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Optimization of Mixed Transportation of Empty Containers Considering Foldable Containers

Shumin Wang[a], Jiankun Hu[b]

Institute of Logistics Science and Engineering, Shanghai Maritime University, Shanghai 201306, China

[a]15039428613@163.com, [b]jkhu@shmtu.edu.cn

Abstract

To explore the economy of standard empty container and foldable empty container mixed use and the effect of foldable empty container on the total cost of empty container transportation under different supply ratio. In order to minimize the total cost of empty container transportation, a mixed integer nonlinear programming model was established for the mixed use of standard empty container and mixed transportation. Use Lingo to solve the problem. For two models, analyze the costs of empty container transportation and the costs of the foldable empty container under different supply ratios. Analyze the cost of foldable empty containers under different supply ratios when the unit transportation cost and demand change. The foldable empty container can save the cost of empty container transportation. When the supply ratio of foldable empty container is 0-20%,the total cost of empty container transportation decreases significantly. The downward trend begins slowly at 20%-75% and the downward trend is not obvious when 75%-100%. The use of foldable empty containers can reduce the cost of empty container transportation. Reasonably arranging the supply ratio of standard empty containers and foldable empty containers can control the total cost of empty container transportation well.

Keywords

Empty Container Transportation; Standard Container; Foldable Container; Mixed Transportation.

1. Introduction

According to statistics, the cost of transport empty containers accounts for about 30% of the total cost of transport empty containers[1]. There are 20%~25% empty containers of the global container volume and the cost of empty container transportation is as high as 30 billion dollars every year[2]. Due to the unbalanced development of global trade, the supply and demand of empty containers in various regions is unbalanced, there is often a shortage of empty containers in export-oriented areas and a backlog of empty containers in import-oriented areas. Empty container transportation is a major problem in the shipping industry. The use of folding container makes four empty containers only occupy the space of a standard container, which saving the space occupied by empty containers. However, the popularity of foldable containers is not enough, various technologies are not mature, the manufacturing cost is too high and the foldable containers are not easy to obtain now. So this paper use foldable empty containers and standard empty containers are mixed for transportation and study the foldable empty containers in which ratio is more economical to alleviate the problem of empty containers transportation.

Domestic and foreign scholars do a lot of research to solve the problem of empty container transportation.Song etc.[3] considered a strategy of flexible destination port, the destination port of empty container transportation is determined according to the latest supply and demand situation in each period. Finally, the simulation result shows that the flexible destination port strategy is better when the supply and demand is unbalanced. Du Fei[4]considered the factors of container leasing limited and randomness of supply and demand from the perspective of empty container storage and established a dynamic stochastic programming model to obtain the optimal empty container storage by Monte Carlo simulation and Genetic Algorithm. Then empty container transportation was studied from the perspective of shipping alliance and solved by Lingo. Francesco[5] studied the case of possible port interruption, the empty container transportation at sea when the parameters are uncertain is and compared with that when the parameters are certain. Zheng[6] considered the coordination ability of liner carriers, studying the empty container allocation problem among liner carriers by using two-stage optimization method and inverse optimization technique. Fang Wei[7]built a cost model that take into account carbon and sulfur emissions to analyze the impact of carbon and sulfur emissions on the cost of empty container transportation. Zhang Yuan-yi[8] studied the empty container transportation in the process of land and sea combined transportation with uncertain empty container demand, used two-stage modeling method and considered the constraints of container leasing limited in order to more realistic.Han Xiao-long[9]studied the empty container transportation strategy of several liner companies collaborate under the mode of multimodal transportation. Wang Chuan-xu[10] considered the cooperation of shipping companies under the supply and demand are random and established a two-stage empty container transportation model to verify that the cooperation shipping companies can reduce the cost of empty container transportation effectively.

