Research on empty container transportation based on (D, U) control strategy under random demand

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Abstract. In order to effectively reduce the cost of empty container dispatching and transportation, an integer programming model for empty container dispatching and transportation with multiple periods and multiple ports was established, and the empty container dispatching and transportation scheme was optimized under the (D, U) inventory control strategy considering the service level. The results show that compared with no inventory control strategy, the (D, U) strategy can effectively reduce the total operating cost of liner companies. Select the service level for sensitivity analysis, and verify that (D, U) control strategy can effectively reduce the dependence of liner companies on container chartering.

Keywords: empty container transportation, (D, U) Control strategy, Service level, Integer programming.

1. Introduction

Based on the current world trade inequality and imperfect management of the situation, there are differences in container storage in world ports. Empty container transportation is beneficial to reduce the cost of empty container inventory, improve the turnover rate of goods at ports and terminals, thus improving customer service level and overall profit margin. At present, empty container inventory management is only a key influencing factor of empty container transportation research, and few researches focus on inventory control strategy. Therefore, it is of certain significance to consider how to rationally arrange empty container transportation through inventory control method to reduce container operation cost of liner companies.

Studies on offshore empty container transportation mainly include: Paper used the two-stage game model to study the impact of empty container relocation cost and information asymmetry on system performance[1]. Reference applied the two-stage optimization method to study an empty container distribution problem considering coordination among liner shipping companies[2]. Reference adopted the two-stage optimization method to solve the decision-making problem of empty container relocation and leasing, and determined the leasing price[3]. The paper used the mixed integer linear programming model to calculate the container transportation problem of liner alliance, and used the reverse optimization method to calculate the cost of capacity exchange between liner companies[4].

In recent years, more studies on multimodal transport have emerged: The paper derived the optimal empty container delivery strategy and the optimal free detention time of the maritime carrier by using the two-stage game model[5]. Reference studied the empty container management strategy in the two-way four-echelon container supply chain of bilateral trade between the two countries[6]. Reference studied the allocation and coordination of empty container inventory at land ports formed by a railway transport company at a land port and a liner company at a sea port in multimodal transport[7]. Paper studied a multi-modal empty container transportation model and proposed a multi-commodity model[8].

In terms of the research on the joint optimization of empty container transportation and empty container inventory, Paper designed a model combining THE ECR problem with the dynamic path problem of tramp ships[9]. Paper considered a joint fleet deployment and inventory management problem by dynamically adjusting the docking order of ship routes and controlling empty container inventory[10]. Reference studied the repositioning of empty container inventory considering

customer demand transformation in multimodal transportation and proposed an inventory coordination strategy based on revenue sharing contract[11]. The paper studied the supply and demand of empty containers in port groups and optimized the empty container volume in ports under the (D, U) control strategy[12].

Based on the above research on empty container transportation, it can be found that the selection of empty container control strategy and the determination of empty container inventory threshold need further research and optimization. To solve the above problems, this paper takes a port on a liner transport line as the research object, comprehensively considers the factors of multi-cycle, service level and (D, U) strategy, and constructs an integer programming model with the goal of minimizing the total cost of empty container transportation, and discusses the influence of (D, U) strategy adopted by shipping companies on the total cost of empty container transportation.

2. Problem description

Due to the imbalance of cargo flow in various regions, the demand and supply of containers in various ports differ greatly, so the reuse and transportation of empty containers has become an important part of container management. And in the container ship transport process, most ships are not fully loaded, and the remaining empty space can be used to move containers between ports.

In addition, in order to reduce the time cost brought by empty container transportation and deal with the uncertainty of empty container supply and demand in the future, the inventory holding interval is set in each port of each cycle. D value represents the minimum empty container inventory of the port, and U value represents the maximum empty container inventory of the port. It means that when the empty container inventory of the port is higher than U value, the excess empty container quantity will be shipped to other ports; When the empty container inventory at the port is lower than D value, the empty container inventory can be made up through inter-port empty container transportation or leasing.

In this paper, in the process of the liner shipping into the target of minimizing the total cost of each cycle number of routes in liner shipping scheduling, the use of space for empty containers on at the same time meet the demand of empty containers in port supply under the premise of empty containers to the port of each cycle inventory management application of the concept of stock ownership interval. Fig. 1 shows the liner transport structure diagram of an airline company on a multi-port connection route.

