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Multiple Periods Minimal Cost Programming Optimization Model for Empty Containers Repositioning with Stock Level

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Abstract

The main problem of empty containers repositioning (ECR) is to dispatch the empty containers among the ports meanwhile cut the costs as possible as. According to the actual operations, the stock policy and various constrains are considered together in this paper firstly. Then we build a multiple periods minimal cost programming optimization model with stock to solve this problem. Furthermore, we adopt the heuristic rule to effectively operate the empty containers since there is a large amount of calculation. Finally, some simulate data are given to assess the model. The results show that our proposed model is feasible and efficient to minimize the operation cost as well as satisfy the demand of customers. Moreover by analyzing the data it can guide us to set the inventory of empty containers of ports in different supply and demand scenarios.

Keywords: *Empty container repositioning; multiple periods; minimal cost model; stock*

1. Introduction

With the explosion of global trades, in the international transportation systems especially in the maritime transportation systems, the container transportation has been increasing since its safe and inexpensive mode. According to incomplete statistics, for the whole international transport of commodity, more than 80% of them are dealt with by sea, and more than 60% of the goods in the shipping are transported by containers. Furthermore, the rate is rising with the acceleration of trades among the countries. However, because of the trade imbalance, it may result in the excess of empty containers in some ports (surplus ports) and scarcity in other ports (deficit ports). For instance, the container cargo flow from Asia to US has approximately 4 million TEUs, while in the opposite direction there are 3.5 million TEUs in 1995. In 2005, the former became 12.4 million and the latter 4.2 million. When the time came to 2007, the annual flow difference between Asia to the US is 10.5 million TEUs [1]. The imbalance trend is more and more obvious.

The existing of surplus and deficit ports has involving many operation costs for liner operator, such as transportation costs between deficit ports and surplus ones, inventory costs of excess empty containers in surplus ports, leasing costs of demand empty containers in deficit ports. Therefore, it is urgent to study the problem of empty containers repositioning (ECR). Since the ECR itself does not generate any profit, reasonable

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repositioning strategies especially by the vacant vessel space with the laden containers can save many costs for liner operators. In generally the liners have the tight schedules, port-calling sequence, and arrival and departure times at ports. So it is critical to relocate empty containers on the basis of the schedule of liners given aforehand and residual transportation capacity left by laden containers and discharged. However, due to the complicated factors influencing ECR strategy, it is always considered to be a challenging combinational optimization problem.

Several ECR strategies have been focused on. They mainly include twofold: firstly it is the inventory-based control mechanisms for empty containers management [4, 11, 12]. Secondly it adopts the dynamic network programming methods to solve this problem [13-15]. Cheung and Chen [2] model ECR as a two-stage stochastic optimization model. They propose a time space network model which is the opening maritime ECR network modeling for discussion. Lam *et al*. [10] apply the actual service schedule so that the general networking techniques to shipping industry can be developed. An approximate dynamic programming approach in operational strategies for ECR is proposed. Meng and Wang [8] combine the hub-and-spoke and multi-port-calling operations, design the liner shipping service network and develop a mixed-integer linear programming model. Crainic *et al*. [3] consider the factor of long-term leasing containers for attacking the dynamic random ECR. To reduce the number of ECR, Li *et al*. [4] study the transportation between ports. Song and Dong [5] 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, Long *et al*. [6] formulate a two-stage stochastic programming model with random demand, supply, ship weight capacity, and ship space capacity. To minimize the total cost, Song and Dong [7] study a single liner long-haul service route design problem including route structure design, ship deployment, and ECR.

From the literatures above, we observe that some points need to be considered further. Firstly most present studies only focused on the operational cost while ignoring the temporary demands. Secondly since there is a large amount of calculation in the problem of ECR, the computational time has to be involved. Thirdly some works, e.g. [9] consider penalty cost instead of leasing cost. This is blamed for difficultly quantify since it may be lost the current and even future sales.

