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Direct shipping service routes with an empty container management strategy

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ABSTRACT

This paper presents an investigation of an empty container management strategy in a two-way four-echelon container supply chain for bilateral trade between two countries. The strategy reduces high maritime transportation costs and long delivery times due to transshipment. The impact of direct shipping was investigated to determine the number of empty containers to be repositioned among selected ports, number of leased containers, and route selection to satisfy the demands for empty and laden containers for exporters and importers in two regions. A hybrid solution procedure based on accelerated particle swarm optimization and heuristic is presented, and corresponding results are compared.

1. Introduction

Containerization has substantially contributed to a steady increase in global maritime trade volume because it promotes excellence in the safety and efficiency for shipments. The introduction of modern containers into freight transportation brought great advantages to the maritime supply chain, such as transmodality, that triggered drastic increases in container use. In 2015, the UNCTAD reported that seaborne trade volume reached more than 10 billion tons, and developing countries accounted for 60% and 62% of exports and imports, respectively. These statistics show the potential of a continuous increase for trade volume led by developing countries. However, the imbalance in intra-continental trade volumes has expanded from year to year. For example, Asia and North America are well-known for export- and import-dominated nations that experience a surplus and shortage of empty containers in ports and depots. Repositioning empty containers has become one of the most efficient approaches to solve this issue of imbalance.

To deal with increasing demand for seaborne trade between inter- and intra-continental routes, global shipping companies have established fixed routes and operate their vessels on a regular basis. Despite providing shipping services covering most of the major seaborne routes, direct shipment for bilateral trade is in high demand, especially for developing countries. Such evidences are found in newly established bilateral trade routes between developing countries themselves. Business Line announced that the central government of India had initiated the first direct container shipping services with Myanmar, Qatar, and Bangladesh in 2014, 2015, and 2016, respectively. These bilateral trade routes help India meet the demand of growing trade volume, substantially reduce transit times and costs, and provide better quality of services in terms of reliability. China has also started the first direct service to Myanmar

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to supply fresh agricultural products at low transportation costs. Without direct shipment agreements, when sufficient demands arise in specific regions, existing shipping services cannot guarantee affordable transportation or quick delivery. For example, because of emerging demand, new seaborne routes between India-Thailand and Dubai-UAE are now serviced weekly by global shipping companies such that a new port rotation was established according to the large demand serviced by nearby ports. In this case, the distances of the routes do not play a key role in determining whether direct shipment is recommended or not.

Because demand is a key factor used to determine the establishment of direct shipments for bilateral trade, statistics derived from the UNCTAD showed that there is a huge potential for establishing more direct shipments in future. For example, no direct service exists between Brazil and India because the trade volume for this route is relatively small compared to other routes. Rather, merchants in Brazil and India ship their containerized cargos through South Africa because each route to and from Brazil and India is directly connected to South Africa. As a consequence, in 2007, the IMF reported that international transportation costs from India to Brazil and from Brazil to India account for 34.36% and 25.81% of respective imports. However, of all the transport costs for the goods transported between India and Brazil, 9.09% are spent for shipments through South Africa. This example indicates the potential savings through direct routes when sufficiently large demands exist.

Existing literature on important topics that can be helpful in establishing direct shipment for bilateral trade include those on service route selection, ship deployment, and empty container repositioning (ECR) used to design a maritime supply chain network. ECR may be considered as part of the pricing strategy for shipping such that the flow of empty containers can be intentionally reduced by lowering the degree of demand imbalance through appropriate pricing. ECR can also be mitigated by horizontal cooperation, such as by slot or container exchange, and vertical cooperation, such as through improved visibility of container flows in the maritime supply chain. Problems of service network designs and routes may include ECR as a sub-problem because both laden and empty containers are moved over the same shipping network. Braekers et al. (2011) presented a detailed description of ECR models for strategic, tactical, and operational planning levels. Similar recent work was published by Khakbaz and Bhattacharjya (2014), who reviewed the ECR literature published between 1994 and 2013 in the fields of engineering, management, transport, and logistics. Song and Dong (2015) studied ECR problems from the supply chain perspective as well as from the modeling technique viewpoint. Usage of heuristic and meta-heuristic algorithms in the solution procedure of ECR problems is used by several studies. Dong and Song (2009) explored the effectiveness of genetic algorithms in a simulation-based optimization approach for an ECR problem of liner shipping systems. The potency of problems with specific heuristic rule-based approaches was studied by Song and Dong (2012). Long et al. (2012) used the sample average approximation method and heuristics based on a progressive hedging strategy to decrease the operational costs in an ECR problem.

In addition to examining ECR, several researchers have studied the performance of an overall maritime supply chain. Shintani et al. (2007) constructed a design problem for a container liner shipping network that addresses repositioning and leasing of empty containers. They used a genetic algorithm (GA) for implementing a solution method for the problem. Moon et al. (2010) studied the ECR problem by considering the simultaneous effects of leasing and purchasing. They also used a GA to reduce computation times and obtain near-optimal solutions. Meng and Wang (2011) demonstrated the potential cost savings by incorporating ECR considerations into the design process of a liner shipping service network operating in the medium term. They used the CPLEX to find the optimal solutions for medium-sized problem. Maraš et al. (2013) investigated the efficiency of MIP heuristics with the commercial MIP-solver, CPLEX, for the task of optimizing transport routes for barge container ships to maximize profits. Moon et al. (2013) used an ECR problem to find the impact of the repositioning costs of foldable containers on the use of standard containers. They proposed two heuristics to find the optimal allocation and compared the results with the LINGO. Li et al. (2014) dealt with empty container reuse problem for green supply chain management in the maritime industry. They claimed that empty container reuse strategy requires supply chain collaboration, which adds economic value to a shipping supply chain for overall profit maximization. Zheng et al. (2015) studied the empty container allocation problem by considering the coordination among shipping liners and proposed a two-stage optimization method to find the optimal allocation. Although, the authors neglected the capacity constraints. Sun et al. (2015) proposed an integrated model for multiple factories and a distribution center with a due-date-based cut-off rule (DBC). In their model, the production processing time was considered in accordance with different types of transportation mode such as inland and maritime. The DBC was used to achieve computational efficiency for their exact algorithm used to solve large instances. By presenting a two-stage optimization method, Zheng et al. (2016) formulated an ECR problem to determine the perceived container leasing prices for different container types, such as standard and foldable, at different ports. Schepler et al. (2017) used restrict-and-fixed heuristics to minimize weighted turnaround times in a multi-terminal and multi-modal maritime port.

Theofanis and Boile (2009) examined and analyzed empty container logistics at the global, inter-regional, regional, and local levels. They discussed key factors affecting empty container logistics management and the strategies implemented by ocean carriers and other stakeholders to manage a container fleet better. Caris et al. (2011) presented an analysis and a comparison of alternative types of container-bundling networks in the ports in the Antwerp area. They developed a discrete event simulation model that is used to examine the effects of the alternative ways to organize container barge transport. Lin and Tsai (2014) studied the ship routing and freight assignment problem under daily frequency operation for a shipping liner and claimed that the liner service quality and reliability can be improved with the model they proposed. In daily frequency operation, a liner dispatches their largest ships to pick up and deliver goods at mega hubs where demands are highest; meanwhile they send feeder ships to handle the demands at smaller ports. It was determined that ship size is one of the essential components for designing an efficient shipping-service network (Ng, 2017; Monemi and Gelareh, 2017; Wang and Meng, 2017). Recently, Lin and Chang (2018) applied a more general model for ship routing and freight assignment to a real world case, called the *Northern Sea Route*, which attracted much attention for ice-free ports. In a similar study, Santini et al. (2018) used a pick-up and delivery method in a container-liner shipping feeder network. In addition, the models of Kelle et al. (2007) and Kheljani et al. (2009) of total supply chain costs for which both the retailer and supplier are taken into account simultaneously. We adopted these ideas about simultaneous cost savings from direct shipments and applied them to the hinterland of a port environment because liners, importers, and exporters tend to minimize costs in these areas.

According to most of the literature, demands for containers by importers and exporters were assumed to be aggregated at ports during transport. However, this assumption is unrealistic and especially impractical when planning previously nonexistent bilateral trade routes between countries. Therefore, for this study, we aimed to optimize the direct shipping line networks for a two-way four-echelon container supply chain by incorporating the demands of importers and exporters in two different regions for bilateral trade. We assumed that the demands were sufficient in both regions to make direct shipment a feasible option. We considered individual demand of exporters and importers in both domestic and overseas regions for the optimal selection of number of ports to be used for container transportation. Hence, management of container operations can be more practical for newly realized direct shipments. Because it can reduce the imbalance in empty container inventories and prompt green and cost-efficient ECR, container reuse was introduced to minimize the overall system costs. We also incorporated ship sizing problems for optimal utilization.

Because CPLEX could not provide solutions within reasonable computation times, we designed a solution procedure combining a heuristic with an accelerated particle swarm optimization (APSO) for route selection and determined the number of empty containers to be repositioned from one port to another. The proposed methodology can be used to handle the problem with more participants at each echelon within reasonable computation times. The advantages of the proposed TFESC are as follows: (i) the decision maker finds optimal routes among the ports in two regions, along with the hinterlands in domestic and overseas regions to satisfy individual needs of exporters and importers; (ii) allows empty container transportation among ports, which leads to a sustainable port operation; (iii) informs the best ship size to use for minimizing operational cost; and (iv) minimizes the number of leased containers by utilizing available empty containers in the system.

The structure of this paper is as follows: The mathematical model of an empty container management strategy in a two-way four-echelon container supply chain (TFESC) and the problem statement related to it are presented in Section 2. In Section 3, the APSO and heuristics are introduced as a means to handle the significant complexity of the model. In Section 4, the performances of the heuristics and sensitivity analyses are shown to provide managerial insights. Finally, we draw conclusions in Section 5.