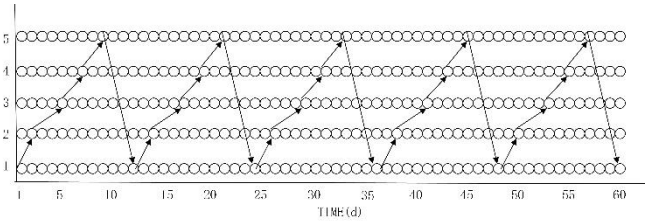


Fig.1 Liner transport structure drawing on multi-port call line

3. Model building

3.1 Hypothesis

The shipping interval on the route is fixed, and the number of heavy containers transported to each port is known, so the ship can arrive at the port on time; Only consider shipping 20ft containers, 40ft containers can be replaced by two 20ft containers; Empty container restrictions for each segment are known; The port can be rented immediately and the amount of leased containers is not limited, so the model does not need to consider returning containers in the decision-making period; Only single route transportation is considered.

3.2 Symbol Description

Mathematical Aggregation: P is the collection of all transport ports, P={1,2,3,…,p}; N is the flight cycle, N={1,2,3... , n}.

Cost Parameters: C_i^r is the unit container rental cost of port I; C_i^s is the unit empty container unloading cost of port I; C_i^v is the unit empty container packing cost of port I; C_i^h is the unit storage cost of port I; C_i^w is the unit shortage cost of port I; C_i^l is the unit transportation cost of empty containers transported by a carrier from port I to the next port;.

Other Parameters: Q_i^n is the empty container demand of port I in the NTH cycle, which is independent and identically distributed random number and follows normal distribution Q_i^n~N(μ_i, σ_i^2);Q_i^n is the empty container supply quantity of port I in the NTH cycle, which is an independent random number with the same distribution and follows the normal distribution S_i^n~N$(m_i,\ s_i^2)$;$r_i^n$is the empty container carrying limit of the carrier at port I in the NTH cycle; D_i is the lower limit of empty container inventory of port I; U_i is the upper limit of empty container inventory of port I; k is the service level of the shipping company.

Decision Variables: X_{ir}^n is the number of containers rented at port I in the NTH cycle; X_{is}^n is the number of empty containers unloaded at port I in the NTH cycle; X_{iv}^n is the number of empty containers loaded at port I in the NTH cycle.

Related Variable: R_i^n is the empty container quantity of port I after leaving port I in the NTH cycle; V_i^n is the amount of empty containers on board after leaving port I in the NTH cycle; W_i^n is the amount of container shortage at port I in the NTH cycle.

3.3 Mathematical Model

In the empty container dispatching and transportation optimization scheme under the strategy (D, U) considering the influence of service level, the objective function is to minimize the total cost of the shipping company in the decision-making period, that is, the minimum sum of the storage cost, leasing cost, packing cost, unloading cost, transportation cost and shortage cost of empty containers. The sum of empty packing, unloading and transportation costs is empty container transportation cost.

$$\begin{aligned} J_{\min} = & \sum_{\mathrm{n}}\sum_{\mathrm{i}} C_i^h R_i^n + \sum_{\mathrm{n}}\sum_{\mathrm{i}} C_i^r X_{ir}^n \\ & + \sum_{\mathrm{n}}\sum_{\mathrm{i}} C_i^s X_{is}^n + \sum_{\mathrm{n}}\sum_{\mathrm{i}} C_i^v X_{iv}^n \\ & + \sum_{\mathrm{n}}\sum_{\mathrm{i}} C_i^l V_i^n + \sum_{\mathrm{n}}\sum_{\mathrm{i}} C_i^w W_i^n \end{aligned} \tag{1}$$

Constraints to be met are as follows:

$$V_i^n = V_{i-1}^n + X_{\mathrm{iv}}^n - X_{is}^n \tag{2}$$

$$W_i^n + R_i^{n-1} + S_i^n \geq Q_i^n \tag{3}$$

$$R_i^n = R_i^{n-1} + S_i^n - Q_i^n + X_{ir}^n + X_{is}^n - X_{\mathrm{iv}}^n \tag{4}$$

$$V_i^n \leq r_i^n \tag{5}$$

$$R_i^n \leq U_i \tag{6}$$

$$R_i^n \geq D_i \tag{7}$$

$$X_{ir}^{n}, X_{is}^{n}, X_{iv}^{n} \geq 0 \tag{8}$$

$$U_i = \mu_i + Z(k) \bullet \sigma_i \tag{9}$$

$$D_i = \max[0, \mu_i - m_i] + Z(k) \bullet \sigma_i \tag{10}$$

Equation (2) refers to the number of empty containers on board when leaving the port. It is the number of empty containers on board when arriving at the port plus the number of empty containers on board at the port minus the number of empty containers unloaded from the ship; Equation (3) represents the container shortage constraint of the port, that is, the container shortage plus the number of empty containers in the port after a period plus the quantity of empty containers supplied in the current period shall be greater than or equal to the empty container demand in the current period; Equation (4) represents the stock of empty containers in port I at the end of the NTH cycle after the demand for empty containers is met, which is the number of empty containers in the port after the previous cycle plus the supply of empty containers in the current cycle minus the demand for empty containers in the current cycle plus the sum of the rent and unloaded empty containers in the current period minus the number of empty containers on board in the current period; Equation (5) means that the number of empty containers on board cannot exceed the ship's maximum transport capacity; Equation (6) and (7) indicates that the empty container inventory of the port should be kept within the threshold range; Equation (8) is a non-negative and integer constraint.