In this paper, we firstly adopt the stock strategy to attack the temporary demands of ports and avoid the rapid increasing of leasing costs. Secondly, owing to the complexity of ECR, we adopt some heuristic mechanism to improve the computational performance. The heuristic rule mainly distinguishes deficit and surplus ports in each period to reduce the computational times. Thirdly, we consider the minimal cost of multiple periods since the liner run periodically. Combining with the constraints conditions such as repositioning capacity, vessel space *etc*, we propose the model: Multiple Periods Minimal Cost Model with Stock (MP-MCMS) for ECR, to solve this problem. This model can satisfy all the demand empty containers in deficit ports in different period and subject to the various constraints. Finally some simulate experiments are represented to evaluate the proposed model. The results show that it is efficient and effective. In addition, by using this model it can also support us to adjust the stocks to fit the demands in different relationships between supply and demand since they may change with the season.

The remainder of this paper is organized as follows. In Section 2, some preliminaries are given including model assumptions and model variables. Section 3 presents the model: MP-MCMS. The simulations and analysis are described in Section 4. Finally, the conclusions and future research are given in Section 5.

2. Preliminaries

2.1. Problem Description

The problem of ECR has become one of the important ones faced by liner operators, as it is almost impossible to avoid the redistribution of empty containers between ports owing to the imbalance trades. For surplus ports the empty containers need to be exported to deficit ones or deports. The repositioning policy has twofold benefits: one is to decrease inventory costs of surplus ports, and another may relieve the pressure of demand empty containers of deficit ports. Furthermore if the deficit ports obtain the demand empty containers as possible as quickly, it can reduce the probability of leasing ones. Generally speaking, leasing costs are higher than repositioning ones. In most of the time the leasing strategy has to be used to satisfy the demands. For example, there are stock-out of empty containers in ports or no residual vessel space to load empty containers from surplus ports to deficit ones.

2.2. Model Assumptions

Since the factors affecting ECR strategy are rather complex, in this paper, we suppose that the model is subject to the following assumptions. We consider multiple periods and multiple ports, where each port has a supply and/or demand for empty containers in different periods. The demand or supply empty containers in ports are stable and known a prior in different periods. Regardless of the repair and scrap of containers, *i.e.*, all of the containers are available. There is no limit on the number of leasing containers for each port in any moment. All the containers and demands are measured in TEUs. The inventory spaces of empty containers are unrestricted for each port in any moment. The demand empty containers must be satisfied for each port and period.

2.3. Model variables

The model variables used in this paper are given as follows.

Parameters

P: set of ports.

P^+: set of surplus ports.

P^+_t: set of surplus ports in period t.

P^-: set of deficit ports.

P^-_t: set of deficit ports in period t.

P^0: set of balance ports that do not ship or receive empty containers.

P^0_t: set of balance ports in period t.

i, j: ports identifier, $i, j \in \{1, 2, \dots, |P|\}$, where $|\cdot|$ is the cardinality of set.

t: periods, $t \in \{1,2,...T\}$, where T is the length of planning horizon.

S_i^t: number of supply empty containers in port i and period t.

D_i^t: number of demand empty containers in port i and period t.

C_i^l: loading cost of container in port i (unit: \$/container/time).

C_i^u: unloading cost of container in port i (unit: \$/container/time).

C_i^r: leasing cost of container in port i (unit: \$/container/time).

C_i^i: inventory cost of container in port i (unit: \$/container/time).

C_{ij}^{tr}: transportation cost from surplus port i to deficit port j (unit: \$/container).

Cap_{ij}^t: capacity constraint of ECR from port i to port j in period t.

$Inv0_i$: initial inventory of port i.

Inv_i^t: inventory of port i in period t, where $0 < t \leq T$.

3. ECR Model

3.1. f_1: MP-MCMS

For f_1 when the demand empty containers cannot be satisfied by the transportation mode, we consider to lease them from the vendors. In each period t∈T, if the number of supply empty containers of port i plus the inventory minus the demand ones is larger than zero, we call it as surplus port in period t, namely, $p^+_t \in P^+_t$. Otherwise the deficit port. That is $p^-_t \in P^-_t$. It is easy to discover that the set of P^+_t and P^-_t are changed along with the time.

3.2. Decision Variables

For the three key issues of ECR: when, where and how many, the decision variables in f_1 are defined as follows:

(1) tr_{ij}^t: it represents the number of ECR from port i to port j in period t.

