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To cite this version:

Hengzhen Zhang, Lihua Lu, Xiaofeng Wang. Two Stages Empty Containers Repositioning of Asia-Europe Shipping Routes Under Revenue Maximization. 2nd International Conference on Intelligence Science (ICIS), Oct 2017, Shanghai, China. pp.379-389, 10.1007/978-3-319-68121-4_41 . hal-01820931

HAL Id: hal-01820931
https://hal.inria.fr/hal-01820931

Submitted on 22 Jun 2018

Two Stages Empty Containers Repositioning of Asia-Europe Shipping Routes 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 between the surplus ports and the deficit ports according to the fixed schedule. Because this problem involves many parameters, variables and constraints, how to build and solve the model is always focus point. Aiming at this problem, firstly one loop itinerary of liner is divided into several stages to analyze the changes of two typical containers located in the ports and on board with the time evolving. Secondly, for attacking the difference between supply and demand empty containers in preview stage t and the ones in next stage t+1, one dynamic region-to-region ECR model, which adopts the dynamic across-region port set to port set redistribution strategy, is proposed to reduce the various possible costs which commonly exist in existing static port-to-port ECR policy. Finally, through some deductive instances and contrast model we analyze these two models. Results show that in any case our proposed model has absolutely more advantages than the one who uses the static port-to-port ECR strategy. Moreover, the former has significant information support for making the safety stock of ports.

Keywords: empty containers repositioning; laden containers transportation; across-region; revenue maximization; dynamic programming

1 Introduction

Containers transportation has increasingly become popular in international trade transportation activities in the last few decades. As various reasons consisting of the history, political and economy the world trades are getting more imbalanced in recent years especially the Trans-Pacific and Asia-Europe shipping routes [1]. The growth of containerized shipping has presented challenges inevitably, in particular to the management of empty containers arising from the highly imbalanced trade between continents. Some ports have accumulated many surplus empty containers, which are called the surplus ports. At the same time, other ports (deficit ports) need many empty containers to load the cargoes and have to lease some ones to meet the customers demand. For example, the Europe region can be regarded as surplus region while the Asia is deficient region. Under such imbalanced situation, efficiently and effectively repositioning

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[1] The “*” refers to the corresponding author.

empty containers by using the residual vessel space has become an important strategy to fortify the competitive market of liner company.

Basically, the liner shipping has fixed service route with a number of vessels deployed in fixed schedules with the weekly service frequency. Reasonable arrangement plan of empty and laden containers not only guarantee the arrival of laden ones on time but ensure to reposition empty containers as possible as reducing the operation cost. However the factors influencing the ECR policy are rather complex including the sail schedule, various costs, laden containers, vessel capacity etc. So this problem is a typical combinational optimization problem.

2 Literature review

There have been many literatures related to the ECR. Crainic et al. [3] consider the factors of long-term leasing containers for attacking the dynamic random ECR. Cheung and Chen [4] model the ECR as a two-stage stochastic optimization model. They propose a time-space network model which is the opening the maritime ECR network modeling for discussion. Lam et al. [5] apply the actual service schedule so that the general networking techniques to the shipping industry can be developed. Bell et al. [6] focus on the assignment of laden and empty containers over a given shipping service network. Erera et al. [7] and Brouer et al. [8] confirmed the economic benefits of simultaneously considering laden and empty containers when modeling cargo allocation in a shipping network. Both above literatures do not consider the asynchronism between planning repositioning and actual repositioning. Song and Dong [9] formulate the problem of ECR for general shipping service routes based on container flow balancing. Imai et al. [10] and Meng and Wang [11] are the only two papers found in the related literatures that explicitly consider ECR decisions together with shipping network design or ship routing, in which the shipping routes are limited within a few pre-specified options. To incorporate uncertainties in the operational model, Long et al. [12] formulate a two-stage stochastic programming model with random demand, supply, ship weight, and ship capacity.

To solve long-haul journey of ECR, we firstly divide one circle journey into several stages to attack the asynchronism of the planned repositioning and actual repositioning. Through analyzing the numerical changes of empty and laden containers in ports and on board in different stages, we can dynamically redistribute the empty containers to meet the current actual demand of different ports. Then the dynamic region-to-region ECR(DRR-ECR) optimization model is built. Fig. 1 shows the details of liner shipping, ports and regions, where the circle represents the port, the directed arc the two successive visited ports, and the rectangle the surplus or deficit region.