2. Mathematical model

As the demand for Korean commodities through direct cross-border e-commerce transactions with China substantially increased, China initiated a shipping service for direct purchases in 2015. Specifically, China opened a seaborne route between Qingdao and Inchon because they are in close geographic proximity to each other. This service resulted in a 30% lower purchase costs for customers, who had previously relied primarily on air transportation for e-commerce transactions. Motivated by this exercise, we developed an optimization model for the TFESC considering an ECR problem and container reuse strategies, selection of a seaborne route along with routes in domestic and overseas hinterlands, and type of vessel to be used. These factors were chosen to determine an efficient direct shipment in terms of operation costs.

According to Song and Dong (2012), empty containers can be presumably repositioned along with laden containers. To provide full service, the transportation company is usually accountable for providing the required number of empty containers, either owned or leased, to exporters. By repositioning and reusing empty containers at domestic and overseas ports, a shipping company can reduce the cost and port congestion because of the empty container inventory levels. Fig. 1 shows the simplified operations associated with

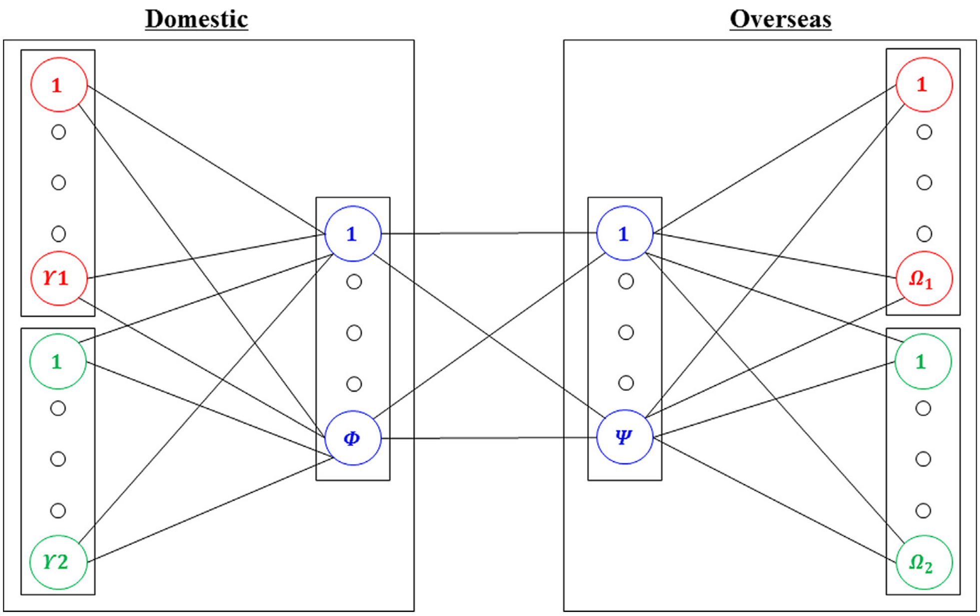

Fig. 1. Example of TFESC network.

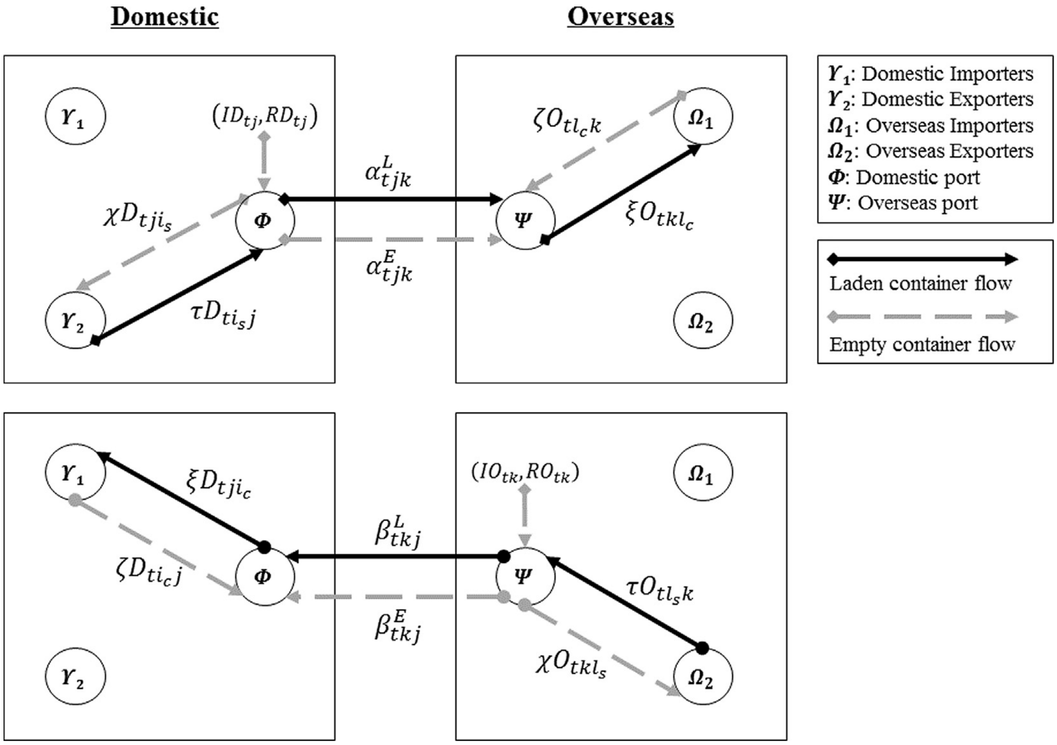

Fig. 2. Basic operation of TFESC from Domestic to Overseas and vice versa.

laden and empty containers between echelons and indicates four echelons: domestic importers and exporters, domestic ports, overseas ports, and overseas importers and exporters (Khalifehzadeh et al. 2015; Rafiei et al. 2018). A shipping company is obligated to operate container flows among the echelons. According to Talley and Ng (2018), determinants of the hinterland transport chain choice could be grouped by the objective of the echelon.

Fig. 2 shows the way the entire operation functions in a two-way four-echelon container supply chain; that is, demands in domestic and overseas regions are satisfied in the same period simultaneously. In the beginning, the company must decide whether to reuse empty containers stocked in a port or lease them from a third party. An exporter in one region receives and fills them with ordered items to transport laden containers to an importer in another region. All empty containers are stored after use at the port of origin to satisfy demands for the next period through use of empty container management strategies.

The detailed assumptions for the problem are described as follows:

(i) Laden container flow from domestic exporters (overseas exporters) to overseas importers (domestic importers) is considered a single period of operation. The demand of each importer must be satisfied, meaning that no shortage is allowed. In practice, Maersk Line operates pairwise service routes such as those that are westbound and eastbound. For example, AE6 routes, from Asia to Europe and vice versa, slightly differ from each other in that they do not call on a port in the same sequence in both directions. However, in our model, we assumed that, despite the route variations, the departure times start simultaneously.

(ii) Importers, exporters, and shipping companies constitute a container supply chain alliance. Containers can be freely transported among alliance members. All routes in the entire network between consecutive echelons are shown in Fig. 1; no other routes are allowed. Similar to the assumption in Li et al. (2015), ECR was permitted among collaborative partners. For connection between ports within the same region, some studies did not consider ECR at a regional level (Boile et al., 2008; Mittal et al., 2013). Therefore, isolation between ports at a regional level for laden and empty containers can be justified to seek reduction in computational complexity.

(iii) The storage capacity of each port is not considered. The total demands of all importers allied with the single company are generally not more than the storage capacity, and the minimization of empty-container holding costs is one of optimized objectives. Therefore, the obtained solutions can ensure that the total overstock of a port is minimized.

(iv) The company can lease empty containers and distribute them among exporters. After delivery, every importer returns empty containers to ports within the same period. (Song and Dong, 2012)

(v) If there are surplus empty containers after fulfilling a consignment, the company decides whether to reposition them to deficit ports elsewhere. By considering the vessel selection between domestic and overseas ports, the number of empty containers to be repositioned is determined. However, ECR, without an associated delivery, is not allowed. (Dong and Song, 2009; Song and Dong, 2012)

(vi) Vessel capacity is expressed in twenty-foot equivalent units (TEU) and distinguished into different categories according to the number of containers the vessel can carry. The shipping company needs to determine the type of a vessel to be deployed for optimal utilization (Hsu and Hsieh, 2007; Wang et al., 2017).
(vii) Containers are leased long-term and this term does not expire during the planning horizon (Choong et al., 2002; Moon and Hong, 2016).

The notation used for developing the TFESC model is presented. We created the sets for each echelon located in the both domestic and overseas regions. Cost parameters, including maritime and hinterland transportation, leasing, and storage for empty containers, were randomly generated, but the unit transportation cost for any vessel did not exceed any in hinterland transportation because of the economies of scale. To find optimal routes for shipment and consignment, arc variables connecting consecutive echelons were necessary for the TFESC in this study.