In recent years, the emergence of foldable containers saves the space occupied by empty containers, which can reduce the inventory cost and transportation cost of containers effectively. ILKYEONG M[11] considered the installation situation of foldable container equipment in each port, a mixed integer linear programming model with minimum transportation cost was established and solved by genetic algorithm. Zheng[12]proposed a two-stage optimization method to determine the container rental price and considered a strategy of folding containers and container replacement in the study. Zhang Li-na[13] studied the situationof foldable container in sea and land combined transportation, established the model of standard container and foldable container and concluded that foldable container is superior to standard container under certain conditions through cost analysis. Xing Lei[14] studied the empty container transportation problem of China-Europe freight train, established three models of using only standard container, using only foldable container and mixed use of two containers and explored the economy of land and sea combined transportation under three conditions. At the same time, Xing Lei[15] also adopted distributed robust opportunity-constrained programming to study the influences of demand changes, different supply ratios of standard empty containers and foldable empty containers and various cost changes on the total cost of empty container transportation. Moon[16]established mathematical model and heuristic algorithm to compared the foldable containers and standard containers. The results shows that the foldable container is a good choice in some conditions but it can not be widely used due to its high manufacturing and maintenance costs and easy damage.

In conclusion, domestic and foreign scholars have done a lot of studies on empty container transportation and have formed a rich knowledge base for foldable empty containers, which plays a guiding role in laying the theoretical foundation for this study. However, the current research on foldable containers mainly focuses on the feasibility analysis. It is generally believed that standard empty containers and foldable empty containers produce supply and demand respectively in the study of the mixed use of standard containers and foldable containers. This paper studies the supply and demand of standard and foldable empty containers are total supply and total demand are not respectively, on the basis of the feasibility of foldable empty containers explore empty container transportation cost changes of foldable empty containers on the different supply ratio in the total

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supply and in order to more realistic considers the conditions of container leasing limited amount and pay a certain cost of punishment the demand can not fully meet.

2. Problem Description

This paper studies empty container transportation from the perspective of shipping companies. The supply port provides empty containers to the demand port, the transportation between supply ports and demand ports cannot be carried out and direct transportation between ports does not require transit.

This paper construct models of only use empty containers and mixed use standard and foldable containers. First, the economical efficiency of the use of foldable empty containers compared with standard empty containers is studied. Secondly, in order to reduce the cost of empty containers transportation consider explore the change of the cost of empty containers transportation when the foldable empty containers occupy different supply ratios when the supply and demand of empty containers are determined. In models, in addition to considering the inventory balance, transport constraints, but also considering the container leasing limited amount and the penalty cost when empty container demand can not be satisfied so that the model is more practical.

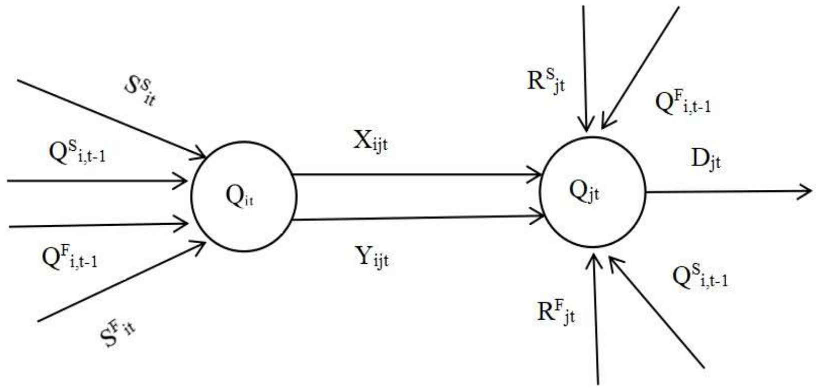

Figure 1. The diagram of empty container repositioning flow

As Figure 1, the empty container flow diagram is drawn according to the empty container inventory balance in the process of empty container transportation. It mainly represents the inflow and outflow of empty containers at supply port and demand port in period t. The inflow of supply port are the supply for empty containers at supply port in period t and the inventory in period t-1. The outflow of supply port is the number of empty containers from the supply port to the demand port in period t. The inflow of demand port are empty container inventory in period t, the number of empty containers from the supply port to the demand port in period t and the amount of empty containers leasing in period t. The outflow of demand port is the demand for empty container at demand port in period t.Together they decide the inventory balance of empty container at supply and demand ports.