(2) $rent_i^t$: it describes the number of leasing empty container in port i and period t. It supplies the important and additional supplement of empty containers from the vendors once the empty containers do not reach the destination ports as required on time.

3.3. Objective Function

Based on the actual business of liner companies, the objective function in our paper is to minimize the whole operational cost in the whole planning horizon T. Obviously, the demand empty containers in deficit ports and different period must be achieved by either repositioning or leasing. The empty containers transportation occurs the transportation costs meanwhile the leasing containers produce the leasing ones. In addition, the redundant empty containers in surplus ports have the inventory costs. So the objective function can be expressed as (1), where the first term is transportation cost, loading cost in surplus ports, and unloading cost in deficit ports. The second term stands for the leasing cost in deficit ports, and the last term is the inventory cost in surplus ports.

$$\mathrm{Min}\ f_1 = \sum_{t\in T}\sum_{i\in P_+^t}\sum_{j\in P_-^t}\left(C_{ij}^{tr} + C_i^l + C_j^u\right) * tr_{ij}^t + \sum_{t\in T}\sum_{j\in P_-^t} C_j^r * rent_j^t + \sum_{t\in T}\sum_{i\in P_+^t} C_i^i * Inv_i^t; \quad (1)$$

3.4. The Constraints Conditions

The container flows that are inbound and outbound at a port in period t include several factors shown as Figure 1, where the supply is the containers that are returned from the consignees, the demand is the consignors' demands for empty containers, exporting is repositioning from surplus ports to deficit ports, importing is inverse flows of exporting empty containers, leasing is the leasing empty containers from the vendors to ensure the consignors' demands, and the inventory is the stock of current port until current period. The above factors directly affect the number of empty containers in each period of ports. So we consider the following constraints conditions.

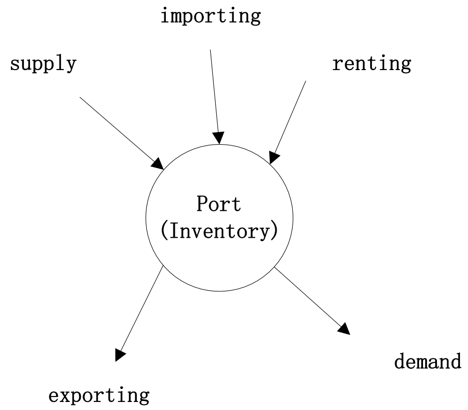


Figure 1. The Container Flows in Ports

(1) Inventory constraint

The inventory at port i in period t can be represented as (1), where the first term represents the inventory of previous period t-1, the second and third terms describe the demand and supply of current period, the fourth and fifth terms show the difference between the import and export, and the last term explains the number of leasing empty containers. Note that when t=0 the $Inv_i^t = Inv0_i$.

$$Inv_i^t = Inv_i^{t-1} - D_i^t + S_i^t - \sum_{j \in P} tr_{ij}^t + \sum_{j \in P} tr_{ji}^t + rent_i^t; \quad (2)$$

To ensure the temporary demand and avoid short-term many repositioning of empty containers, we also consider maintaining some certain stock. So the Inv_i^t should subject to (3), which represents the stock ranges from lb and ub. It also refers to as safe stock level. Since it is not our focus, here we assume that it has been given beforehand. If it is less than lb, the port i should be imported the empty containers. Otherwise if it is larger than ub, the empty containers need to be exported from the port i.

$$Inv_i^t \in [lb, ub]; \forall i \in P, t \in T, ub > lb \geq 0; \quad (3)$$

(2) Transportation constraint

$$Inv_i^{t-1} - D_i^t + S_i^t \geq \sum_{j \in P_-^t} tr_{ij}^t; \ \forall i \in P_+^t, t \in T; \quad (4)$$

$$|Inv_j^{t-1} - D_j^t + S_j^t| \leq \sum_{i \in P_+^t} tr_{ij}^t; \ \forall j \in P_-^t, t \in T; \quad (5)$$

Only do the ECR take place when the surplus and deficit ports exist in the same period t. As the supply/demand empty containers in surplus/deficit ports are limit, the number of dispatching ones to the deficit ports must be subject to (4) and (5), where (4) describes the outbound empty containers for each surplus port in each t should be less than its available ones, (5) explains the inbound empty containers from all surplus ports to some deficit port in each t should be larger than its inventory of previous period minus net demand empty containers, and |·| represents the corresponding absolute value.