Sets

Υ_1	Domestic importers (index: i_c), $\lvert\Upsilon_1\rvert = DI$
Υ_2	Domestic exporters (index: i_s), $\lvert\Upsilon_2\rvert = DE$
Ω_1	Overseas importers (index: l_c), $\lvert\Omega_1\rvert = OI$
Ω_2	Overseas exporters (index: l_s), $\lvert\Omega_2\rvert = OE$
Φ	Domestic ports (index: j), $\lvert\Phi\rvert = DP$
Ψ	Overseas ports (index: k), $\lvert\Psi\rvert = OP$
Σ	Container vessels (index: m), $\lvert\Sigma\rvert = V$
Γ	Periods (index: t), $\lvert\Gamma\rvert = T$

Parameters

$DD_{ti_sl_c}$	Number of laden containers to be transported from domestic exporter i_s to overseas importer l_c in period t
$DO_{tl_si_c}$	Number of laden containers to be transported from overseas exporter l_s to domestic importer i_c in period t
cap_m	Capacity of vessel type m in TEU
tc^L_{jk}	Unit transportation cost for a laden container from domestic port j (or overseas port k) to overseas port k (or domestic port j)
tc^E_{jk}	Unit transportation cost for an empty container from domestic port j (or overseas port k) to overseas port k (or domestic port j)
h^D_j	Unit inventory holding cost for a container at domestic port j
h^O_k	Unit inventory holding cost for a container at overseas port k
bd_j	Unit leasing cost for a container at domestic port j
bo_k	Unit leasing cost for a container at overseas port k
SC_m	Fixed cost for using vessel type m
INV^D_{1j}	Initial inventory of empty containers at domestic port j
INV^O_{1k}	Initial inventory of empty containers at overseas port k
$tc^D_{i_sj}$	Unit transportation cost for a container from exporter i_s (or port j) to port j (or exporter i_s) in domestic region
$tc^O_{l_sk}$	Unit transportation cost for a container from exporter l_s (or port k) to port k (or exporter l_s) in overseas region
$tc^D_{i_cj}$	Unit transportation cost for a container from importer i_c(or port j) to port j (or importer i_c) in domestic region
$tc^O_{l_ck}$	Unit transportation cost for a container from importer l_c(or port k) to port k (or importer l_c) in overseas region

Decision variables

ID_{tj}	Number of empty containers in period t at domestic port j after the ship has sailed
IO_{tk}	Number of empty containers in period t at overseas port k after the ship has sailed
α^L_{tjk}	Number of laden containers to be transported from domestic port j to overseas port k in period t
α^E_{tjk}	Number of empty containers to be transported from domestic port j to overseas port k in period t
β^L_{tkj}	Number of laden containers to be transported from overseas port k to domestic port j in period t
β^E_{tkj}	Number of empty containers to be transported from overseas port k to domestic port j in period t
RD_{tj}	Number of empty containers to be leased at domestic port j in period t
RO_{tk}	Number of empty containers to be leased at overseas port k in period t
ζD_{ti_cj}	Number of empty containers moved from domestic importer i_c to domestic port j in period t
ζO_{tl_ck}	Number of empty containers moved from overseas importer l_c to overseas port k in period t
χD_{tji_s}	Number of empty containers moved from domestic port j to domestic exporter i_s in period t
χO_{tkl_s}	Number of empty containers moved from overseas port k to overseas exporter l_s in period t
ξD_{tji_c}	Number of laden containers moved from domestic port j to domestic importer i_c in period t

ξO_{tkl_c}	Number of laden containers moved from overseas port k to overseas importer l_c in period t
τD_{ti_sj}	Number of laden containers moved from domestic exporter i_s to domestic port j in period t
τO_{tl_sk}	Number of laden containers moved from overseas exporter l_s to overseas port k in period t
$\vartheta_{ti_sl_cjk}$	$\vartheta_{ti_sl_cjk} = 1$, if domestic port j and overseas port k are selected for shipment by domestic exporter i_s to overseas importer l_c in period t; $\vartheta_{ti_sl_cjk} = 0$, otherwise
$\mu_{tl_si_ckj}$	$\mu_{tl_si_ckj} = 1$, if overseas port k and domestic port j are selected for shipment by overseas exporter l_s to domestic importer i_c in period t; $\mu_{tl_si_ckj} = 0$, otherwise
λ_{tjkm}	$\lambda_{tjkm} = 1$, if vessel type m is used for transportation from domestic port j to overseas port k in period t; $\lambda_{tjkm} = 0$, otherwise
υ_{tkjm}	$\upsilon_{tkjm} = 1$, if vessel type m is used for transportation from overseas port k to domestic port j in period t; $\upsilon_{tkjm} = 0$, otherwise

In the TFESC, the total relevant costs were composed of leasing, repositioning, storage for empty containers at ports, vessel selection, maritime, and hinterland transportation in domestic and overseas regions to be minimized.

$$\begin{aligned}\text{Minimize}\,TC = &\sum_{t\in T}\sum_{j\in DP}\sum_{k\in OP} tc^L_{jk}(\alpha^L_{tjk}+\beta^L_{tkj}) + tc^E_{jk}(\alpha^E_{tjk}+\beta^E_{tkj}) + \sum_{t\in T}\sum_{j\in DP} bd_j RD_{tj} + \sum_{t\in T}\sum_{k\in OP} bo_k RO_{tk}\\ &+\sum_{t\in T}\sum_{j\in DP} h^D_j ID_{tj} + \sum_{t\in T}\sum_{k\in OP} h^O_k IO_{tk} + \sum_{t\in T}\sum_{j\in DP}\sum_{k\in OP}\sum_{m\in V} SC_m(\lambda_{tjkm}+\upsilon_{tkjm})\\ &+\sum_{t\in T}\sum_{j\in DP}\sum_{i_s\in DE} tc^D_{i_sj}(\tau D_{ti_sj}+\chi D_{tji_s}) + \sum_{t\in T}\sum_{j\in DP}\sum_{i_c\in DI} tc^D_{i_cj}(\zeta D_{ti_cj}+\xi D_{tji_c})\\ &+\sum_{t\in T}\sum_{k\in OP}\sum_{l_s\in OE} tc^O_{l_sk}(\tau O_{tl_sk}+\chi O_{tkl_s}) + \sum_{t\in T}\sum_{k\in OP}\sum_{l_c\in OI} tc^O_{l_ck}(\zeta O_{tl_ck}+\xi O_{tkl_c})\end{aligned}$$

subject to

$$ID_{1j} = INV^D_{1j} - \sum_{k\in OP}\alpha^L_{tjk} - \sum_{k\in OP}\alpha^E_{tjk} + RD_{tj}, \quad \forall\, j\in DP \tag{1}$$

$$ID_{tj} = ID_{t-1,j} + \sum_{k\in OP}\beta^L_{t-1,kj} + \sum_{k\in OP}\beta^E_{t-1,kj} - \sum_{k\in OP}\alpha^L_{tjk} - \sum_{k\in OP}\alpha^E_{tjk} + RD_{tj}, \quad \forall\, t=2,\cdots,T,\, j\in DP \tag{2}$$

$$IO_{1k} = INV^O_{1k} - \sum_{j\in DP}\beta^L_{tkj} - \sum_{j\in DP}\beta^E_{tkj} + RO_{tk}, \quad \forall\, k\in OP \tag{3}$$

$$IO_{tk} = IO_{t-1,k} + \sum_{j\in DP}\alpha^L_{t-1,jk} + \sum_{j\in DP}\alpha^E_{t-1,jk} - \sum_{j\in DP}\beta^L_{tkj} - \sum_{j\in DP}\beta^E_{tkj} + RO_{tk}, \quad \forall\, t=2,\cdots,T,\, k\in OP \tag{4}$$

$$\alpha^L_{tjk} + \alpha^E_{tjk} \le \sum_{m\in V} cap_m\cdot\lambda_{tjkm}, \quad \forall\, t\in T, j\in DP, k\in OP \tag{5}$$

$$\sum_{m\in V}\lambda_{tjkm} \le \alpha^L_{tjk} + \alpha^E_{tjk}, \quad \forall\, t\in T, j\in DP, k\in OP \tag{6}$$

$$\beta^L_{tkj} + \beta^E_{tkj} \le \sum_{m\in V} cap_m\cdot\upsilon_{tkjm}, \quad \forall\, t\in T, j\in DP, k\in OP \tag{7}$$

$$\sum_{m\in V}\upsilon_{tkjm} \le \beta^L_{tkj} + \beta^E_{tkj}, \quad \forall\, t\in T, j\in DP, k\in OP \tag{8}$$

$$\sum_{m\in V}\lambda_{tjkm} \le 1, \quad \forall\, t\in T, j\in DP, k\in OP \tag{9}$$

$$\sum_{m\in V}\upsilon_{tkjm} \le 1, \quad \forall\, t\in T, j\in DP, k\in OP \tag{10}$$

$$\alpha^L_{tjk} = \sum_{i_s\in DE}\sum_{l_c\in OI} DD_{ti_sl_c}\vartheta_{ti_sl_cjk}, \quad \forall\, t\in T, j\in DP, k\in OP \tag{11}$$

$$\alpha^E_{tjk} \le M\sum_{i_s\in DE}\sum_{l_c\in OI}\vartheta_{ti_sl_cjk}, \quad \forall\, t\in T, j\in DP, k\in OP \tag{12}$$

$$\beta^L_{tkj} = \sum_{l_s\in OE}\sum_{i_c\in DI} DO_{tl_si_c}\mu_{tl_si_ckj}, \quad \forall\, t\in T, j\in DP, k\in OP \tag{13}$$

$$\beta^E_{tkj} \le M\sum_{l_s\in OE}\sum_{i_c\in DI}\mu_{tl_si_ckj}, \quad \forall\, t\in T, j\in DP, k\in OP \tag{14}$$

$$\tau D_{ti_sj} = \sum_{l_c\in OI}\sum_{k\in OP} DD_{ti_sl_c}\vartheta_{ti_sl_cjk}, \quad \forall\, t\in T,\, i_s\in DE, j\in DP \tag{15}$$

$$\sum_{j\in DP}\sum_{k\in OP}\vartheta_{ti_sl_cjk} = \begin{cases}1 & if \quad DD_{ti_sl_c} > 0\\ 0 & if \quad DD_{ti_sl_c} = 0\end{cases}, \quad \forall\, t\in T,\, i_s\in DE,\, l_c\in OI \tag{16}$$

$$\tau O_{tl_sk} = \sum_{i_c\in DI}\sum_{j\in DP} DO_{tl_si_c}\mu_{tl_si_ckj}, \quad \forall\, t\in T,\, l_s\in OE, k\in OP \tag{17}$$

$$\sum_{k \in OP} \sum_{j \in DP} \mu_{tl_s i_c kj} = \begin{cases} 1 & if \quad DO_{tl_s i_c} > 0 \\ 0 & if \quad DO_{tl_s i_c} = 0 \end{cases}, \quad \forall\ t \in T,\ l_s \in OE,\ i_c \in DI \tag{18}$$