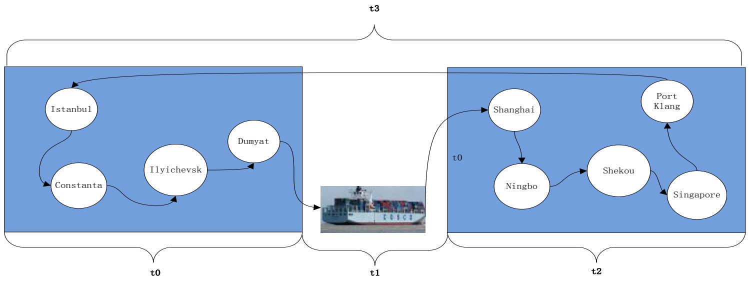


Fig. 1. Shipping line between Europe and Asia.

2.1 Phase t_0 : planned stage

Since the Asia is the deficit region, it sends the total number of demand empty containers of all ports to the control center in stage t_0 . Then each port in Europe firstly loads the laden containers to the vessel according to the control center. The number of loading empty containers of each port equals to the minimum value of demand ones of Asia, supply ones of Europe and residual vessel space in t_0 . Meanwhile 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 temporarily be transported to the Asia or other ports will incur the storage costs.

2.2 Phase t_1 : on board stage

After the liners successively visit the ports in Europe, they will sail into stage t_1 . In this stage, the numbers of empty and laden containers on board are unchanged until the liners reach the first port of Asia: Shanghai. But note that the demand or supply empty containers in all ports are constantly changing with the time evolving because the other liners may visit the corresponding ports. This will cause the changes of ports states and their number of empty and laden containers.

2.3 Phase t_2 : dynamic repositioning stage

When the liners arrive the first port of Asia in t_2 , it can observe that the actual states of ports have changed compared with the corresponding ones in t_0 . It is mainly caused by the unpredictable demand/supply in ports. For the laden containers, which reach the destination ports, they will be discharged and release their space. For the empty containers, the control center will dynamically redistribute and discharge them to meet the actual demands. Moreover, the vessels also load the laden containers, which will be shipped to their corresponding destination ports in Europe.

2.4 Phase t_3: return trip stage

The liners visit each port in Asia and discharge the laden and empty containers as well as loading the laden ones whose destination ports are the ones in Europe. In general, it does not involve the problem of ECR since the Asia region is the deficit one. The above four phases go round and round until the shipping line is altered caused by the tactical level or the seasonal change.

In this paper, we firstly consider the ECR coupled with the laden containers transportation in shipping service. Then the one circulation trip is divided into four phases to analyze the changes of empty/laden containers including the ports and vessels. Finally a maximized revenue optimization model: DRR-ECR is proposed to dynamically solve the empty/laden containers transportation problem.

The remainder of this paper is organized as follows. In the next section, the ECR and laden containers transportation problem are formulated. In the subsequent section, it presents the experimental results. Finally, conclusions are drawn and future researches are derived.

3 Problem formulation

3.1 Problem description

In this paper suppose that all the proposed models are subject to the following assumptions. The schedules of services are given and fixed in advance. In the different stages, the numbers of deficit/surplus empty containers in all ports have been dealt with by the branch lines and they refer to the integrate ones. In t_0, the number of surplus/deficit empty containers in their corresponding regions is also known a prior according to the history data of ports. There is no limit on the number of leasing containers for each port in any moment. All the containers are measured in TEU. The demand empty containers must be satisfied. All costs are calculated in dollars.

3.2 Parameters

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

P : set of ports within the scope of research, $P = PE \bigcup PA$.

PE / PA: set of Europe/Asia ports within the scope of research.

i : port identifier in Europe region, $i \in \{1, 2, ..., |PE|\}$.

j : ports identifier in Asia region, $j \in \{1, 2, ..., |PA|\}$.

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, $t \in \{t_0, t_1, t_2, t_3\}$.

$S_{i,t}$: supply empty containers in i and t, $t \in \{t_0, t_1, t_2, t_3\}$.

$LadenTrans_{ij,t}$: number of transportation laden containers from i to j in t.

$CE_i^l / CL_i^l / CL_i^u / CE_i^r / CE_i^s$ /: loading/discharging/loading/leasing/storage cost of unit empty container in i (Unit: \$/container/time).

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 .

CL_{ij}^{tr} : transportation cost of unit laden containers from i to j .

PL_{ij}^{tr} : profit of unit laden container from i to j .

$Capacity$: the vessel capacity.

3.3 Decision variables

According to the problem, we give the decision variables as follows.

$trLaden_{ij,t_0}$: number of transportation laden containers from i to j in t_0

$trLaden_{ji,t_3}$: number of transportation laden containers from j to i in t_3 .