3. Modeling

3.1 Model Assumption

(1) The supply and demand for empty containers are known.

(2) The demand of the demand port can not be fully met but it will produce penalty cost.

(3) Consider leasing containers and the number of containers rented at each port is limited.

(4) This paper does not consider the problem of reloading leased containers.

(5) Only standard 40 ft and foldable containers are considered.

(6) Foldable empty containers must be folded during transportation and storage.

(7) Four empty foldable containers can be folded to a standard container.

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3.2 Symbol description

The collection of supply port S is i and the collection of demand port D is j (i=1,2,...S, j=1,2,...D); t is the decision cycle (t=1,2,... T).

ct_{ij}^{S}: The unit transportation cost of standard empty container from port i to port j;

ct_{ij}^{F}:The unit transportation cost of foldable empty container from port i to port j;

cs_{i}^{S}:Unit storage cost of standard empty container at port i;

cs_{i}^{F}:Unit storage cost of foldable empty container at port i;

ca_{i}^{S}:Unit handling cost for standard empty containers at port i;

ca_{i}^{F}:Unit handling cost for foldable empty containers at port i;

cr_{jt}^{S}:Unit leasing cost for standard empty container;

cr_{jt}^{F}:Unit leasing cost for foldable empty container;

cl_{jt}:The unit shortage cost;

M_{i}^{F}:Unit folding cost of foldable empty container at port i in period t;

M_{i}^{U}:Unit unfolding cost of foldable empty container at port i in period t;

X_{ijt}:Standard empty container quantity transported from port i to port j in period t;

Y_{ijt}:Foldable empty container quantity transported from port i to port j in period t;

Q_{it}^{S}:Inventory of standard empty containers at port i in period t;

Q_{it}^{F}:Inventory of foldable empty containers at port i in period t;

L_{jt}:The Shortage of containers in period t;

R_{jt}^{S}:The quantity of leasing standard empty container at port j in period t;

R_{jt}^{F}:The quantity of leasing foldable empty container at port j in period t;

Rl_{jt}:The limitation on the amount of containers leased at port j in period t;

S_{it}^{S}:The supply of standard empty container at port i in period t;

S_{it}^{F}:The supply of foldable empty container at port i in period t;

D_{jt}:The demand of Empty container of port J in period t;

K_{ijt}:The limitation of transport capacity from port i to port j in period t;

N_{it}^{F}:The quantity of foldable container that need to be folded at port i in period t;

N_{it}^{U}:The quantity of foldable container that need to be unfolded at port i in period t.

3.3 Model

Model 1, Mathematical programming model using standard empty containers:

$$MinC=\sum_{t=1}^{T}\sum_{i=1}^{S}\sum_{j=1}^{D}ct_{ij}^{S}X_{ijt}+\sum_{t=1}^{T}\sum_{i=1}^{S}cs_{i}^{S}Q_{it}^{S}+\sum_{t=1}^{T}\sum_{j=1}^{D}cs_{j}^{S}Q_{j}^{S}+\sum_{t=1}^{T}\sum_{i=1}^{S}\sum_{j=1}^{D}(ca_{i}^{S}+ca_{j}^{S})X_{ijt}$$
$$+\sum_{t=1}^{T}\sum_{j=1}^{D}cr_{jt}^{S}R_{jt}^{S}+\sum_{t=1}^{T}\sum_{j=1}^{D}L_{jt}cl_{jt} \quad (1)$$

$$Q_{it}^{S}=Q_{it-1}^{S}+S_{it}^{S}-\sum_{j=1}^{D}X_{ijt} \quad \forall \mathrm{i}\in S,t\in T \quad (2)$$

