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ACROSS-REGION DYNAMIC CONTAINERS TRANSPORTATION MANAGEMENT UNDER REVENUE MAXIMIZATION

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Abstract. *The problem of empty containers repositioning (ECR) is to dispatch the empty containers coupled with laden containers transportation flow among ports according to the fixed schedule. Aiming at this problem, to begin with, one loop itinerary of liner is divided into several stages to analyze the changes of empty containers located in the ports and on board with the time evolving based on the actual business. Then, to attack the difference between supply and demand empty containers in period t and the ones in period $t+1$, one model: dynamic region-to-region ECR (DRR-ECR), which adopts the dynamic across-region port set to port set redistribution strategy, is proposed to reduce the possible increasing costs which commonly exist in static port-to-port ECR policy: SPP-ECR. Furthermore, to evaluate these two models, we compare them with some deductive instances. Results show that in any case the DRR-ECR has absolutely more advantages than SPP-ECR. Moreover, DRR-ECR has significant impact on the safety stock of ports since reasonable and efficient DRR-ECR among ports can reduce the stock and decrease the corresponding storage cost.*

Keywords: Empty containers repositioning, Laden containers transportation, Across-region, Revenue maximization, Dynamic programming

1. Introduction.

Containerization has increasingly become popular in international trade transportation activities since its high handling efficiency, reducing costs and increasing trade flows. As the world trades are getting more imbalanced in recent years, especially the Trans-Pacific and Asia-Europe shipping routes, some ports have many surplus empty containers which incurred the storage costs. At the same time, other ports need a lot of empty containers to load the cargoes and have to lease some ones to meet the demand. We call the former as surplus ports and the latter deficit ports. The region, in which a lot of surplus/deficit ports are intensive, means the surplus/deficit region. Taking the Europe as example, it can be regarded as surplus region, and the Asia the deficit region. In actual business, the empty containers do not generate any profit compared with the laden containers. Under this imbalanced situation, efficiently and effectively repositioning empty containers by using the residual vessel space besides loading laden containers has become an important strategy to fortify the competitive market of liner company.

There has been many literature related to the problem of ECR. Bell et al. [1] focus on the assignment of laden and empty containers over a given shipping service network. Erera et al. [2] and Brouer et al. [3] confirmed the economic benefits of simultaneously considering laden and empty containers when modelling cargo allocation in a shipping network. Both above literature does not consider the asynchronism between planing repositioning and actual repositioning. Song and Dong [4] formulate the problem of ECR for general shipping service routes based on container flow balancing. In this paper, two types of flow balancing mechanisms are explained. One is based on point-to-point balancing. The other is based on coordinated balancing in the whole service. The research is similar to our proposed method except the dynamic redistribution policy which is given in our model. Imai et al. [5] and Meng and Wang [6] are the only two papers found in the literature that explicitly consider ECR decisions together with shipping network design or ship routing, in which they are limited within a few pre-specified options. Song and Dong [7] deal with the problem of joint cargo routing and ECR at the operational level for a shipping network with multiple service routes, multiple deployed vessels, and multiple regular voyages. To incorporate uncertainties in the operations model, Yin et al. [8] formulate a two-stage stochastic programming model with random demand, supply, ship weight capacity, and ship space capacity. In order to minimize the total cost, Song and Dong [9] study a single liner long-haul service route design problem including route structure design, ship deployment, and ECR. These studies have solved the ECR aiming at the determined supply/demand of empty containers of ports and do not consider the uncertainty at all. However, we all know that the supply/demand are always changing; meanwhile, the uncertainty usually exists.

Different from above literature, aiming at the characteristics of ocean liners, which are long-haul journey and visit ports with portcall sequences between two regions, such as Asia-Europe (A-E), Asia-North America (A-N) and Europe-North America (E-N), the duration of voyage is also long. Furthermore, both the planned import/export number of ECR of ports in one period and the actual ones in another period are always different since the status of empty containers in ports and liners continuously update. To solve this kind of ECR problem, we firstly divide one circle journey into several stages to attack the asynchronism of the planned repositioning and actual repositioning. Through analyzing the changes of empty and laden containers in ports and vessels under different stages, we dynamically redistribute the empty containers to meet the present actual demand of different ports. Then the DRR-ECR optimization model is built.