(3) Repositioning capacity constraint

The number of empty containers that are repositioned from surplus ports to deficit ports in period t cannot exceed the vacant vessel space in corresponding t shown as (6).

$$tr_{ij}^t \leq Cap_{ij}^t, \forall i \in P_+^t, j \in P_-^t, t \in T; \quad (6)$$

(4) Leasing constraint

Once the transportation empty containers cannot satisfy the demands, the leasing strategy must be employed. It is described as (7).

$$rent_j^t = \left| Inv_j^{t-1} - D_j^t + S_j^t + \sum_{i \in P_+^t} tr_{ij}^t \right|, \forall j \in P_-^t, t \in T;$$

(7)

4. Simulations and Analysis

4.1. Dataset

To evaluate the proposed model, the dataset generate and obey the rules below. We regard t as the weekly period. The corresponding inventory cost, leasing cost, loading and unloading cost of each port are estimated to be approximately in a period t according to the standard of foreign and domestic trade containers import trade containers. Generally the inventory cost is about $8 per TEU in one period. Since the purchasing price of a TEU which is amortized for a year, is roughly $946, we consider the leasing cost of per container in a period t as $7. The loading and unloading costs of per empty TEU per time are both $23. The transportation costs between ports randomly generate within [$50, $100]. The following scenarios are used to assess the models, where the inventory and leasing costs in all ports are identical in Scenario 1, Scenario 2 and Scenario 3.

(1) Scenario 1: supply empty containers are larger than demand ones in the T.

(2) Scenario 2: supply empty containers are less than demand ones in the T.

(3) Scenario 3: supply and demand empty containers are balanced in the T.

(4) Scenario 4: leasing and inventory costs in port 1-6 are the half ones of port 7-12.

In this paper we use the cplex 12.6 to solve these models. Simulations are made on a PC with Intel Core Quad Q8400, CPU 2.66 GHz and 2 GB memory. Note that the planning horizon T is assumed to be 1, 2, 3 and 4 periods.

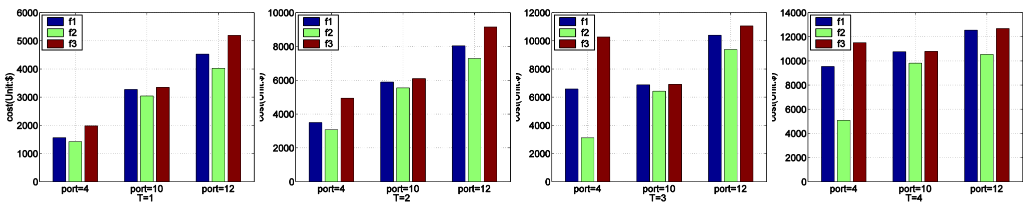
4.2. Strategies for Comparison

To analyze and evaluate our proposed model: f_1, there are other three ECR models are designed. The first one is the f_2 which is similar to f_1 but excludes the repositioning capacity constraint (6) to explain the effect of residual vessel capacity constraint. The second one is the f_3 which does not consider the stock strategy. The last one f_4 is designed not to use the heuristic rule, which distinguish the surplus and deficit ports in each period t. The objective function of f_4 is formed as (8).

$$\text{Min } f_4 = \sum_{t\in T}\sum_{i\in P}\sum_{j\in P}\left(C_{ij}^{tr} + C_i^{l} + C_j^{u}\right) * tr_{ij}^{t} + \sum_{t\in T}\sum_{i\in P} C_i^{r} * rent_i^{t} + \sum_{t\in T}\sum_{i\in P} C_i^{i} * Inv_i^{t}; \quad (8)$$