Based on the reference, Equation (9) and Equation (10) add the relevant theories of safety stock, thus introducing the service level k, and give the derivation formula of empty container threshold of ports under different cycles [19]. μ_i said flight out of the empty container ports issue I mean (i.e., the demand of empty container), m_i said I port each flight into the chamber average (i.e., the supply of empty containers), σ_i said port I empty containers in each cycle demand standard deviation, the $Z(k)$ for the confidence level for k corresponding Z statistics, can be obtained by querying the normal distribution table. The upper limit of the inventory threshold is the sum of standard deviations of the demand for empty containers at the port and the demand affected by the inventory service level. The lower limit of the inventory threshold is the sum of the standard deviation of the inflow difference between port demand and supply and the demand affected by the inventory satisfaction level. The inflow difference between demand and supply is a reference to the research conclusion, in order to make empty containers flow from excess port to shortage port as much as possible[19].

4. analysis of example

4.1 Known Conditions

Assuming that a liner company operates an ocean liner line with five ports, the empty container transportation scheme of each port in the next five decision-making periods is studied. Assuming that the service level of liner company is 98%, the corresponding Z-statistic value can be obtained by querying the normal distribution table.

The chartering cost, unloading cost, loading cost, storage cost, segment transportation cost and initial empty container stock of each port are shown in TABLE I. The limitation of empty container traffic at sea for each port in each cycle during the decision period is shown in TABLE II below. Empty container demand and empty container supply of each port in each cycle obey normal distribution. According to formula (9)-(10) for the upper and lower limits of empty container inventory threshold, the empty container inventory holding interval of each port can be obtained, as shown in TABLE III.

Table 1. Cost of each port (USD·TEU-1)

	Port 1	Port 2	Port 3	Port 4	Port 5
Leasing Cost	8	9	27	25	25
Unloading Cost	3	3	2	2	2
Loading Cost	2	3	2	2	2
Storage Cost	3	4	1	2	1
Lacking Cost	19	22	37	55	32
Segment Transportation Cost	1	2	1	1	2

Table 2. Limit of Empty Containers (TEU)

	Port 1	Port 2	Port 3	Port 4	Port 5
First Period	280	290	200	220	180
Second Period	270	260	300	250	200
Third Period	290	350	320	280	230
Fourth Period	320	290	300	260	200
Fifth Period	300	310	260	270	250

Table 3. Empty Container Demand, Supply distribution function and Inventory Interval (TEU)

	Demand Distribution	Supply Distribution	(D, U)
Port 1	(120,202)	(220,202)	(42,162)
Port 2	(140,202)	(260,202)	(42,182)
Port 3	(160,202)	(120,202)	(80,202)
Port 4	(220,202)	(100,202)	(162,262)
Port 5	(330,202)	(80,202)	(292,372)

4.2 Analysis Of Calculation Results

According to the constructed empty container transportation model, the optimal empty container transportation scheme can be obtained by solving it with the help of CPLEX12.6. The total cost is USD 41942, the empty container rental cost is USD 19,252, the empty container transportation cost including loading and unloading cost and transportation cost is USD 17,799, and the empty container storage cost is USD 3,675. The shortage cost is $1,216. The details of container leasing, container transfer and space allocation at ports in each cycle are shown in TABLE IV-VII. Among them, only 38TEU was missing in the fifth port of the first cycle during the whole decision period.

Table 4. The amount of containers rented (TEU)

	Port 1	Port 2	Port 3	Port 4	Port 5
First Period	379	87	0	78	386
Second Period	148	0	0	0	84
Third Period	63	0	0	0	75
Fourth Period	0	0	0	0	86
Fifth Period	13	0	0	0	54

Table 5. Unloaded empty containers at each port (TEU)

	Port 1	Port 2	Port 3	Port 4	Port 5
First Period	0	0	102	188	0
Second Period	0	0	4	91	165
Third Period	0	0	67	114	169
Fourth Period	0	0	65	76	149
Fifth Period	0	0	58	96	156

Table 6. loaded empty containers at each port (TEU)