2. Problem Description.

Given the portcall sequence in Figure 1 we assume that the port *Istanbul* is the first portcall. The following sequence of portcalls are successively *Constanta*, *Ilyichevsk*, *Dumyat*, *Shanghai*, *Ningbo*, *Shekou*, *Singapore* and *Port Klang.*

2.1. Phase t_0: planned stage.

Since Asia is the deficit region, it sends the sum number of demand empty containers of all ports to the control center (CC) in t_0. Then all the ports in Europe firstly load the laden containers to the vessel according to the CC. Only does the vessel have the residual space when considering to load the empty containers. The numbers of loading empty containers of all ports are the demand of Asia. Assume that the laden containers are prior to the empty ones in the whole transportation procedure. The numbers of loading empty containers are equal to the minimum value of demand ones of Asia, supply ones of Europe and residual vessel space in t_0. At the same time, the number of containers in each leg of liner shipping should be less than the vessel space. In addition, the empty containers in surplus ports which do not be transported to the Asia will incur the storage costs.

2.2. Phase t_1: on board stage.

After the liner successively visits the ports: *Istanbul*, *Constanta*, *Ilyichevsk* and *Dumyat*, it will leave the Europe region and sail in t_1. In this

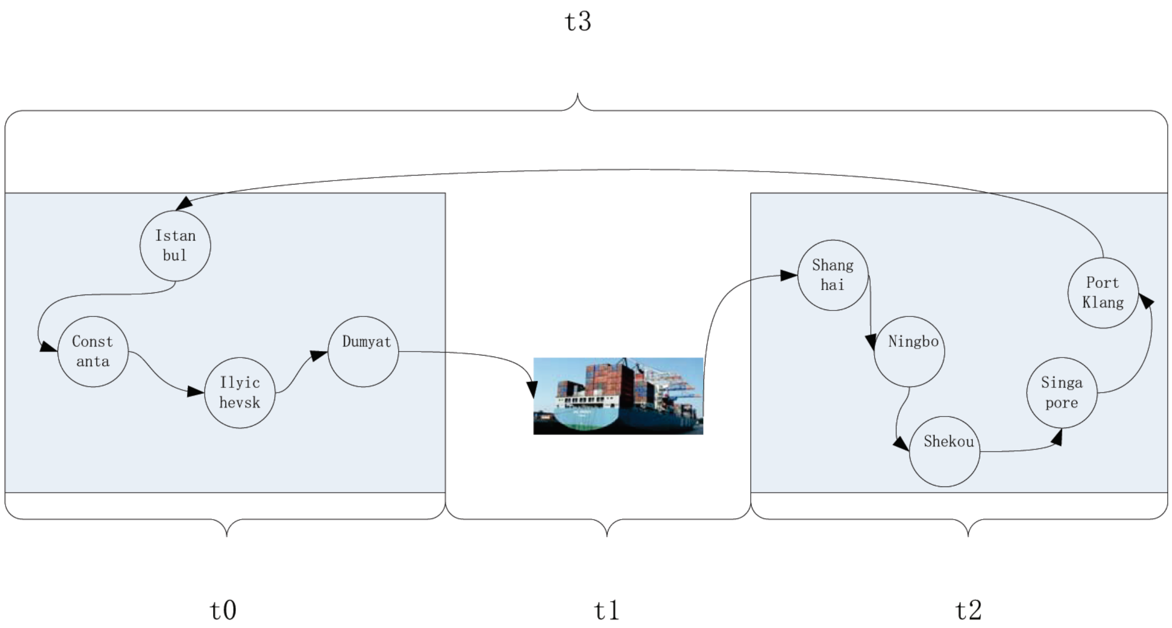

Figure 1. Shipping line between Europe and Asia

phase, the number of empty and laden containers on board are unchanged until it reaches the first port of Asia: *Shanghai*. However, note that the demand/supply empty containers in all ports are constantly changing with the time evolving.

2.3. **Phase t_2: dynamic repositioning stage.** When the liner arrives at the first port of Asia in t_2, it can obverse that the actual demand empty containers in all ports of Asia have changed compared with the ones in t_0 since the demand and supply ones in ports are unpredictable, such as the returned ones from customers, the demand ones in local port, the exporting and importing ones. For the laden containers, which reach the destination ports, they will be discharged and release some space. For the empty containers, the CC will dynamically redistribute and discharge them to meet the current demands. Moreover, the vessel also loads the laden containers which will be shipped to their corresponding destination ports in Europe. Once the residual vessel space is not enough to load the laden containers, the empty ones have to be discharged to ensure the priority of laden containers. In addition, the leasing strategy is employed to satisfy the demand empty containers of ports in Asia if they cannot be met by the transportation mode.