$$\xi D_{tji_c} = \sum_{l_s \in OE} \sum_{k \in OP} DO_{tl_s i_c} \mu_{tl_s i_c kj}, \quad \forall\ t \in T,\ i_c \in DI,\ j \in DP \tag{19}$$

$$\zeta D_{ti_c j} = \xi D_{tji_c}, \quad \forall\ t \in T,\ i_c \in DI,\ j \in DP \tag{20}$$

$$\chi D_{tji_s} = \tau D_{ti_s j}, \quad \forall\ t \in T,\ i_s \in DE,\ j \in DP \tag{21}$$

$$\xi O_{tkl_c} = \sum_{i_s \in DE} \sum_{j \in DP} DD_{ti_s l_c} \vartheta_{ti_s l_c jk}, \quad \forall\ t \in T,\ l_c \in OI,\ k \in OP \tag{22}$$

$$\zeta O_{tl_c k} = \xi O_{tkl_c}, \quad \forall\ t \in T,\ l_c \in OI,\ k \in OP \tag{23}$$

$$\chi O_{tkl_s} = \tau O_{tl_s k}, \quad \forall\ t \in T,\ l_s \in OE,\ k \in OP \tag{24}$$

$$\alpha^L_{tjk},\ \alpha^E_{tjk},\ \beta^L_{tkj},\ \beta^E_{tkj},\ RD_{tj},\ RO_{tk},\ ID_{tj},\ IO_{tk},\ \zeta D_{ti_c j},\ \zeta O_{tl_c k},\ \chi D_{tji_s},\ \chi O_{tkl_s},\ \xi D_{tji_c},\ \xi O_{tkl_c},\ \tau D_{ti_s j},\ \tau O_{tl_s k} \geq 0, \quad \forall\ i_c,\ i_s,\ l_c,\ l_s,\ j,\ k,\ t \tag{25}$$

$$\vartheta_{ti_s l_c jk},\ \mu_{tl_s i_c kj},\ \lambda_{tjkm},\ \upsilon_{tkjm} \in \{0,\ 1\}, \quad \forall\ i_c,\ i_s,\ l_c,\ l_s,\ j,\ k,\ t \tag{26}$$

Constraints (1) and (2) represent the number of empty containers stored at domestic port j. This inventory in period t depends on the inventory level in the previous period $(t-1)$, numbers of laden and repositioned containers shipped from overseas ports in the previous period, numbers of laden and repositioned containers transported from domestic ports in period t, and number of leased containers in period t. Constraint (1) triggers leasing containers in the beginning of planning horizon if demands exceed the initial inventory level at port j. Similarly, Constraints (3) and (4) represent the balance equation for the empty container inventory at overseas port k. Constraint (5) ensures that the total numbers of laden and empty containers transported from domestic port j to overseas port k cannot exceed the capacity of the selected vessel type. Constraint (6) allows the selection of a vessel if container movement is possible. Constraint (7) also guarantees that the total numbers of laden and empty containers from overseas port k to domestic port j cannot exceed the capacity of the selected vessel type. Constraint (8) has the same meaning for overseas regions as Constraint (6) does for domestic regions. Constraints (9) and (10) allow only one vessel to be operated from each port for both regions. Constraints (11) and (13) ensure the number of laden containers to be transported from domestic port j (overseas port k) to overseas port k (domestic port j) to satisfy the demands of domestic and overseas exporters i_s and l_s. Constraints (12) and (14) permit the movement of empty containers if laden containers are moved through selected routes. Constraints (15) and (17) also allow the movement from domestic exporter i_s (overseas exporter l_s) to domestic port j (overseas port k) to satisfy the demands of the importers of the other regions. Specific routes where four different echelons are located can be selected by Constraints (16) and (18) to satisfy demand for shipments from exporters to importers. Constraints (19)–(24) show the balances of arcs in the network for both regions. Constraints (25) and (26) are non-negativity and binary decisions. The total numbers of binary and continuous decision variables in the system can be found by using the following algebraic expressions, $OP \times \mathrm{DP} \times \mathrm{T} \times (DE \times OI + OE \times DI) + 2 \times DP \times OP \times T \times V$ and $2 \times DP \times T + 2 \times OP \times T + 4 \times DP \times OP \times T + 2 \times DP \times DI \times T + 2 \times OP \times OI \times T + 2 \times DP \times DE \times T$, respectively.

$+ 2 \times OP \times OE \times T$

3. Solution procedure for the TFESC

Various types of heuristics are widely employed in many fields, including vehicle routing and maritime logistics, because of the high computational complexity of the models (Chen et al., 2016; De et al., 2016). According to the known literature, a four echelon network for direct shipment has not been extensively studied to date. Thus, a comparative study for other heuristics was not involved in the scope of this study, but the performance of our heuristics was subject to tests, as discussed in Section 4.

3.1. Proposed problem transformed into a pseudo-function-based optimization problem

The encoding scheme is considered one of the critical factors for successful implementation of any continuous meta-heuristic algorithm for optimization problems involving a large number of binary or integer variables. In fact, the encoding scheme paves the way for redefining decision variables that enhance the effectiveness of meta-heuristic algorithms. Researchers have successfully employed several techniques, such as priority-based encoding (Lotfi and Tavakkoli-Moghaddam, 2013), generic encoding with rounding off, and random-key (Hottung and Tierney, 2016) techniques for many optimization problems.

In the proposed four-stage container shipment, repositioning, and leasing problems with multiple periods, two 5-dimensional binary variables were exclusively responsible for the entire route selection. For maintaining the integrity of the original problem, the following notations were used for encoding the original problem to implement the APSO and heuristics:

φ_{tj}^{D}	Likelihood of selecting domestic port j for shipping containers from domestic to overseas regions in period t
φ_{tk}^{O}	Likelihood of selecting overseas port k for shipping containers from domestic to overseas regions in period t
ϕ_{tj}^{D}	Likelihood of selecting domestic port j for shipping containers from overseas to domestic regions in period t
ϕ_{tk}^{O}	Likelihood of selecting overseas port k for shipping containers from overseas to domestic regions in period t

We initialized these four variables with random numbers generated uniformly in (0, *R*) where *R* is any non-negative real number. Four additional dummy variables corresponded to those variables to store their values temporarily for performing further computations. The main objective was to implement the concept of inverse transform sampling to the set values of $\vartheta_{tis l_c jk}$ and $\mu_{tl_s i_c kj}$ (Devroye, 1986). Thus, we normalized the dummy variables so their sums would be unity to characterize the probability mass functions by using these variables. For example, $\varphi_{tj}^{D\_temp}$ corresponding to φ_{tj}^{D} represents the likelihood that domestic port *j* is selected in period *t* from all domestic ports conducting overseas transportation and that $\sum_{j=1}^{DP}\varphi_{tj}^{D\_temp}=1$ for all *t*. Thereafter, each dummy variable was converted to describe the cumulative distribution function for the application of inverse transform sampling. A detailed explanation for a particular period is as follows:

If $DP = 4$, then φ_{tj}^{D} can be represented as

0.2	0.6	0.5	0.3

Therefore, we store the values of φ_{tj}^{D} in the dummy variable $\varphi_{tj}^{D\_temp}$ after normalization, such that

0.125	0.375	0.312	0.188

Finally, the $\varphi_{tj}^{D\_temp}$ is obtained as follows:

0.125	0.500	0.812	1.000

This normalization process is similar to that of a cumulative distribution function. In this case, random numbers *u* and *v* are drawn from *U*(0, 1) to obtain

$$\vartheta_{ti_s l_c jk}=\begin{cases}1 & \text{if} \quad \varphi_{t(j-1)}^{D\_temp}<u\le\varphi_{tj}^{D\_temp}\wedge\varphi_{t(k-1)}^{O\_temp}<v\le\varphi_{tk}^{O\_temp}\wedge DD_{ti_s l_c}>0\\ 0 & \qquad\qquad\qquad \text{otherwise}\end{cases}$$

Similarly, we also converted the variable representing the route selection from the overseas to domestic regions as follows:

$$\mu_{tl_s i_c kj}=\begin{cases}1 & \text{if} \quad \phi_{t(j-1)}^{D\_temp}<u\le\phi_{tj}^{D\_temp}\wedge\phi_{t(k-1)}^{O\_temp}<v\le\phi_{tk}^{O\_temp}\wedge DO_{tl_s i_c}>0\\ 0 & \qquad\qquad\qquad \text{otherwise}\end{cases}$$

3.2. Objective function evaluation

After obtaining the values of $\vartheta_{ti_s l_c jk}$ and $\mu_{tl_s i_c kj}$, solutions for the decision variables $\tau D_{ti_s j}$, $\tau O_{tl_s k}$, $\zeta D_{ti_c j}$, $\zeta O_{tl_c k}$, χD_{tji_s}, χO_{tkl_s}, ξD_{tji_c}, ξO_{tkl_c}, α_{tjk}^{L} and β_{tjk}^{L} were generated by using Eqs. (11), (13), (15), (17), (19), and (20)–(24). These solutions accounted for the number of containers to be transported between each echelon. These variables were unaffected by the number of empty containers repositioned. The other four dummy variables were also employed as follows: L_{tj}^{D}, L_{tk}^{O}, E_{tj}^{D}, and E_{tk}^{O}. L_{tj}^{D} and L_{tk}^{O} were used to count the number of laden containers received at a port at the end of a period; E_{tj}^{D}, and E_{tk}^{O} were used to count the number of empty containers required at a port in a period to satisfy the demands of exporters in domestic and overseas regions. These four variables were used in the ECR heuristics and inventory calculations. The variables are defined as follows:

$$E_{tj}^{D}=\sum_{k=0}^{OP}\alpha_{tjk}^{L},\ L_{tk}^{O}=\sum_{j=0}^{DP}\alpha_{tjk}^{L},\ E_{tk}^{O}=\sum_{j=0}^{DP}\beta_{tkj}^{L},\ L_{tj}^{D}=\sum_{k=0}^{OP}\beta_{tkj}^{L}$$