$trEmp_{iS,t_0}$: number of transportation empty containers from i to super port S .

$trEmp_{Sj,t_2}$: distribution number of empty containers from the liner to j in t_2 .

lA_{j,t_2} : number of leasing empty containers in Asia port j and in t_2 .

sE_{i,t_0} : number of storage empty containers in Europe port i and in t_0 .

sA_{i,t_2} : number of storage empty containers in Asia port i and in t_2 .

3.4 Objective function

The objective function of our paper is to maximize the total profit minus the various costs. The formal model is described in (1), which is subject to constraints (2)-(12).

$$
\begin{aligned}
&\mathit{maximize}\\
&\sum_i \sum_j trLaden_{ij,t_0} * PL_{ij}^{tr} + \sum_j \sum_i trLaden_{ji,t_3} PL_{ji}^{tr} - \sum_i \sum_j trLaden_{ij,t_0} * (CL_{ij}^{tr} + CL_i^l + CL_j^u)\\
&- \sum_j \sum_i trLaden_{ji,t_3} * (CL_{ji}^{tr} + CL_j^l + CL_i^u) - \sum_i trEmp_{iS,t_0} * (CE_{iS}^{tr} + CE_i^l)\\
&- \sum_i sE_{i,t_0} * CE_i^s - \sum_j trEmp_{Sj,t_2} * (trEmp_{Sj} + CE_j^l) - \sum_j sA_{j,t_2} * CE_j^s - \sum_j lA_{j,t_2} * CE_j^l;
\end{aligned}
\tag{1}
$$

$$trEmp_{iS,t_0}^{tr} \le S_{i,t_0} \; ; \tag{2}$$

$$\sum_i trEmp_{iS,t_0}^{tr} \le \min\left(\sum_i S_{i,t_0}, \sum_j D_{j,t_0}\right) \; ; \tag{3}$$

$$\sum_i trEmp^{tr}_{iS,t_0} = \sum_j trEmp_{Sj,t_2} \ ; \tag{4}$$

$$sE_{i,t_0} = S_{i,t_0} - trEmp_{iS,t_0} \ ; \tag{5}$$

$$\sum_j sA_{j,t_2} = \sum_i trEmp^{tr}_{iS,t_0} - \sum_j trEmp_{Sj,t_2} \tag{6}$$

$$lA_{j,t_2} = \max((D_{j,t_2} - trEmp^{tr}_{Sj,t_2}),0) \tag{7}$$

$$\sum_i \sum_j trLaden^{tr}_{ij,t_0} \le Capactity \tag{8}$$

$$\sum_j \sum_i trLaden^{tr}_{ji,t_3} \le Capactity \tag{9}$$

$$\sum_i trEmp^{tr}_{iS,t_0} \le Capactity - \sum_i \sum_j trLaden^{tr}_{ij,t_0} \tag{10}$$

$$trLaden^{tr}_{ij,t_0} \le LadenTrans_{ij,t_0} \tag{11}$$

$$trLaden^{tr}_{ji,t_3} \le \sum_j \sum_i LadenTrans_{ji,t3} \tag{12}$$

The first two terms in (1) represent the profits between Europe and Asia. 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 ones and leasing cost of deficit ones.

4 Experimental Results and Analysis

4.1 Dataset

Table 1. Characteristics of the instances.

Instance subset	transportation cost	in t_3 demand of Europe	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%]

To evaluate DRR-ECR, one case, which simulates the shipping company business, is conducted in this section. Assume that the surplus region has 5 ports and the deficit region 4 ports. The number of transportation laden containers from surplus region to deficit one or in the opposite direction are randomly ranged from 100 to 200. Both two directional laden containers flows have the same profits which is random generated within [650,1500].The laden containers transportation costs are changed between 100 and 150 since they are different among ports. Suppose that they discount 20%~30% compared with the transportation costs of laden containers and are 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 actual demand empty containers in deficit region in t_3 are the fluctuation with $\pm 5\%$ based on the supply ones in surplus region in t_0, where the positive value represents the increasing rate and the negative one the decreasing rate.

To test the performances of DRR-ECR, many 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 tested. We refer to the data generated with the above method as base instance. The other instances are deduced from it. Table 1 show 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.