$$Q_{jt}^{S}=\max(0,R_{jt}^{S}+Q_{jt-1}^{S}+\sum_{i=1}^{S}X_{ijt}-D_{jt}) \quad \forall \mathrm{j}\in D,t\in T \quad (3)$$

$$L_{\mathrm{jt}}=\max(0,D_{jt}-R_{jt}^{S}-Q_{jt}^{S}-\sum_{\mathrm{i}=1}^{S}X_{ijt}) \quad \forall \mathrm{j}\in D,t\in T \quad (4)$$

$$X_{ijt}\le K_{ijt} \quad \forall \mathrm{i}\in S,\forall \mathrm{j}\in D,t\in T \quad (5)$$

$$R_{jt}^{S}\le Rl_{jt} \quad \forall \mathrm{i}\in S,\forall \mathrm{j}\in D,t\in T \quad (6)$$

X_{ijt} ,Q_{it}^{S}, Q_{jt}^{S},L_{jt},R_{jt}^{S} are integers greater than or equal to zero.

Formula (1) is the objective function. The total cost of empty container transportation is composed of transportation cost, inventory cost, handling cost, leasing cost and penalty cost for lack of containers respectively; Formula (2) represents the empty containers' inventory at the supply port in the current period. Formula (3) represents the empty containers' inventory at the supply port in the current period. Formula (4) represents the shortage of containers when the demand of demand port cannot be fully met. Formula (5) represents the limitation of transportation capacity. Formula (6) represents the limitation of container leasing.

Model 2, Mathematical programming model for mix use of standard and foldable empty containers:

$$MinC=\sum_{t=1}^{T}\sum_{i=1}^{S}\sum_{j=1}^{D}(ct_{ij}^{S}X_{ijt}+ct_{ij}^{F}Y_{ijt})+\sum_{t=1}^{T}\sum_{i=1}^{S}(cs_{i}^{S}Q_{it}^{S}+cs_{i}^{F}Q_{it}^{F})+\sum_{t=1}^{T}\sum_{j=1}^{D}(cs_{j}^{S}Q_{jt}^{S}+cs_{jt}^{F}Q_{\mathrm{jt}}^{F})$$
$$+\sum_{t=1}^{T}\sum_{i=1}^{S}\sum_{j=1}^{D}[(ca_{i}^{S}+ca_{j}^{S})X_{ijt}+(ca_{i}^{F}+ca_{j}^{F})Y_{ijt}]+\sum_{t=1}^{T}\sum_{j=1}^{D}(cr_{jt}^{S}R_{jt}^{S}+cr_{jt}^{F}R_{jt}^{F}) \quad (7)$$
$$+\sum_{t=1}^{T}\sum_{j=1}^{D}L_{jt}cl_{jt}+\sum_{t=1}^{T}\sum_{j=1}^{D}(M_{j}^{F}N_{jt}^{F}+M_{j}^{U}N_{jt}^{U})$$

$$Q_{it}^{S}=Q_{it-1}^{s}+S_{\mathrm{it}}^{s}-\sum_{j=1}^{D}X_{ijt} \quad \forall \mathrm{i}\in S,t\in T \quad (8)$$

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$$Q^{F}_{it} = Q^{F}_{it-1} + S^{F}_{it} - \sum_{j=1}^{D} Y_{ijt} \quad \forall i \in S, t \in T \tag{9}$$

$$Q^{S}_{jt} + Q^{F}_{jt} = \max(0, Q^{S}_{jt-1} + Q^{F}_{jt-1} + R^{s}_{jt} + R^{F}_{jt} + \sum_{i=1}^{S} X_{ijt} + \sum_{i=1}^{S} Y_{ijt} - D_{jt}) \quad \forall j \in D, t \in T \tag{10}$$