S_{tj}^{D} and S_{tk}^{O} represent the available number of empty containers from domestic regions to be repositioned in overseas regions, and vice versa, during a period without introducing shortage in the next period, while B_{tj}^{D} and B_{tk}^{O} represent the number of leased containers when ECR does not take place. The variables I_{tj}^{D} and I_{tk}^{O} were used to store temporarily the number of empty containers stored in a port. Thus, the value of S_{tj}^{D} is obtained as follows (the procedure for S_{tk}^{O} is omitted because it is analogous to that for S_{tj}^{D}):

$$S_{tj}^{D}=\begin{cases}L_{tj}^{D}+I_{tj}^{D}-E_{(t+1),j}^{D},\ \forall j\wedge t\le T-1 & \text{iff}\quad I_{tj}^{D}>0\wedge L_{tj}^{D}+I_{tj}^{D}>E_{(t+1),j}^{D}\wedge L_{tj}^{D}-E_{(t+1),j}^{D}\le 0\\ I_{tj}^{D},\ \forall j\wedge t\le T-1 & \text{iff}\quad I_{tj}^{D}>0\wedge L_{tj}^{D}+I_{tj}^{D}>E_{(t+1),j}^{D}\wedge L_{tj}^{D}-E_{(t+1),j}^{D}>0\end{cases}$$

$$\text{where}\quad I_{tj}^{D}=INV_{1j}-E_{tj}^{D},\ \forall j\wedge t=1\quad\text{and}\quad I_{tj}^{D}=I_{(t-1),j}^{D}+L_{(t-1),j}^{D}-E_{tj}^{D},\ \forall j\wedge t\ne 1$$

Leasing of empty containers is done when the following condition is met:

$$B_{tj}^{D} = -I_{tj}^{D}, \quad \forall\ t, j \quad iff \quad I_{tj}^{D} < 0$$

It is assumed that all the decision variables are initialized at 0 except for $\vartheta_{ti_s l_c jk}$ and $\mu_{tl_s i_c kj}$. Next, the following iterative algorithm was used to determine the number of empty containers to be moved from domestic ports for repositioning in overseas ports and vice versa.

ECR heuristics

For $t = 2$ to T:
  For j in {1,…,DP}:
    For k in {1,…,OP}:
      If $B_{tk}^{O} > 0$ **AND** $\alpha_{(t-1),jk}^{l} > 0$ **AND** $S_{(t-1),j}^{D} > 0$:
        If $B_{tk}^{O} > S_{(t-1),j}^{D}$:
          $\alpha_{(t-1),jk}^{E} = S_{(t-1),j}^{D}$
          $B_{tk}^{O} = B_{tk}^{O} - \alpha_{(t-1),jk}^{E}$
          $S_{(t-1),j}^{D} = 0$
        Else:
          $\alpha_{(t-1),jk}^{E} = B_{tk}^{O}$
          $S_{(t-1),j}^{D} = S_{(t-1),j}^{D} - B_{tk}^{O}$
          $B_{tk}^{O} = 0$
        End If
      $L_{(t-1),k}^{O} = L_{(t-1),k}^{O} + \alpha_{(t-1),jk}^{E}$
      $E_{(t-1),j}^{D} = E_{(t-1),j}^{D} + \alpha_{(t-1),jk}^{E}$
    End If
  End For
End For
For k in {1,…,OP}:
  For j in {1,…,DP}:
    If $B_{tj}^{D} > 0$ **AND** $\beta_{(t-1),kj}^{l} > 0$ **AND** $S_{(t-1),k}^{O} > 0$:
      If $B_{tj}^{D} > S_{(t-1),k}^{O}$:
        $\beta_{(t-1),kj}^{E} = S_{(t-1),k}^{O}$
        $B_{tj}^{D} = B_{tj}^{D} - \beta_{(t-1),kj}^{E}$
        $S_{(t-1),k}^{O} = 0$
        Else:
          $\beta_{(t-1),kj}^{E} = B_{tj}^{D}$
          $S_{(t-1),k}^{O} = S_{(t-1),k}^{O} - B_{tj}^{D}$
          $B_{tj}^{D} = 0$
        End If
        $L_{(t-1),j}^{D} = L_{(t-1),j}^{D} + \beta_{(t-1),kj}^{E}$
        $E_{(t-1),k}^{O} = E_{(t-1),k}^{O} + \beta_{(t-1),kj}^{E}$
      End If
    End For
  End For
End For

Using the above heuristics, the values of α_{tjk}^{E} and β_{tkj}^{E} were acquired. The values of ID_{tj} and RD_{tj} were calculated to satisfy balance equations (1)–(4) and non-negativity constraint (25). Therefore, λ_{tjkm} and υ_{tkjm} are now calculated as follows:

$$\lambda_{tjkm} = \begin{cases} 1 & \forall\ t, j, k, \quad iff \quad CAP_{(m-1)} < \beta_{tkj}^{L} + \beta_{tkj}^{E} \leq CAP_{(m)} \wedge \beta_{tkj}^{L} + \beta_{tkj}^{E} > 0 \\ 0 & Otherwise \end{cases}$$

$$v_{tkjm} = \begin{cases} 1 & \forall\ t, j, k, \quad iff \quad CAP_{(m-1)} < \alpha_{tjk}^{L} + \alpha_{tjk}^{E} \le CAP_{(m)} \wedge \alpha_{tjk}^{L} + \alpha_{tjk}^{E} > 0 \\ 0 & Otherwise \end{cases}$$

3.3. Heuristics for reducing the number of leased containers

The objective for using the heuristics described in this subsection was to improve the solutions of $\vartheta_{ti_sl_cjk}$ and $\mu_{tl_si_ckj}$, which were decoded from φ_{tj}^{D}, φ_{tk}^{O}, ϕ_{tj}^{D}, and ϕ_{tk}^{O}. Six dummy variables, $\varphi_{tj}^{D\_T}$, $\varphi_{tk}^{O\_T}$, $\phi_{tj}^{D\_T}$, $\phi_{tk}^{O\_T}$, $\vartheta_{ti_sl_cjk}^{T}$, and $\mu_{tl_si_ckj}^{T}$, were introduced to store the values of φ_{tj}^{D}, φ_{tk}^{O}, ϕ_{tj}^{D}, ϕ_{tk}^{O}, $\vartheta_{ti_sl_cjk}$ and $\mu_{tl_si_ckj}$ respectively. Additional variables, ID_{tj}^{T} and IO_{tk}^{T}, were used to represent the number of empty containers stored at a port at the end of a period. To improve the solution, we identified a port for which the values of ID_{tj}^{T} and IO_{tk}^{T} were maximum in period *t-1* and then overwrote the values of $\varphi_{tj}^{D\_T}$ and $\phi_{tk}^{O\_T}$ by *x,* which depends on the initial selection of *R*. In this process, the usage of existing containers in the system was maximized by increasing the selection probability of a particular port, which has the maximum number of empty containers after laden container shipments were delivered at the end of a period. We stored the value of temporary variables in the corresponding original variables only if the solution was improved.

ReduceLease(): Inputs: φ_{tj}^{D}, φ_{tk}^{O}, ϕ_{tj}^{D}, ϕ_{tk}^{O}, ID_{tj}, IO_{tk}, α_{tjk}^{L}, β_{tkj}^{L}, α_{tjk}^{E}, β_{tkj}^{E}, $\vartheta_{ti_sl_cjk}$ and $\mu_{tl_si_ckj}$
Create temporary variables $\varphi_{tj}^{D\_T}$, $\varphi_{tk}^{O\_T}$, $\phi_{tj}^{D\_T}$, $\phi_{tk}^{O\_T}$, ID_{tj}^{T}, IO_{tk}^{T}, $\vartheta_{ti_sl_cjk}^{T}$ and$\mu_{tl_si_ckj}^{T}$
Copy φ_{tj}^{D}, φ_{tk}^{O}, ϕ_{tj}^{D}, ϕ_{tk}^{O}, $\vartheta_{ti_sl_cjk}$ and $\mu_{tl_si_ckj}$ in $\varphi_{tj}^{D\_T}$, $\varphi_{tk}^{O\_T}$, $\phi_{tj}^{D\_T}$, $\phi_{tk}^{O\_T}$, $\vartheta_{ti_sl_cjk}^{T}$ and $\mu_{tl_si_ckj}^{T}$
$ID_{tj}^{T} = ID_{tj} + \sum_{k=0}^{OP} \beta_{tkj}^{E} + \sum_{k=0}^{OP} \beta_{tkj}^{L}$ for all t, j
$IO_{tk}^{T} = IO_{tk} + \sum_{j=0}^{DP} \alpha_{tjk}^{E} + \sum_{j=0}^{DP} \alpha_{jk}^{L}$ for all t, k
For t = T to 2:
  Get d_{max} where $ID_{(t-1),d_{max}}^{T} \ge ID_{(t-1),j}^{T}$ for all j in {1,…,DP}
  Get o_{max} where $IO_{(t-1),o_{max}}^{T} \ge IO_{(t-1),k}^{T}$ for all k in {1,…,OP}
    If$ID_{(t-1),d_{max}}^{T} > 0$:
      $\varphi_{t,d_{max}}^{D\_T} = x$
      $\phi_{(t-1),d_{max}}^{D\_T} = x$
    End If
    If$IO_{(t-1),o_{max}}^{T} > 0$
      $\phi_{t,o_{max}}^{O\_T} = x$
      $\varphi_{(t-1),o_{max}}^{O\_T} = x$
    End If
End For
  Decode $\varphi_{tj}^{D\_T}$, $\varphi_{tk}^{O\_T}$, $\phi_{tj}^{D\_T}$, and $\phi_{tk}^{O\_T}$ in $\vartheta_{ti_sl_cjk}^{T}$ and$\mu_{tl_si_ckj}^{T}$
  If $\vartheta_{ti_sl_cjk}^{T}$ and $\mu_{tl_si_ckj}^{T}$ are better solutions than $\vartheta_{ti_sl_cjk}$ and$\mu_{tl_si_ckj}$
    Copy $\vartheta_{ti_sl_cjk}^{T}$ and $\mu_{tl_si_ckj}^{T}$ in $\vartheta_{ti_sl_cjk}$ and$\mu_{tl_si_ckj}$
  End If
End Function

3.4. Accelerated particle swarm optimization

PSO was developed by Eberhart and Kennedy (1995) and has turned out to be one of the most widely used swarm intelligence-based algorithms because it is simple and flexible. The PSO algorithm starts with a randomly generated swarm with different positions. Position and velocity are iteratively updated according to the changes in the fitness function value. In a standard PSO, *individual best* and *global best* solutions both are used to increase diversity in the solutions. However, the diversity obtained by the standard velocity equation can be simulated by employing randomness. APSO (Yang et al., 2011) leverages this fact by discarding the contribution of the individual best from the velocity equation and employing a scaled random variable. For this study, we used the modified velocity equation of APSO because it involves many binary variables. We hybridized the APSO with two heuristics to increase the rate of convergence of the algorithm.