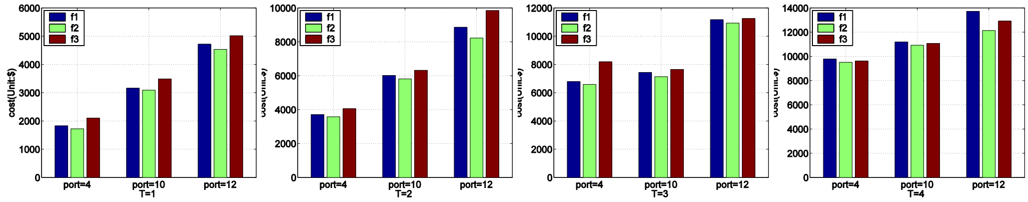
4.3. Experimental Results and Analysis

In this section, the above models are evaluated on the basis of three indicators: the whole operational cost, the percentage of each cost in whole operational cost and actual running time.



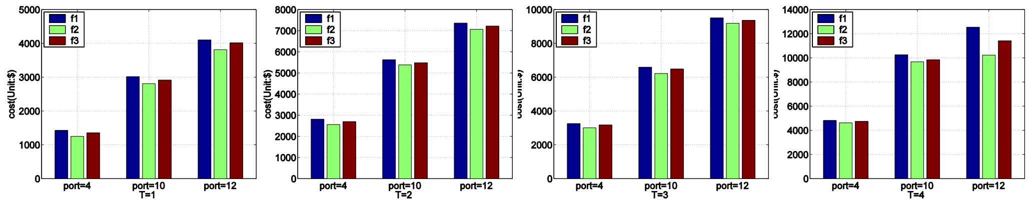
(a) (b) (c) (d)

Figure 2. Operational Costs in Scenario 1



(a) (b) (c) (d)

Figure 3. Operational Costs in Scenario 2



(a) (b) (c) (d)

Figure 4. Operational Costs in Scenario 3

4.3.1. Operational Cost

Figure 2, Figure 3 and Figure 4 give the operational costs in Scenario 1, Scenario 2 and Scenario 3 respectively. To begin with from the overall view, it is easy to discover that the model f_2 has priority over other two models under different T, number of ports and scenarios. The main reason is due to that the f_2 only aims at the cost and does not subject to the residual vessel capacity constraint. Most of the time the transportation planning does not be executed if there is no residual vessel space enough since the laden containers have more higher priority over the empty one. Although the f_2 has the lower cost than others, its shortage is also obvious. In contrast, the f_1 has considered both the various constraints and stock to meet the demands in actual business. The stock policy alleviates the urgent transportation demands to a certain extent and directly results in the decreasing of transportation and leasing costs. Ulteriorly, as the f_3 does not take the stock into account at all, it is not avoidable that the leasing and transportation costs will happen once the deficit ports have no empty containers to be used.

Then, compared with these three figures under different scenarios, we can say that the operational costs are the lowest ones in scenario 3. As opposed to scenario 3, scenario 1 has higher costs as the supply empty containers are larger than the demand ones. The surplus empty containers will produce the inventory costs. Similar to scenario 1, scenario 2 will generate more leasing costs to satisfy the deficit ports.

Furthermore, with the increasing of T there is little rise in operational costs of f_1 and f_2 than f_3. It attributes the results to the stock policy. The repositioning policy must be maintained to ensure the safe stock in each period. For the multiple periods, the previous periods: …, t-1, t, have dealt with the transportation empty containers in advance to guaranty the demands in future periods: t+1, …, T. The various costs in periods afore may be prepaid for the following ones. So with the evolving of time, the rising of operational cost is little in the models which have considered the stock policy.

Finally, from these three group figures it is obvious that the stock constraint condition is more influential factor than the residual vessel capacity since the cost of f_3 is larger than f_2 in each scenario. In actual business, all ports generally keep some certain stocks to reply the temporary demands although they have to take the inventory costs.

4.3.2. Analysis on Each Cost in Whole Operational Cost

In this section, we evaluate the effect of each cost in total operational cost through analysis their percentages. The results are shown in Table 1-3 under T=4 and port=12 in Scenario 4 when there are different relationships of demand and supply. To illustrate efficiently, we use the handling cost instead of the loading and unloading ones.

