However, our experiments have limitations carried out within the specified parameter range. Experiments were conducted based on actual values, but shipping logistics vary greatly because of their characteristics, so there will be a range of foldable containers with greater effectiveness and a range with no effect at all. However, we believe that the use of foldable containers is likely to be effective in addressing other types of imbalance as well. For future research, we, therefore, intend to study different logistics dynamics and imbalance situations. Furthermore, as our experiment was conducted based on a deterministic scenario, it would be valuable to develop a stochastic model for more robust and realistic research. We are also interested in a new cost model related to the lease of foldable containers. Cost analysis through the recently emerging subscription model will also be a meaningful topic.

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Author Contributions

The authors confirm contribution to the paper as follows: study conception and design: M.S. Kim, I.K. Moon; data collection: M.S. Kim; analysis and interpretation of results: M.S. Kim, B. Lu, I.K. Moon; draft manuscript preparation: M.S. Kim, B. Lu, I.K. Moon. All authors reviewed the results and approved the final version of the manuscript.

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Supplemental Material

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