The following parameters were used for the APSO algorithm.

N	Total number of particles, $n = 1, 2\ldots,N$
I	Maximum number of iteration, $i = 1, 2\ldots,I$
p_g^i	Best solution before iteration i
p_n^i	Solution of particle k in iteration i
v_n^i	Velocity of particle n in iteration i
w	Inertia coefficient, $w\in (0,1)$
χ	Constriction $\chi \in (0,1)$

The velocity and position of particles in iteration i is updated as follows:

$$v_n^{i+1} = \left[v_n^i w + c_1 u(p_g^i - p_n^i) + c_2 \varepsilon\left(1-\frac{i}{I}\right)\right]\chi \tag{27}$$

$$p_n^{i+1} = p_n^i + v_n^{i+1} \tag{28}$$

where u and ε are random numbers drawn from a uniform distribution $U(0, 1)$ and Gaussian distribution $N(0, 1)$, respectively. Coefficients c_1 and c_2 dominate the direction and magnitude of the resultant velocity vector. In Eq. (27), w captures the induced effect of the velocity of a particle in previous iteration whereas c_1 and c_2 control the tendency of the particles to follow the leader (p_g^i) or to proceed towards a random direction. In addition, c_1 and c_2 represent the tendency of moving toward a random direction of particles that must be scaled down in the end. Therefore, $1-\frac{i}{I}$ is used to reduce the magnitude of the randomness. Furthermore, χ acts as a scaling factor for the resultant velocity vector. The detailed description of the pseudo-code of the APSO is as follows:

Function optimize ():
  For $n \in \{1,2\ldots,N\}$:
    Initialize v_n^1
    Initialize p_n^1, p_n^i contains φ_{tj}^D, φ_{tk}^O, ϕ_{tj}^D, and ϕ_{tk}^O
    Decode p_n^1 in r_n^1, r_n^i contains $\vartheta_{tl_sl_cjk}$ and $\mu_{tl_si_ckj}$
  End For
    $p_g^1 = p_k^1$ where nth solution is best in $\{1,2\ldots,N\}$
    $r_g^1 = r_k^1$ where nth solution is best in $\{1,2\ldots,N\}$
  For i in $\{1,2\ldots,I\}$:
    For n in $\{1,2\ldots,N\}$:
      Update velocity using Eq. (27)
      Update position using Eq. (28)
      Decode p_n^i in r_n^i
      ReduceLease()
    End For
    If the best solution from $r_n^i\in \{1,2\ldots,N\}$ is better than r_g^i:
      $p_g^{i+1} = p_n^i$
      $r_g^{i+1} = r_n^i$
    Else:
      $p_g^{i+1} = p_g^i$
      $r_g^{i+1} = r_g^i$
    End If
  End For
  Outputr_g^{final}
End Function

The velocity and position of particles were first initialized with 0 and uniformly distributed by random numbers in interval $(0, R)$, respectively. The velocity and position variables, v_n^i and p_n^i, contain copies of φ_{tj}^D, φ_{tk}^O, ϕ_{tj}^D, and ϕ_{tk}^O that are specific to each. These values were decoded and evaluated to infer the quality of each solution. The detailed procedure of this calculation is described in Sections 3.1 and 3.2. After decoding p_n^i, the decoded solution is stored in r_n^i. In addition, *Reduce Lease* heuristics was implemented after we evaluated the solutions of each particle during the iteration to accelerate the rate of convergence.

Table 1
Cost and demand parameters.

	Domestic	Overseas
Long-term leasing cost	US$480	US$480
Inventory holding cost	US$50	US$50
Empty container transportation cost from hinterland (port) to port (hinterland) in $/unit	*U*(170, 220)	*U*(180, 230)
Maritime transportation cost for empty container in $/unit	*U*(120, 160)	*U*(120, 160)
Initial inventory level of each port	500	500
Demand for importers	*U*(40, 60)	*U*(20, 50)

4. Computational experiments

We performed a series of numerical experiments of different sizes to evaluate the effectiveness of the solution procedure for the TFESC problem by comparing solutions with those of the CPLEX. To ensure an objective performance evaluation, all computational

Table 2
Performance of CPLEX and proposed solution procedure in solved instances.

Instance	Computation times (s)		Gap
	CPLEX	APSO	
1	17	168	3.17%
2	18	275	3.39%
3	36	303	2.73%
4	922	362	2.00%
5	83	412	2.10%
6	94	417	2.06%
7	80	110	3.91%
9	192	330	3.21%
10	453	470	2.58%
12	11,216	867	3.19%
13	13	73	2.98%
14	16	149	2.94%
15	25	212	3.00%
16	90	327	2.78%
17	68	436	3.77%
19	48	380	2.00%
20	58	484	2.31%
21	70	590	1.99%
22	152	760	3.08%
23	32	860	3.24%
24	272	977	3.73%
25	585	489	2.72%
26	486	592	2.26%
27	186	725	3.21%
28	1608	866	2.25%
29	4853	1088	3.29%
30	891	1230	3.62%
31	11	221	3.34%
32	7405	324	2.30%
33	11,349	439	3.00%
37	101	357	5.36%
38	1583	468	4.35%
39	450	554	3.45%
43	2419	681	5.45%
44	816	925	4.62%
45	2947	943	4.17%
46	2602	934	3.93%
47	278	847	4.03%
49	91	248	4.81%
51	662	705	6.24%
52	191	973	6.20%
53	2374	1024	4.57%
55	214	112	4.99%
57	1657	428	5.35%
58	2846	640	4.54%
Total Average	1346	551	3.52%

experiments were executed with Intel Core i5-4590 CPU with 3.30 GHz processors and 16.0 GB RAM and the time limit was set to 14,400 s. In experimental settings, we used cost parameters derived from Konings (2005), Shintani et al. (2010), and Moon and Hong (2016). All relevant costs, inventory levels, and demand levels for the TFESC are shown in Table 1. The transportation costs and demands followed a uniform distribution, which was useful for coping with the establishment of new shipping service routes, and each port in domestic and overseas regions had 500 empty containers for initial inventory. Malinowski et al. (2018) studied global supply chain planning by directly considering traveling distances for a vessel.

In our study, distances between echelons were indirectly considered. Differences between the maximum and minimum hinterland and maritime transportation costs can easily capture the distances between two consecutive echelons. These cost parameters can be adjusted according to the selection of bilateral trade routes (see also Feng et al. 2017). They considered stochastic parameters, including the fixed cost of sending products to buyers, that follows uniform distributions. Transportation costs for laden containers were 30% higher than those for empty containers. For executing the algorithm, we set the values of parameters as follows: $R = 1, x = 1.3, w = 0.7, c_1 = 1.5, c_2 = 2, I = 20,000, \chi = 0.7$and $N = 35$.

Moreover, after validating the performance of the proposed solution procedure in terms of computation times and gaps, which is equal to $\frac{APSO - CPLEX}{CPLEX} \times 100$, we implemented sensitivity analyses to acquire useful managerial insight on ways to connect and manage the newly established routes. The first experiment was conducted with various numbers of echelons and periods. Specifically, we used 60 instances in which the number of echelons varied along with the periods, which ranged from 4 to 16, and the importers and exporters for both regions numbered between 5 and 30. We proportionally increased the number of each echelon, and the demands were randomly generated to ensure the performance of the APSO for each case. More information on echelons and periods is given in Appendix A.

Tables 2 and 3 show the comparison of the CPLEX and APSO with heuristics performance in terms of computation times and gaps for solved and unsolved instances. In Table 2, one can observe that when experiments on relatively small instances were executed, APSO with ECR heuristics could not outperform the CPLEX in terms of computation times, but for overall performances, our solution procedure outperformed CPLEX in terms of total average computation times. In Table 3, one can observe that the average computation time of our solution procedure, which was 645 s, for the instances where CPLEX could not find solutions within the time limit. For the instances that were solved by CPLEX, the average computation time was 551 s. Although the instances in Table 3 were not solved within the time limit by CPLEX, the average computation time for our algorithm was not noticeably degraded. These findings indicate the robustness of our solution procedure using the APSO and the ECR heuristics. In fact, when a bilateral trade network is designed, many more members in each echelon than the instances in our experiment are likely to be considered, and this experiment proves the effectiveness of the proposed solution procedure to handle large instances within reasonable computation times. The optimal solutions found for some instances were excluded from Table 2. Detailed descriptions of experimental data for Tables 2 and 3 are presented in Table 4 in Appendix A.

In one sensitivity analysis, we kept the number of participants unchanged while increasing the number of periods from four to seven. Other parameters, including demands and costs, were generated in a way similar to the process in the previous experiment for which the numbers of echelons and periods varied. Detailed descriptions of experimental data for Figs. 3–5, which show the results of the analysis, are presented in Table 5 in Appendix A. Each experiment presented in these figures featured a fixed number of echelons in increments of two for every echelon, except that for domestic and overseas ports, while the period was increased. Comparing each experiment as a group, the average number of repositioned containers per period among experiments decreased in general while the average number of leased containers per period and the average cost per period increased. We inferred that greater demand of importers increased the average number of leased containers and the average cost, but more echelons could reduce the average number of repositioned containers. Within each experiment, four different periods were used for investigating the effect of empty container management strategies. The number of repositioned containers was rapidly expanded while the number of leased

Table 3
Performance of CPLEX and proposed solution procedure in unsolved instances.