4.2 Compared model

To discuss the DRR-ECR, a static port-to-port ECR model (SPP-ECR) is also designed. .Its objective function and constraints conditions are given as (13)-(21).

$$\begin{aligned}
&\mathit{maximize}\\
&\sum_i \sum_j trLaden_{ij,t_0} * PL_{ij}^{tr} + \sum_j \sum_i trLaden_{ji,t_3} PL_{ji}^{tr} - \sum_i \sum_j trLaden_{ij,t_0} * (CL_{ij}^{tr} + CL_i^l + CL_j^u)\\
&- \sum_j \sum_i trLaden_{ji,t_3} * (CL_{ji}^{tr} + CL_j^l + CL_i^u) - \sum_i \sum_j trEmp_{ij,t_0} * (CE_{ij}^{tr} + CE_i^l + CE_j^u)\\
&- \sum_j (D_{j,t_0} - \sum_i trEmp_{ij}) * CE_j^r - \sum_i (S_{i,t_0} - \sum_j trEmp_{ij}) * CE_i^S
\end{aligned} \tag{13}$$

$$\sum_j trEmp_{ij,t_0}^{tr} \le S_{i,t_0} \ ; \ i \in PE, j \in PA \tag{14}$$

$$\sum_i trEmp_{ij,t_0}^{tr} \le D_{j,t_0} \ ; \quad j \in PA \tag{15}$$

$$\sum_i \sum_j trEmp_{ij,t_0}^{tr} \le \min(\sum_i S_{i,t_0}, \sum_j D_{j,t_0}) \tag{16}$$

$$\sum_i \sum_j trLaden_{ij,t_0} \le Capactity \ ; \tag{17}$$

$$\sum_{j}\sum_{i} trLaden_{ji,t_3} \le Capactity\,; \tag{18}$$

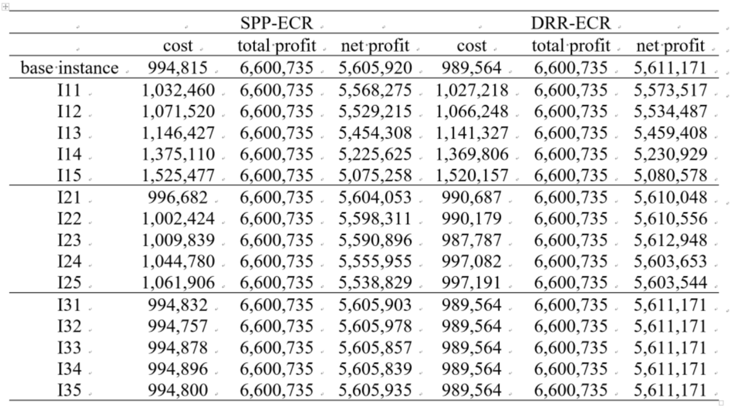
$$\sum_{i}\sum_{j} trEmp_{ij,t_0} \le Capactity - \sum_{i}\sum_{j} trLaden_{ij,t_0}\ ; \tag{19}$$

$$\sum_{i}\sum_{j} trLaden^{tr}_{ij,t_0} \le \sum_{i}\sum_{j} LadenTrans_{ij,t_0}\ ; \tag{20}$$

$$\sum_{j}\sum_{i} trLaden^{tr}_{ji,t_3} \le \sum_{j}\sum_{i} LadenTrans_{ji,t_3}\ ; \tag{21}$$

We use CPLEX 12.6 to solve these mathematical models. For each instance, we run 10 replications and achieve the average value. Two indicators are employed to analyze them. One is the values of objective functions. Another is the decreasing rates of total cost for 8 extracted instances which are the combination of four parameters.

Table 2. Cost, total profit and net profit when the transportation cost, the demand of deficit region and leasing cost in deficit region 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

4.3 Objective function

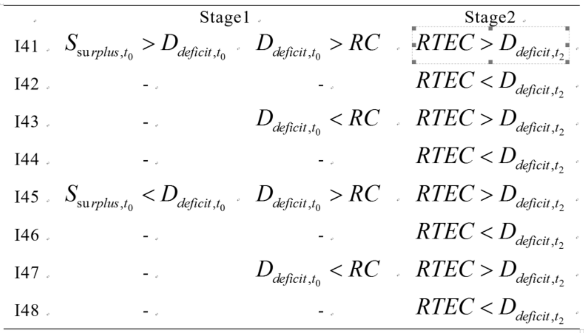
Table 2 gives the details when various costs fluctuate in deficit region. In the third line of Table 2, the cost, total profit and net profit of the base instance are first shown in order to compare with other instances.

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. The instances I11-I35 have the same total profits in column 3 and 6.And it is no difficulty to observe that the DRR-ECR is always superior to the SPP-ECR with no relationship with any cost parameter. The reason is mainly that both the storage costs and leasing costs in DRR-ECR are lower than the ones of ECR-SPP because we use the dynamic redistribution strategy in t_3.