$$L_{jt} = \max(0, D_{jt} - R^{s}_{jt} - R^{F}_{jt} - Q^{s}_{jt} - Q^{F}_{jt} - \sum_{i=1}^{S} X_{ijt} - \sum_{i=1}^{S} Y_{ijt}) \quad \forall j \in D, t \in T \tag{11}$$

$$R^{s}_{jt} + R^{F}_{jt} \le Rl_{jt} \quad \forall i \in S, \forall j \in D, t \in T \tag{12}$$

$$X_{ijt} + Y_{ijt}/4 \le K_{ijt} \quad \forall i \in S, \forall j \in D, t \in T \tag{13}$$

$$N^{F}_{it} \ge S^{F}_{it} - \sum_{j=1}^{D} Y_{ijt} \quad \forall j \in D, t \in T \tag{14}$$

$$N^{U}_{it} \ge \sum_{j=1}^{D} Y_{ijt} - S^{F}_{it} \quad \forall j \in D, t \in T \tag{15}$$

$$N^{F}_{jt} \ge \sum_{i=1}^{S} Y_{ijt} + \sum_{i=1}^{S} X_{ijt} - D_{jt} \quad \forall j \in D, t \in T \tag{16}$$

$$N^{U}_{jt} \ge D_{jt} - \sum_{i=1}^{S} Y_{ijt} - \sum_{i=1}^{S} X_{ijt} \quad \forall j \in D, t \in T \tag{17}$$

$X_{ijt}, Q^{S}_{it}, Q^{S}_{jt}, L_{jt}, R^{S}_{jt}, Y_{ijt}, Q^{F}_{it}, Q^{F}_{jt}, R^{F}_{jt}, N^{F}_{it}, N^{U}_{it}, N^{F}_{jt}, N^{U}_{jt}$ are integers greater than or equal to zero.

The model using two kinds of empty containers is basically similar to the model using standard empty containers but it has more costs of foldable empty containers.

4. Computational Result

4.1 Known Conditions

This paper assumes that transportation system has three supply ports and three demand ports, sets the planning period as 3, assumes that the initial inventory of the supply port is 4 and the initial inventory of both standard and foldable empty containers is 2 when there are foldable empty containers input. Other conditions are shown in the following table:

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Table 1. Demand and supply of empty container for each node TEU

Period	Port					
	S1	S2	S3	D1	D2	D3
t=1	20	44	66	40	56	80
t=2	30	70	56	50	80	60
t=3	48	68	60	68	60	64

Table 2. Unit empty container repositioning cost of each node $/TEU

Port	D1	D2	D3
S1(standard)	96	100	100
S1(foldable)	24	25	25
S2(standard)	92	96	108
S2(foldable)	23	24	27
S3(standard)	104	100	96
S3(foldable)	26	25	24

Table 3. Unit empty container costs $/TEU

Port	D1	D2	D3	S1	S2	S3
leasing(standard)	110	110	110	\	\	\
leasing(foldable)	176	176	176	\	\	\
storage(standard)	48	48	48	48	48	48
storage(foldable)	12	12	12	12	12	12
fold/unfold	6	6	6	6	6	6
handing	4	4	4	4	4	4
shortage	180	180	180	\	\	\

Table 4. Capacity constraint of each node TEU

Port	Period		
	t=1	t=2	t=3
(S1,D1)	20	10	20
(S1,D2)	20	20	23
(S1,D3)	16	22	18
(S2,D1)	15	20	26
(S2,D2)	26	26	22
(S2,D3)	26	26	10
(S3,D1)	20	24	20
(S3,D2)	24	10	30
(S3,D3)	14	30	25

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Table 5. limit of container leasing TEU

Port	Period		
	t=1	t=2	t=3
D1	10	8	7
D2	6	10	6
D3	8	4	10

4.2 Results Analysis

The calculation results are shown in Table 6 and Table 7:

Table 6. The total repositioning cost of standard containers $

	Only use standard empty containers		
	t=1	t=2	t=3
Transportation scheme	3(S1,D1) 1 (S1,D2) 16 (S1,D3) 7(S2,D1) 25(S2,D2) 12(S2,D3) 20 (S3,D1) 24(S3,D2) 14(S3,D3)	8(S1,D1) 20(S1,D2) 2(S1,D3) 20(S2,D1) 26(S2,D2) 24 (S2,D3) 16(S3,D1) 10(S3,D2) 30(S3,D3)	20(S1,D1) 10 (S1,D2) 18(S1,D3) 16(S2,D1) 22(S2,D2) 10(S2,D3) 13(S3,D1) 22(S3,D2) 25(S3,D2)
Leasing	10(D1) 6 (D2) 8 (D3)	6 (D1) 10(D2) 4 (D3)	7 (D1) 6 (D2) 10(D3)
Storage	4(S1) 4(S2) 12(S3)	4(S1) 4(S2) 12(S3)	4(S1) 14(S2) 12(S3)
Shortage	30 (D3)	14 (D2)	2 (D1) 1 (D3)
Transportation cost	43848		
Inventory cost	3360		
Handling cost	3552		
Leasing cost	7370		
Penalty cost	8460		
Total cost	66590		

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Table 7. The total repositioning cost of foldable and standard containers $

	Mixed use of standard and foldable empty containers					
	t=1		t=2		t=3	
Transportation scheme	standard: 5(S1,D1) 1(S1,D3) 15(S2,D1) 3(S2,D2) 21(S3,D2) 3(S3,D3)	foldable: 10(S1,D1) 5(S1,D3) 26(S2,D2) 42(S3,D3)	standard: 10(S1,D1) 12(S1,D3) 16(S2,D1) 22(S2,D2) 2(S2,D3) 8(S3,D2) 26(S3,D3)	foldable: 8(S1,D2) 16(S2,D1) 14(S2,D2) 6(S3,D2) 16(S3,D3)	standard: 14(S1,D1) 2(S1,D3) 26(S2,D1) 2(S2,D2) 11(S3,D2) 19(S3,D3)	foldable: 23(S1,D1) 9(S1,D3) 40(S2,D2) 6(S3,D2) 24(S3,D3)
Leasing	standard: 10(D1) 6 (D2) 8 (D3)		standard: 8(D1) 10(D2) 4(D3)		standard: 5(D1) 1(D2) 10(D3)	
Storage	standard: 2(S1) 2(S2) 2(S3)	foldable: 2(S1) 2(S2) 2(S3)	standard: 2(S1) 2(S2) 2(S3)	foldable: 2(S1) 2(S2) 2(S3)	standard: 2(S1) 2(S2) 2(S3)	foldable: 2(S1) 2(S2) 2(S3)
Shortage	22(D3)		12(D2)			
Transportation cost	26758					
Inventory cost	1080					
Handling cost	3680					
Leasing cost	6820					
Penalty cost	6120					
Fold/Unfold cost	576					
Total cost	45034					

The result shows that the total cost of standard empty container is 66,590 $, the total cost of the mixed use of standard empty container and foldable empty container is 45034 $. The cost of mixing the two kinds of empty container is about 33% lower than that of standard empty container, which indicates that the use of foldable empty container can reduce the cost of empty container transportation.

4.3 Unit Transportation Cost Analysis

It can be concluded from Table 6 and Table 7 that the cost can be saved by mixing standard empty containers and foldable empty containers. In order to explore the potential possibility of foldable empty containers to reduce the total cost, the supply ratio of standard empty container and foldable empty container is studied next. The result is shown in Table 8.