Instance	Computation times (s)		Gap
	CPLEX	APSO	
8	—	205	—
11	—	664	—
18	—	555	—
34	—	478	—
35	—	632	—
36	—	704	—
40	—	623	—
41	—	632	—
42	—	704	—
48	—	713	—
50	—	394	—
54	—	1105	—
56	—	226	—
59	—	813	—
60	—	1229	—
Total Average	—	645	—

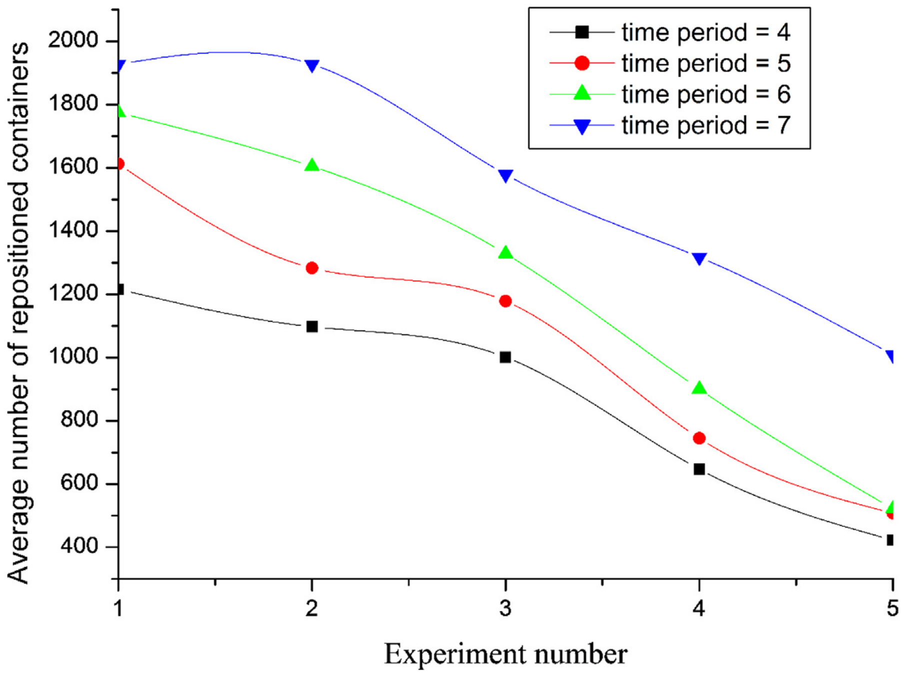

Fig. 3. Average number of repositioned containers per period.

containers remained almost unchanged. Moreover, the total cost per period slightly decreased.

The findings imply that a long planning horizon has the greatest flexibility for the manager to reposition additional empty containers without increasing costs. In this case, more containers were reused from the container storage area in a port to satisfy demands within the same region. Moreover, the average number of leased containers significantly decreased as the average cost also diminished slightly. Therefore, in a case such as this, a long planning horizon not only reduces operational costs, but also promotes a green supply chain by utilizing empty container management strategies such as an increase in ECR and reduction in leasing containers. We conducted another analysis by changing the numbers of ports and periods and found results similar to those from the analysis on various echelons and periods.

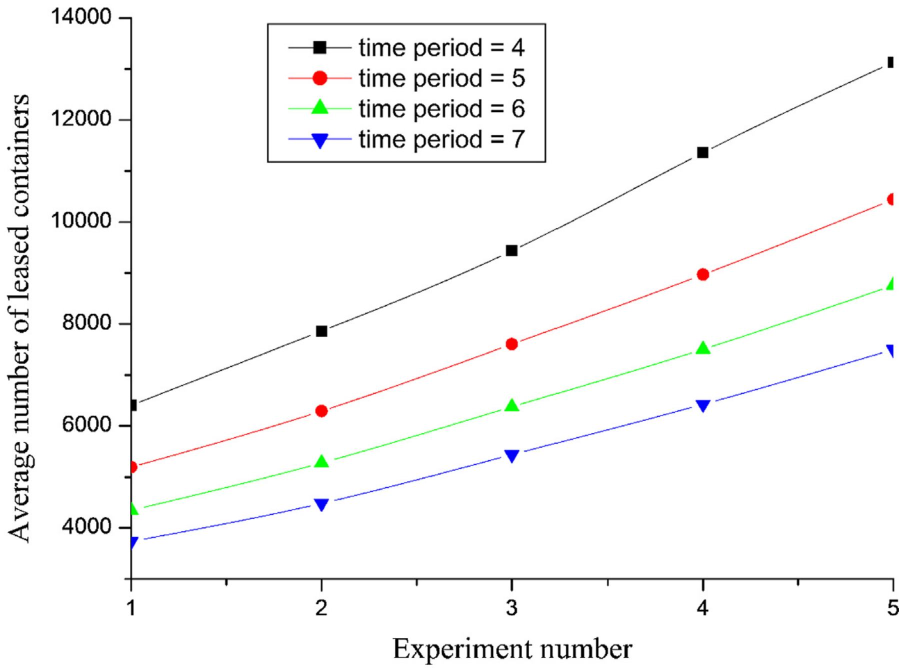

Fig. 4. Average number of leased containers per period.

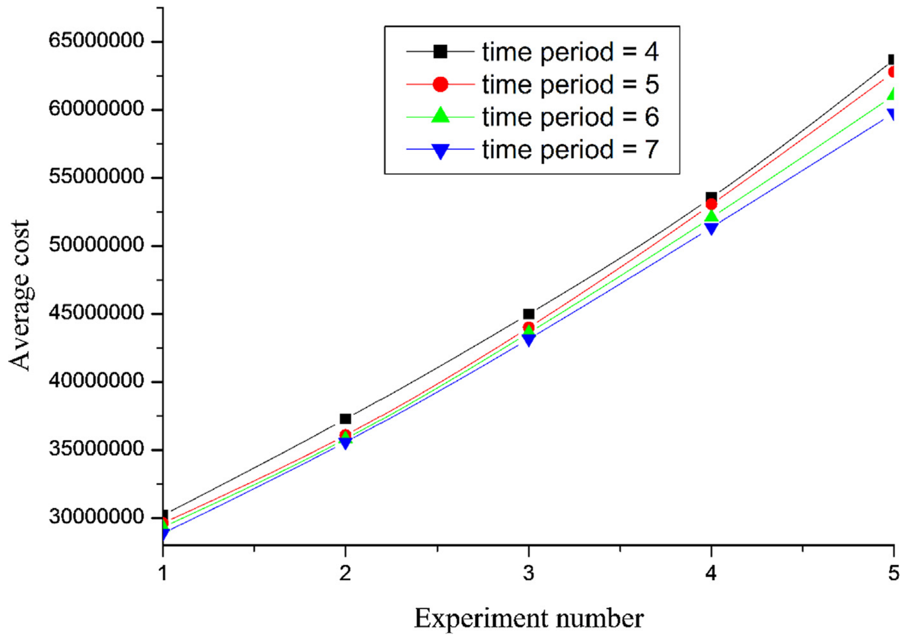

Fig. 5. Average cost per period.

In another sensitivity analysis, we kept the number of the domestic and overseas ports unchanged, while the number of exporters and importers was increased and the number of periods was changed from four to seven. Detailed descriptions of the experimental data, shown as results in for Figs. 6–8, are presented in Table 6 in Appendix A. In each experiment, bars with different colors represent ports 1–5 with a fixed number of echelons and periods. Comparing each experiment as a group, large reductions in the average number of leased containers per period and an average cost per period were observed as a period was increased (see Fig. 6). Simultaneously, the average number of repositioned containers per period was expanded (see Fig. 7). Therefore, a relatively long planning horizon in this case contributed to the promotion of green activities and significant reduction of average costs. Within each experiment, the average number of repositioned containers and the average cost generally fluctuated.

We inferred that ports in both regions tended to control the sufficient empty container inventories at ports to reposition them for satisfying exporter demands within the same region. In the aggregate, repositioning of empty containers is considered a beneficial activity as a period is increased because more ports then have the opportunity to ship empty containers to exporters easily. Another analysis was also conducted in which the number of exporters was decreased to investigate the best way to manage laden container shipments when fewer exporters can operate because of unexpected breakdowns or natural disasters that affect transport.

Despite the existing literature on aggregate demands for importers and ports, we investigated the effects of TFESC through experiments from a micro-level perspective for which the demands of importers and exporters were treated separately. From this viewpoint, we

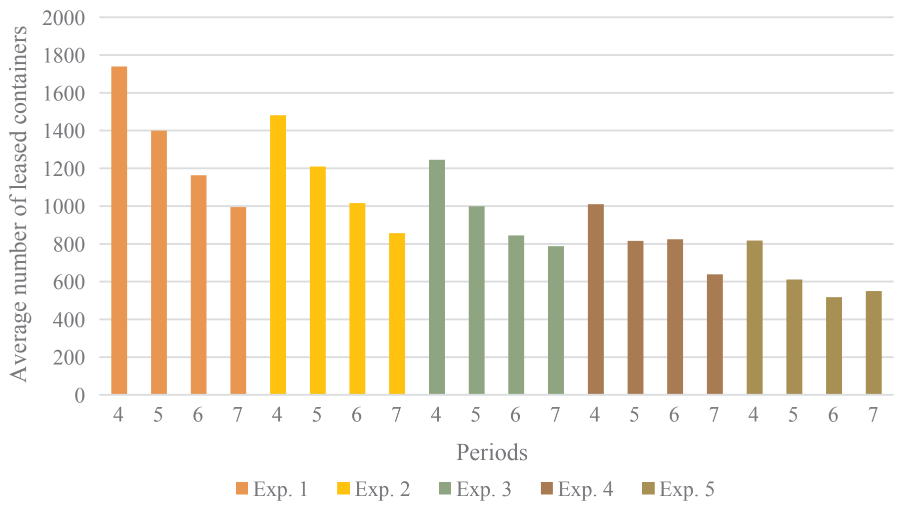

Fig. 6. Average number of leased containers with respect to increasing ports per period.