4.4 The cost, total profit and net profit under different circumstances

Considering with the actual numbers of ECR, which is limited by the residual space of liners excluding the laden containers, the supply ones of surplus region in t_0 ,and the demand ones of deficit region in t_0 and t_2 ,we divide the whole process into two stages. The first stage is planned stage and the second stage the implementation stage. We combine with these parameters and deduce eight instances shown as Table 3 to explain above models, where the RTEC refers to the real transportation empty containers and the RC the residual capacity. For example, the $S_{surplus,t_0} > D_{deficit,t_0}$ means the whole supply in surplus region is larger than the total demands ones in deficit region. The $S_{defict,t_0} > RC$ describes that the whole demand of all ports in deficit region is larger than the residual capacity. Table 4 describes the details. From it, we can discover that the RTEC always equals to the minimum value of RC, the whole supply empty containers of surplus region in t_0 , and the whole demand ones of deficit region in t_0 .

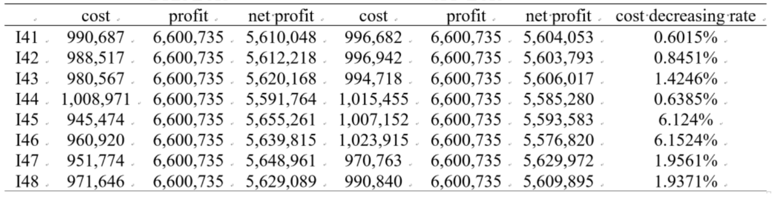
Table 3. Eight combined instances according to the whole supply empty containers in surplus region in t_0 , the demand ones in deficit region in t_0 and in t_2 .



	Stage1		Stage2
I41	$S_{surplus,t_0} > D_{deficit,t_0}$	$D_{deficit,t_0} > RC$	$RTEC > D_{deficit,t_2}$
I42	-	-	$RTEC < D_{deficit,t_2}$
I43	-	$D_{deficit,t_0} < RC$	$RTEC > D_{deficit,t_2}$
I44	-	-	$RTEC < D_{deficit,t_2}$
I45	$S_{surplus,t_0} < D_{deficit,t_0}$	$D_{deficit,t_0} > RC$	$RTEC > D_{deficit,t_2}$
I46	-	-	$RTEC < D_{deficit,t_2}$
I47	-	$D_{deficit,t_0} < RC$	$RTEC > D_{deficit,t_2}$
I48	-	-	$RTEC < D_{deficit,t_2}$

Compared with other instances, both I45 and I46 have higher costs reducing, because the RTEC, which equals to the surplus empty containers of surplus region in t_0 , fluctuates wildly than the demand ones of deficit region in t_2 .So, for SPP-ECR it directly leads to that both the storage cost in deficit region and the transportation cost increase. However, for DRR-ECR the dynamic redistribution policy among the ports of deficit region brings down the storage cost to some extent.

Table 4. the percentage of each cost in the total operation cost of these two models.



	DRR-ECR			SPP-ECR			
	cost	profit	net profit	cost	profit	net profit	cost decreasing rate
I41	990,687	6,600,735	5,610,048	996,682	6,600,735	5,604,053	0.6015%
I42	988,517	6,600,735	5,612,218	996,942	6,600,735	5,603,793	0.8451%
I43	980,567	6,600,735	5,620,168	994,718	6,600,735	5,606,017	1.4246%
I44	1,008,971	6,600,735	5,591,764	1,015,455	6,600,735	5,585,280	0.6385%
I45	945,474	6,600,735	5,655,261	1,007,152	6,600,735	5,593,583	6.124%
I46	960,920	6,600,735	5,639,815	1,023,915	6,600,735	5,576,820	6.1524%
I47	951,774	6,600,735	5,648,961	970,763	6,600,735	5,629,972	1.9561%
I48	971,646	6,600,735	5,629,089	990,840	6,600,735	5,609,895	1.9371%

5 Conclusion and future work

This paper presents a dynamic across-region ECR model: DRR-ECR, in which we use the region-region redistribution strategy to reduce the possible increasing costs which commonly exist in tradition static port-port ECR policy. To evaluate these models, we compare them through some deductive instances. Moreover, the DRR-ECR has significant impact on the safety stock of ports.

In this paper, our model considers the numbers of supply/demand empty containers given in advance. This cannot match the practice. So, one of the extensions is to develop the uncertainties. Another possible future work is to study by combining the problem of ECR with the tactical level decision even the strategic level decision. If we take the two level decisions or three level decisions into account, the meta-heuristic algorithms have to be involved to face this complex problem.

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