	Port 1	Port 2	Port 3	Port 4	Port 5
First Period	280	10	0	0	0
Second Period	203	57	0	0	0
Third Period	215	135	0	0	0
Fourth Period	140	150	0	0	0
Fifth Period	176	134	0	0	0

Table 7. Distribution of shipping space (TEU)

	Port 1	Port 2	Port 3	Port 4	Port 5
First Period	280	299	188	0	0
Second Period	203	260	256	165	0
Third Period	215	350	283	169	0
Fourth Period	140	290	225	149	0
Fifth Period	176	310	252	156	0

In view of the randomness of empty container demand and supply in the actual operation of empty container transportation of liner companies, this paper substituted the calculated empty container transportation scheme into the simulation experiment for simulation. Due to the uncertainty of the demand, the shortage cost increased slightly, and the average total cost during the decision period was $42,324. This also verifies the effectively and feasibility of the model constructed in this paper.

4.3 Sensitivity analysis

Fig. 2 shows how the total cost changes under different service levels. Among them, the sum of empty packing, unloading and transportation costs is empty container transportation cost. It can be seen that under the condition that other factors remain unchanged, all costs show an upward trend with the increase of service level. In other words, the higher the service level set by the liner company, the higher the empty container transportation cost will be, but when the service level is improved to a certain extent, the higher the cost will be to continue to improve the service level. For example, in Fig. 2, when the service level is raised to 99%, the total cost increases steeply. This shows that improving the service level can increase customer satisfaction, but when the service level is too high, further improving the service level will lead to a substantial increase in cost, so that the benefit brought by improving the service level is less than the cost paid, so liner companies need to balance between the service level and operating cost.

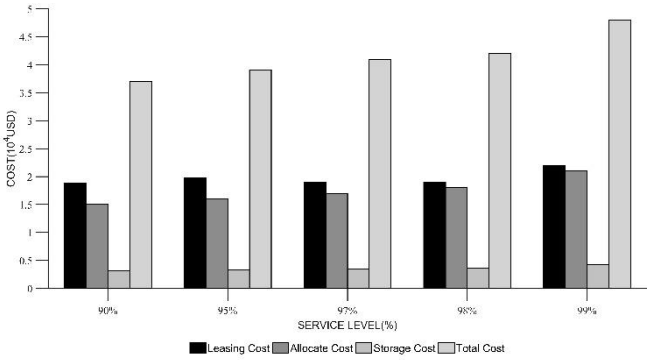


Fig.2 The impact of changes in service levels on various costs

Fig. 3 shows the impact of an increase in empty container demand to 50% on total cost. As the port demand increases, so does the total cost. When the quantity demanded increased by 10% and 20%, the total cost increased by 7.3% and 4.5%, respectively, while when the quantity demanded increased from 30% to 50%, the total cost increased by only about 2%. Obviously, the larger the increase in demand is, the smaller the fluctuation range of the total cost of the model is. Other costs also grow steadily, while the fluctuation range of storage cost is small. This is because under the strategy of (D, U), the empty container inventory at the port is kept within a reasonable range, so that liner companies can use the empty container inventory to meet the demand even if there is a large demand fluctuation, instead of making up for the missing demand through a large number of container leasing and container transfer.

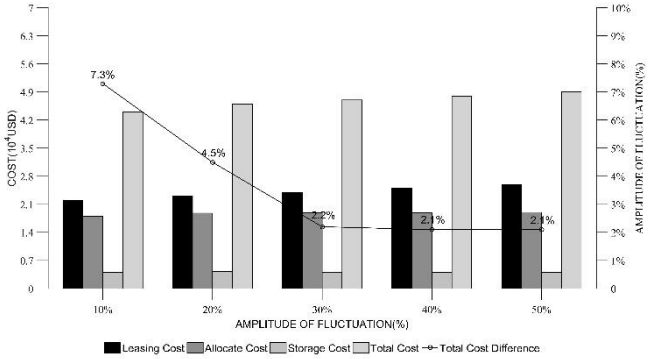


Fig.3 The impact of empty container demand changes on various costs

5. Conclusion

Problem of empty container transportation on the sea, this paper established the liner companies more cycles of empty containers of dispatching model, (D, U) strategy is used to determine the

ownership empty containers in port range, to verify the (D, U) strategy can effectively reduce the cost of empty container transportation liner company, at the same time reduces the demand changes impact on the scheduling scheme and the cost of empty containers. Reasonable and effective inventory control strategy can increase the stability of shipping scheme and reduce the dependence of liner companies on temporary container chartering, which is more conducive to the long-term development of the company. There are still some shortcomings in this study, such as not considering the multi-modal transport, multi-route transport, multi-container type and other factors in empty container transportation.

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