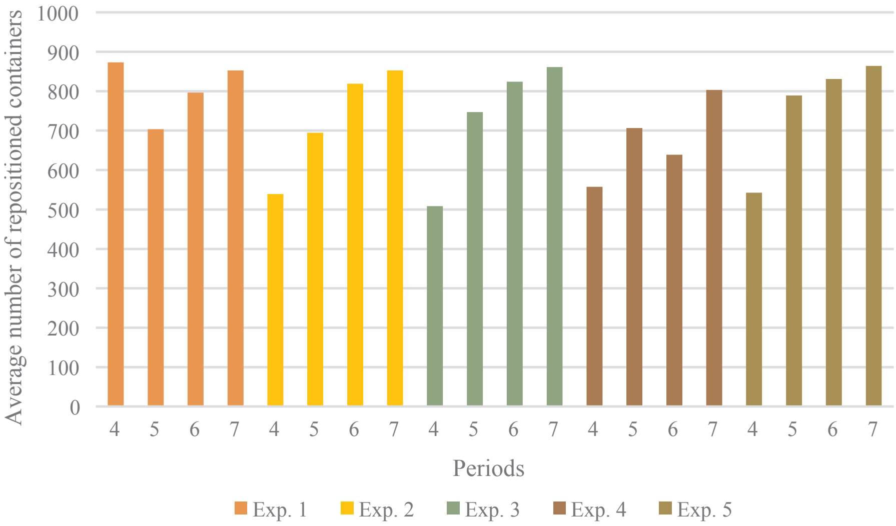

Fig. 7. Average number of repositioned containers with respect to increasing ports per period.

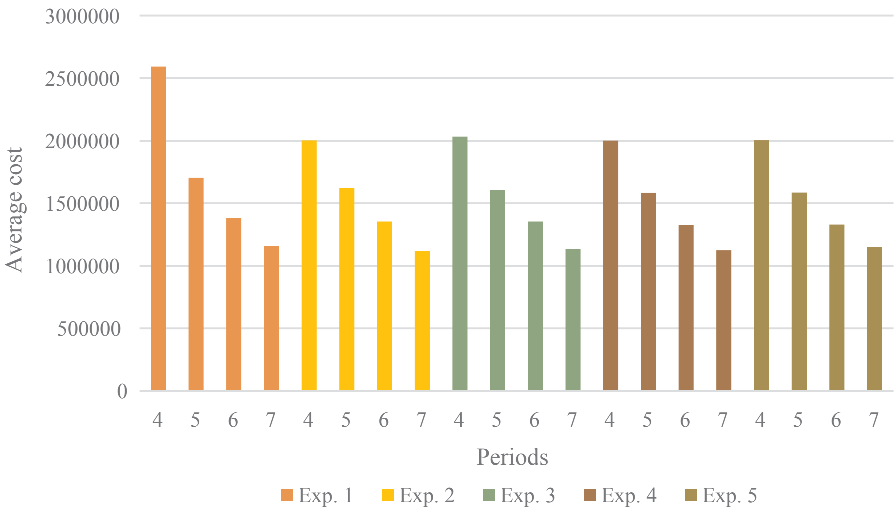

Fig. 8. Average cost per period.

found that a long-term planning horizon encourages more ECR activities, and more ports lead to a use of fewer leased containers. These intuitive analyses validate the proposed model and offered meaningful managerial insight on ways to handle empty container flows.

5. Conclusions

We developed the TFESC model to design direct shipments for two regions where sufficiently large demands are found for bilateral trade. Specifically, we incorporated service-route selection, ship deployment, and ECR; and the proposed MIP model shows optimized routes according to the total relevant cost minimization.

Through sensitivity analyses, we also investigated the effect of establishing new service routes for direct shipment when the numbers of echelons and planning periods varied. The results showed that repositioning and reusing activities should be encouraged because the average costs did not increase at all. In fact, the average cost per a period decreased as the planning horizon expanded. Therefore, a manager should consider the unproductive but green activities such as ECR undertaken when new routes are established.

The results of another analysis also showed that the average number of leased containers and average cost decreased as the number of ports and periods increased. Comparing to the first sensitivity analysis, more ports tend to hold higher inventory levels to satisfy the expected demands of exporters during the subsequent period and resulted in sharp reductions in leasing containers and average cost. Consequently, a longer planning horizon promoted green activities. Therefore, this study presents several useful implications for a manger to use to cope with any variations in the number of echelons. Moreover, we successfully applied a two-sided operation in which exporters and importers from two regions can satisfy demands for those in the other region. In practice, managing empty container flow from both regions is a realistic strategy for dealing with green efforts and sharp reductions in the congestion of container traffic at ports. However, most of the literatures investigate only one-sided operation when repositioning empty containers. Therefore, more realistic empty container management can be achieved in our proposed model.

We introduced heuristic methods for ECR and improving the solutions by maximizing the existing number of empty containers for a port, which simultaneously stores the maximum number of empty containers to encourage ECR and reduces the number of leased containers. We successfully used the APSO with heuristics to test the performance in terms of computation times and gaps by comparing it with that of the proposed MIP model. The performance of the proposed model was competitive in dealing with large instances according to periods and ports.

In addition, we acknowledge some limitations of this study: (i) For travel times in seaborne routes, movement between domestic and overseas hinterlands was considered as a unit period, and container handling time was neglected; (ii) empty containers were always returned from the importers to a port before satisfying the demands for the next period; and (iii) connection between ports situated in the same region was also neglected. This study primarily focused on empty container management strategies for direct shipment between two countries. In the future, we can extend this research by considering the impact of empty container transportation among ports in domestic or overseas regions or among exporters and importers in hinterlands within the same region. We can apply *street turn* strategy, in which importers have the option to send empty containers directly to exporters instead of returning them to intermediate ports. Therefore, an interesting extension of the work might be a study on the impact of lateral transshipments of empty containers between exporters and importers in both domestic and overseas regions. Also, an investigation into use of different types of containers, such as those that are foldable, of a quarter of height comparing to standard one, might yield interesting results. Future research might be done to consider additional aspects of port collaboration from the perspective of a green maritime supply chain.

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Appendix A

See Tables 4–6.

Table 4
Data of Tables 2 and 3.

Instance		Domestic echelons		Overseas echelons		Domestic port	Overseas port
	Γ	Υ_1	Υ_2	Ω_1	Ω_2	Φ	Ψ
1	6	9	10	8	17	2	2
2		11	12	10	15		
3		13	14	12	13		
4		15	16	14	11		
5		17	18	16	9		
6		19	20	18	7		
7	12	5	4	5	6	2	2
8		7	6	7	8		
9		9	8	9	10		
10		11	10	11	12		
11		13	12	13	14		
12		15	14	15	16		
13	8	5	4	5	6	2	2
14		7	6	7	8		
15		9	8	9	10		
16		11	10	11	12		
17		13	12	13	14		
18		15	14	15	16		
19	4	20	15	15	20	2	2
20		22	17	17	22		
21		24	19	19	24		
22		26	21	21	26		
23		28	23	23	28		
24		30	25	25	30		
25	5	20	15	15	20	2	2
26		22	17	17	22		
27		24	19	19	24		
28		26	21	21	26		
29		28	23	23	28		
30		30	25	25	30		

(*continued on next page*)

Table 4 (*continued*)

Instance		Domestic echelons		Overseas echelons		Domestic port	Overseas port
	Γ	Y_1	Y_2	Ω_1	Ω_2	Φ	Ψ
31	10	9	10	9	10	2	2
32		11	12	11	12		
33		13	14	13	14		
34		15	16	15	16		
35		17	18	17	18		
36		19	20	19	20		
37	10	9	10	8	17	2	3
38		11	12	10	15		
39		13	14	12	13		
40		15	16	14	11		
41		17	18	16	9		
42		19	20	18	7		
43	16	9	8	17	15	2	3
44		11	10	15	13		
45		13	12	13	11		
46		15	14	11	9		
47		17	16	9	7		
48		19	18	7	5		
49	12	5	4	5	6	3	3
50		7	6	7	8		
51		9	8	9	10		
52		11	10	11	12		
53		13	12	13	14		
54		15	14	15	16		
55	8	5	4	5	6	3	3
56		7	6	7	8		
57		9	8	9	10		
58		11	10	11	12		
59		13	12	13	14		
60		15	14	15	16		

Table 5
Data of Figs. 3–5.

Experiment		Domestic echelons		Overseas echelons		Domestic port	Overseas port
	Γ	Y_1	Y_2	Ω_1	Ω_2	Φ	Ψ
1	4	20	15	15	20	2	2
	5						
	6						
	7						
2	4	22	17	17	22	2	2
	5						
	6						
	7						
3	4	24	19	19	24	2	2
	5						
	6						
	7						
4	4	26	21	21	26	2	2
	5						
	6						
	7						
5	4	28	23	23	28	2	2
	5						
	6						
	7						

Table 6
Data of Figs. 6–8.

Experiment		Domestic echelons		Overseas echelons		Domestic port	Overseas port
	Γ	Υ_1	Υ_2	Ω_1	Ω_2	Φ	Ψ
1	4 5 6 7	8	10	8	10	1	1
2	4 5 6 7	8	10	8	10	2	2
3	4 5 6 7	8	10	8	10	3	3
4	4 5 6 7	8	10	8	10	4	4
5	4 5 6 7	8	10	8	10	5	5

Appendix B. Supplementary material

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.tre.2018.07.009.

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