Table 8. The cost of foldable containers at different supply ratio $

The foldable empty containers occupy different supply ratios	Transportation cost	Leasing cost	Inventory cost	Handling cost	Fold/Unfold cost	Penalty cost	Total cost
0	43848	7370	3360	3552	\	8460	66590
20%	38708	6930	1128	3688	564	5940	56958
25%	36648	6820	1080	3696	576	6120	55036
33%	33603	6600	1080	3712	582	6120	51841
50%	27665	6820	1080	3696	576	6120	46053
66%	22562	6820	1080	3696	576	6120	40950
75%	19303	6820	1080	3696	576	6120	37691
80%	17737	6820	1080	3696	576	6120	36125
100%	8338	10912	432	3696	3348	6120	32846

With the increase of the supply ratio of foldable empty containers, the cost factors of empty container transportation are changing constantly and the total cost and transportation cost of empty container transportation are decreasing with the increase of the supply ratio of foldable empty containers.

It can also be seen from Table 8 that as the ratio of the supply of foldable empty containers increases from 0 to 100%, the transportation cost takes up more than half of the total cost of empty container transportation. Therefore, transportation cost is a major factor affecting the cost of empty container transportation. Then, the influences of unit transportation cost and the supply ratio about foldable empty containers on the total cost of empty container transportation are studied.

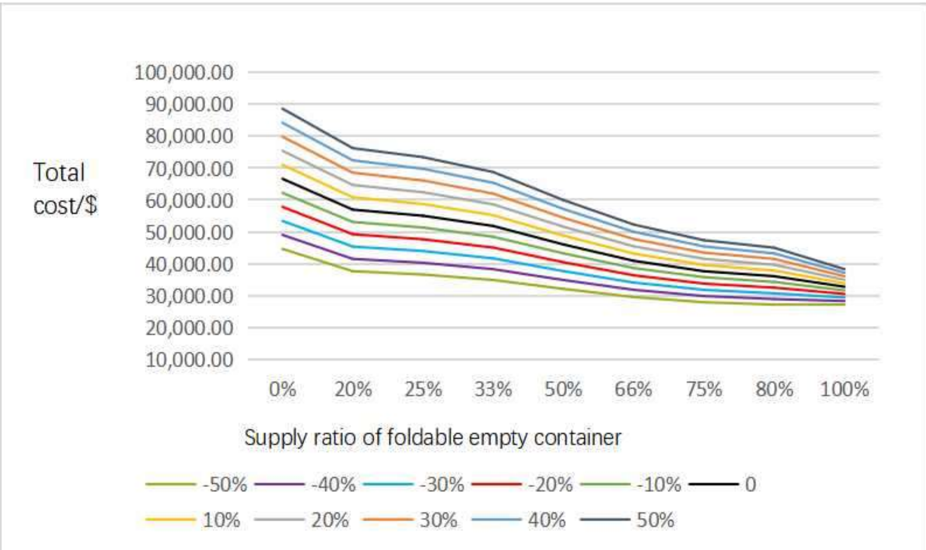

Figure 2. The influence of unit transportation cost and the proportion of supply of foldable empty containers on the total cost of empty containers repositioning

As is shown in Figure 2. when the supply ratio of foldable empty containers is 0-20%, the total cost of empty container transportation decreases obviously.when the supply ratio of foldable empty containers is 20%-75%, the decline trend becomes slow.when the supply ratio of foldable empty containers is 75%-100%, the decline trend is not obvious.

5. Conclusion

First it is concluded that mixed use of standard empty containers and foldable empty containers can help save transportation cost by comparing the transportation cost of empty containers only using standard empty containers and mixed use of standard empty containers and foldable empty containers and then analyzed the change of transportation cost of foldable empty containers under different supply ratio and the change of unit transportation cost and demand under different supply ratio. The results show that: when the supply ratio of foldable empty containers is 0-20%, the total cost of empty container transportation decreases obviously. When the supply ratio of foldable empty containers is 20%-75%, the decline trend becomes slow. When the supply ratio of foldable empty containers is 75%-100%, the decline trend is not obvious. Therefore, we should arrange the supply of standard empty containers and foldable empty containers reasonable ,which can help us save the total cost of empty container transportation in life.

Acknowledgments

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