2.4. **Phase t_3: return trip stage.** The liner visits each port in Asia and discharges the laden and empty containers as well as loading the laden ones whose destination ports are the ones in Europe. Basically, it does not involve the problem of ECR since the Asia is the deficit region. The above four phases go round and round until the shipping line is changed by the tactical level.

To facilitate the elaboration of the problem, here suppose that all the models are subject to the following assumptions. For the liners shipping, the schedules of services are given and fixed. In different periods, the demands/supplies in all port have been dealt with by the branch lines and they refer to the integrate ones. In t_0, the number of supply/demand empty containers in surplus/deficit region are known a prior while we know the forecasting for demand or supplies ones of Asia in t_2 according to the history data of ports. Moreover, when the liner arrives to the Asia in t_2, the actual demand or supply empty containers of all ports are also given. Regardless of the repair and scrap of containers, i.e., all of them are available. There is no limit on the number of leasing containers for each port in any moment. All the containers are measured in TEU. The inventory spaces of empty containers are unrestricted for each port in any moment. The demand empty containers must be satisfied for each port.

3. Dynamic Region-to-Region ECR (DRR-ECR) Model.

3.1. parameters.

To simplify the narrative, the following notations are introduced to formulate the containers transportation problems.

P, PE, PA: set of ports, Europe ports and Asia ports, $P = PE \cup PA$.
i: port identifier in Europe region, $i \in \{1, 2, \ldots, |PE|\}$.
j: ports identifier in Asia region, $j \in \{1, 2, \ldots, |PA|\}$.
S: super port which refers to the liner.
t_0, t_1, t_2, t_3: time stage.
$D_{j,t}$: demand empty containers in j and t.
$S_{i,t}$: supply empty containers in i and t.
$LadenTrans_{ij,t}$: number of transportation laden containers from i to j in t.
CE_i^l: loading cost of unit empty container in i (Unit: \$/container/time).
CE_j^u: discharging cost of unit empty container port j (Unit: \$/container/time).
CL_i^l: loading cost of unit laden container in i (Unit: \$/container/time).
CL_i^u: discharging cost of unit laden container in i (Unit: \$/container/time).
CE_i^r: leasing cost of unit empty container in i (Unit: \$/container/stage).
CE_i^s: storage cost of unit empty container in i (Unit: \$/container/stage).
CE_{ij}^{tr}: transportation cost of unit empty containers from i to j (Unit: \$/container).
CE_{iS}^{tr}: transportation cost of unit empty containers from i to S (Unit: \$/container).
CL_{ij}^{tr}: transportation cost of unit laden containers from i to j (Unit: \$/container).
PL_{ij}^{tr}: profit of unit laden container from i to j (Unit: \$/container).
$Capacity$: the vessel capacity.

3.2. Decision variables.

The decision variables are given as follows.

$trLaden_{ij,t0}$: number of transportation laden containers from i to j according to the demand of ports of Asia in t_0, vessel capacity and the number of laden containers transportation.
$trLaden_{ji,t_3}$: number of transportation laden containers from j to i in t_3.
$trEmp_{iS,t_0}$: number of transportation empty containers from i to S in t_0.
$trEmp_{Sj,t_2}$: actual distribution number of empty containers from the liner to j in t_2.
lA_{j,t_2}: number of leasing empty containers of Asia port j in t_2.
sE_{i,t_0}: number of storage empty containers of Europe port i in t_0.
sA_{i,t_2}: number of storage empty containers of Asia port i in t_2.

3.3. Objective function.

The objective function is to maximize the total profit minus the various costs. The detail is described in (1).

$$\begin{aligned} maximize \sum_i \sum_j trLaden_{ij,t0} * PL_{ij}^{tr} + \sum_j \sum_i trLaden_{ji,t3} * PL_{ji}^{tr} - \sum_i \sum_j trLaden_{ij,t0} \\ * \left(CL_{ij}^{tr} + CL_i^l + CL_j^u\right) - \sum_j \sum_i trLaden_{ji,t3} * \left(CL_{ji}^{tr} + CL_j^l + CL_i^u\right) \\ - \sum_i trEmp_{iS,t0} * \left(CE_{iS}^{tr} + CE_i^l\right) - \sum_i sE_{i,t0} * CE_i^s \\ - \sum_j trEmp_{Sj,t2} * \left(trEmp_{Sj} + CE_j^l\right) - \sum_j sA_{j,t2} * CE_j^s - \sum_j lA_{j,t2} * CE_j^l; \end{aligned} \tag{1}$$