Table 1. The Percentage of Each Cost in Whole Operational Cost in Scenario 1 (Unit: $)

	transportation cost	leasing cost	inventory cost	handling cost	whole operational cost
f_1	10%	13%	21%	56%	13,717
f_2	14%	10%	18%	58%	12,138
f_3	13%	12%	20%	55%	12,924

In Table 1, for these three models the whole operational costs are larger than scenario 3 respectively, where the percentages of inventory costs decrease meanwhile the leasing costs increase. As for f_1 the inventory cost is 21% in scenarios 1 as well as 16% in scenario 3. It is highly relevant with the total net empty containers. Similar to f_1, f_2 and f_3 also have the same situations.

Table 2. The Percentage of Each Cost in Whole Operational Cost in Scenario 2 (Unit: $)

	transportation cost	leasing cost	inventory cost	handling cost	whole operational cost
f_1	6%	18%	19%	57%	14,349
f_2	13%	12%	15%	60%	12,563
f_3	9%	18%	12%	61%	13,568

From Table 2, we can obverse that the percentages of handling cost become approximately compared with scenario 3. For f_1 the leasing cost is higher than the one in Table 2 and 3 because the supply empty containers are less than the demand ones in the whole T. The shortages have to resort to leasing strategy which directly leads to the increasing of corresponding costs.

Table 3. The Percentage of Each Cost in Whole Operational Cost in Scenario 3 (Unit: $)

	transportation cost	leasing cost	inventory cost	handling cost	whole operational cost
f_1	12%	16%	16%	56%	12,541
f_2	13%	14%	15%	58%	10,226
f_3	9%	19%	11%	61%	11,419

From Table 3 we discover that for all models the percentages of handling cost are the first. It is mainly due to the balance of demand and supply which directly leads to the reduction of inventory and leasing costs. Second, for f_2 and f_3, which give up the residual vessel capacity and stock constraint respectively, they have more proportions of handling and leasing costs than f_1. Third, f_3 has the top handling cost since it does not keep the stock, which involves many unloading and loading empty containers.

In actual business, scenario 2 is closer to the reality than others because the total demand empty containers are much larger than the supply ones. For above three tables, it can conclude that the handling costs have the largest proportion in operational cost and exceeds 55%. It indicates that improving its efficiency could be the most important factor in reducing the total cost. This result is also consistent with the actual situation in liner shipping. So we should reduce the times of handling and transshipment of empty containers as possible as.

4.3.3. Running Time

Table 4 describes the running time of f_1 and f_4. It can easily observe that f_1 has good time performance than f_4 in different T. The computational times are the key points. Since f_1 distinguishes the deficit and surplus ports in each period, it will dramatically reduce the search space. Suppose that the number of ports are N, the average deficit and surplus ports are 0.6*N and 0.4*N respectively, the computational times will be the $0.6*N*0.4*N*T=0.24*N^2*T$ in f_1 instead of the N^2*T in f_4. The computational time of the former is only the quarter of the latter. Furthermore, with the decreasing of proportion of deficit and surplus ports, it also reduces respectively. So the heuristic rule used in f_1 reduces the calculation times.

Table 4. Running Time in Scenario 1 When T=4 and Port=12 (Unit: Second)

	T=1	T=2	T=3	T=4
f_1	0.92	1.63	2.74	3.69
f_4	1.67	3.74	5.48	7.41

4. Conclusion

This paper presents a heuristic programming model to model the ECR problem in operational level. This model minimizes the whole operational cost by considering both various constraints and stock policy. Some contrasted strategies are proposed to compare with it. In addition, the whole operational cost, the percentage of each cost in whole operational cost and actual running time are employed to analyze their performances. The results state that on one thing the proposed model can deal with the ECR problem efficiently and effectively. On another thing, it can also guide us to make the decision on the stock level according to the different scenarios. In this paper, our model considers the supply and demand are given in advance; one of the extensions of this paper is to develop the uncertainties in them since it can match practice. Furthermore, inspired by the concept of ambient intelligence given in the literature [17], we can consider the whole environment of ECR to build the corresponding model. Another possible future work is to transport the empty containers with transshipping policy which can accelerate the arrival time of goods although it may be increasing the handling costs. Sometimes, we have to find a compromise between the time and cost.

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