Subject to

$$trEmp_{iS,t0}^{tr} <= S_{i,t0}; \tag{2}$$

$$\sum_i trEmp^{tr}_{iS,t0} <= \min\left(\sum_i S_{i,t0}, \sum_j D_{j,t0}\right); \tag{3}$$

$$\sum_i trEmp^{tr}_{iS,t0} = \sum_j trEmp_{Sj,t2}; \tag{4}$$

$$sE_{i,t0} = S_{i,t0} - trEmp_{iS,t0}; \tag{5}$$

$$\sum_j sA_{j,t2} = \sum_i trEmp^{tr}_{iS,t0} - \sum_j trEmp_{Sj,t2}; \tag{6}$$

$$lA_{j,t2} = \max\left(\left(D_{j,t2} - trEmp^{tr}_{Sj,t2}\right), 0\right); \tag{7}$$

$$\sum_i \sum_j trLaden^{tr}_{ij,t0} <= Capactity; \tag{8}$$

$$\sum_j \sum_i trLaden^{tr}_{ji,t3} <= Capactity; \tag{9}$$

$$\sum_i trEmp^{tr}_{iS,t0} <= Capactity - \sum_i \sum_j trLaden^{tr}_{ij,t0}; \tag{10}$$

$$trLaden^{tr}_{ij,t0} <= LadenTrans_{ij,t0}; \tag{11}$$

$$trLaden^{tr}_{ji,t3} <= \sum_j \sum_i LadenTrans_{ji,t3}; \tag{12}$$

where the first two terms in (1) represent the whole profit. The next two terms describe the corresponding transportation costs, loading costs and discharging costs. The fifth and sixth terms show various costs in Europe region. The last three terms explain the cost of redistribution empty containers from liner to the ports of Asia, storage cost of additional empty containers and leasing cost of deficit empty containers.

The first constraint (2) represents that for each port in PE the number of exporting empty containers to the vessel in t_0 does not exceed its supply ones. (3) requires that for all ports in PE the sum of exporting empty containers to the vessel in t_0 should be the minimal value of the whole supply of PE and the whole demand of PA in t_0. (4) ensures that the transportation empty containers from Europe to vessel and from vessel to Asia keep unchanged before the liner reaches to the Asia region. (5) indicates that for each port in PE the numbers of storage empty containers are its supply ones minus the exporting ones. Only is it larger than zero when the corresponding port incurs inventory cost. (6) demonstrates that the numbers of storage empty containers of all ports in PA are the difference between the demand ones in t_2 and the supply ones in t_0. If this value is larger than zero, the leasing strategy is employed. Otherwise, there is no deficit port. For the additional empty containers, they have to be stored once the importing ones are larger than the demands ones. For these empty containers it can also be repositioned with intra-region through branch shipping lines to other ports. In this paper, we adopt the former to calculate the operation cost. (7) declares that for each port in Asia the leasing empty containers are equal to the maximal value of its demand ones minus importing ones and zero. (8) and (9) describe that the number of transportation laden containers from the Europe to Asia or in the opposition direction should be both less than the ship capacity. (10) asserts that the numbers of transportation empty containers are less than the residual vessel space beside the laden containers. (11) and (12) show that the number of transportation laden containers should not exceed the supply ones between two regions.

4. **Experimental Results and Analysis.**

4.1. **Dataset.** To evaluate DRR-ECR, one case, which simulates the shipping business, is conducted in this section. The surplus region has 5 ports and the deficit region 4 ports. The numbers of transportation laden containers from surplus region to deficit one or in the opposite direction are ranged from 100 to 200. Both two directional laden containers flows have the same profits which randomly generate within $[650, 1{,}500]$. The laden containers transportation costs are changed between 100 and 150. Considering with the empty containers transportation which use the residual space and do not increase the additional transportation, their costs discount within $[20, 50]$. The supply empty containers in surplus region are from 150 to 400 and the demand ones in deficit ports $[150, 200]$ in t_0 as the imbalance exists. The real demand empty containers of deficit region in t_3 are the fluctuation with ±5% based on the supply ones of surplus region in t_0, where the positive value represents the increasing rate and the negative one the decreasing rate. Without loss of generality, assume that the demand empty containers of the first two ports are increasing and the last two ports are reduced. The storage and leasing costs of empty containers in deficit region are changed within $[10, 20]$ and $[150, 250]$, separately. The storage costs of empty containers in surplus region are from 50 to 80 since there are more ones to be stored than the ones of deficit region. For the loading and discharging cost in all ports, we suppose that they are identical with each other and change between 10 and 20.

To test the performances of DRR-ECR, a lot of instances with varying characteristics are generated. The entire set of instances is divided into some subsets so that different cost parameters influencing the total cost can be evaluated. We refer to the data generated with the above method as base instance. The other instances are deduced from it. Table 1 shows the details for each subset, where instances I11-I15 are changed in the transportation cost, instances I21-I25 the demand of Europe and instances I31-I35 the leasing cost. The symbol "–" represents the corresponding values are the same as the base instance.

Table 1. Characteristics of the instances

instance subset	transportation cost	demand of Europe in t_3	leasing cost of Asia
base instance			
I11	+5%	–	–
I12	+10%	–	–
I13	+20%	–	–
I14	+50%	–	–
I15	+70%	–	–
I21	–	[–10%, 10%]	–
I22	–	[±10%, ±20%]	–
I23	–	[±20%, ±50%]	–
I24	–	[±50%, ±80%]	–
I25	–	[±80%, ±100%]	–
I31	–	–	[–10%, 10%]
I32	–	–	[±10%, ±20%]
I33	–	–	[±20%, ±50%]
I34	–	–	[±50%, ±80%]
I35	–	–	[±80%, ±100%]

4.2. **Compared model.** To discuss the performance of DRR-ECR, we also design the SPP-ECR model. Its objective function is formed as (13). We do not go into the details since the notations and constraints conditions are similar to (1).

$$\begin{aligned} maximize &\sum_i \sum_j trLaden_{ij,t0} * PL^{tr}_{ij} + \sum_j \sum_i trLaden_{ji,t3} PL^{tr}_{ji} \\ &- \sum_i \sum_j trLaden_{ij,t0} * \left(CL^{tr}_{ij} + CL^l_i + CL^u_j\right) \\ &- \sum_j \sum_i trLaden_{ji,t3} * \left(CL^{tr}_{ji} + CL^l_j + CL^u_i\right) \\ &- \sum_i \sum_j trEmp_{ij,t0} * \left(CE^{tr}_{ij} + CE^l_i + CE^u_j\right) \\ &- \sum_j \left(D_{j,t0} - \sum_i trEmp_{ij}\right) * CE^r_j \\ &- \sum_i \left(S_{i,t0} - \sum_j trEmp_{ij}\right) * CE^s_i; \end{aligned} \tag{13}$$

For each instance, we run 10 replications and achieve the average values to support our conclusions. All the experiments are executed on a PC with Intel(R) Core(TM) i5-2520M CPU, 4G memory and 64-bit windows 7.

4.3. **Experimental results and analysis.** Table 2 describes the details when various costs in deficit region fluctuate. In the second line, the cost, total profit and net profit of the base instance are first shown to compare with other instances. As we do not change the numbers of laden containers transportation in the whole operation and they are less than the vessel space, all the laden containers can be transportation from Europe to Asia or in the opposite direction. The instances I11-I35 have the same total profits in columns 3 and 6. At the same time, it is easy to obverse that the DRR-ECR is always superior to the SPP-ECR without relationship with any cost parameter. The main reason is that the

Table 2. Cost, total profit and net profit when the factors fluctuate

	SPP-ECR			DRR-ECR		
	cost	total profit	net profit	cost	total profit	net profit
base instance	994,815	6,600,735	5,605,920	989,564	6,600,735	5,611,171
I11	1,032,460	6,600,735	5,568,275	1,027,218	6,600,735	5,573,517
I12	1,071,520	6,600,735	5,529,215	1,066,248	6,600,735	5,534,487
I13	1,146,427	6,600,735	5,454,308	1,141,327	6,600,735	5,459,408
I14	1,375,110	6,600,735	5,225,625	1,369,806	6,600,735	5,230,929
I15	1,525,477	6,600,735	5,075,258	1,520,157	6,600,735	5,080,578
I21	996,682	6,600,735	5,604,053	990,687	6,600,735	5,610,048
I22	1,002,424	6,600,735	5,598,311	990,179	6,600,735	5,610,556
I23	1,009,839	6,600,735	5,590,896	987,787	6,600,735	5,612,948
I24	1,044,780	6,600,735	5,555,955	997,082	6,600,735	5,603,653
I25	1,061,906	6,600,735	5,538,829	997,191	6,600,735	5,603,544
I31	994,832	6,600,735	5,605,903	989,564	6,600,735	5,611,171
I32	994,757	6,600,735	5,605,978	989,564	6,600,735	5,611,171
I33	994,878	6,600,735	5,605,857	989,564	6,600,735	5,611,171
I34	994,896	6,600,735	5,605,839	989,564	6,600,735	5,611,171
I35	994,800	6,600,735	5,605,935	989,564	6,600,735	5,611,171

storage and leasing costs in DRR-ECR are both lower than the ones of SPP-ECR since we adopt the dynamic redistribution strategy in t_3.

To begin with, when we change the transportation cost between surplus region and deficit region, the total costs of two models are both increasing respectively. For the base instance, the total costs of model DRR-ECR is 989,564 and SPP-ECR 994,815. On the basis of the latter, the former is reduced by 0.5278%. Analogy with the base instance, when the transportation costs correspondingly increase with 5%, 10%, 20%, 50% and 70%, the total costs also decrease between 0.5% to 0.3%.

Then, considering with the characteristics of these two models, we change the demand empty containers in t_3 when the liner arrives to the deficit region. From I21-I25 in Table 2, it can say that compared with the demand empty containers of deficit region in t_0, the greater the changes of demand ones in t_3 are, the better the ECR-DRR is. For I21, whose demand empty containers in t_3 is changed within ±10%, the difference of both models is 5,995. However, when the range of demand empty containers in deficit region in t_3 fluctuates between 80% and 100%, their difference reaches to 64,715. The huge decreasing cost is due to the DRR-ECR which adopts the dynamic redistribution empty containers according to the demand ones in t_3 when the liner arrives the deficit region, instead of the planned ones in t_0.

Furthermore, we evaluate these two models through changing the leasing cost in deficit region. In Table 2, instances I31-I35 give the corresponding results. For DRR-ECR, total cost and net profit are invariable no matter what the leasing cost is as the demand empty containers in deficit region in t_3 can be met by the transportation mode. However, in SPP-ECR the leasing cost has to be generated since the ports, whose planned transportation empty containers in t_0 cannot satisfy the actual demand ones in t_3, exist in deficit region. At the same time, in deficit region, other surplus ports have to store the additional empty containers which exceed their actual demand ones in t_3. Precisely because of the demand changes of ports in t_3 compared with the ones in t_0, it leads to the supply and demand are inconsistent. Our proposed model makes up the defects of SPP-ECR. When the liner arrives to the deficit region, it can dynamically reposition these empty containers among all the ports according to the actual demand ones in t_3 instead of the planned distribution ones in t_0.

Finally, in the macro-perspective when the costs consisting of the transportation cost, demand fluctuation in deficit region during t_0 and t_3, and leasing cost in deficit region change, the DRR-ECR can always deal with the empty containers better than SPP-ECR. And it is not hard to obverse that advantages of the former are more obvious than the latter once the change ranges become larger. The main reason is that through the real-time redistribution empty containers it can cut down some storage cost and leasing cost since the demand and supply ones in ports change all time.

5. Conclusion and Future Work.

This paper presents a dynamic across-region ECR model: DRR-ECR coupled with laden containers transportation. It divides one loop itinerary of liner into four periods. In different period, we analyze the changes of empty containers including the ports and vessel with the time evolving. Aiming at the difference of supply and demand empty containers in t and the ones in $t+1$, in DRR-ECR we use the region-region redistribution strategy to reduce the possible increasing costs which commonly exist in tradition port-port ECR policy. We compare them with some deductive instances. Results show that our proposed model DRR-ECR has absolutely more advantages than SPP-ECR.

In this paper, our model considers the numbers of supply and demand empty containers in any moment which are given in advance. This does not match the practice. So, one of the extensions of this paper is to develop the uncertainties in them. Another possible future work is to supply multi-periods dynamic across-region ECR since the liners are always continually operating. Apart from the above possible future work on the operational level, we can do further studies by combining the problem of ECR with the tactical level even the strategic level.

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