Optimization of container transportation between multi terminals based on carrier cooperation

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Abstract. To optimize the inter-terminal transportation (ITT) problem, trucks transporting containers from one terminal to another are likely to have the situation of "Full load to empty vehicle return" or "empty vehicle to full load return", a container transportation method proposed in which container carriers. Taking the maximization of the carrier's profit as the goal, considering the terminal operation's busy degree, the task volume between terminals, and the carrier's number, a container transportation task allocation model based on carrier cooperation is established. The analysis and comparison between the carrier's "cooperation" strategy and the "non-cooperation" strategy show that if multiple container truck carriers cooperate by sharing trucks and orders, The total profit will increase by 32.3% and the number of trucks will decrease by 25.7%.

Keywords: inter terminal transportation, carriers cooperation, genetic algorithm, task allocation.

1. Introduction

A large number of containers need to be transshipped at a port composed of multiple container terminals, and arriving containers usually need to be transshipped from one terminal to another within a certain time. However, due to the non-sharing of information and business resources between carriers, the round-trip between terminals of trucks is often in a one-way empty state, resulting in too many empty journeys between terminals. This paper assumes that the truck companies cooperate by sharing the delivery orders of multiple carriers to minimize the empty journey and thus reduce unnecessary transportation costs.As shown in Figure 1.

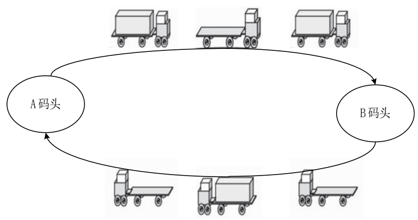

Figure 1. An illustration of inter-terminal transportation

Therefore, to maximize the profit of the container companies, this paper proposes a multi-carrier cooperation method to reduce the unnecessary empty journey of the container trucks, reduce the empty cost, and make the carriers obtain higher profits, to encourage more container companies to participate in the cooperation. At the same time, taking into account the time window of the task and the busy degree of the terminal operation, this paper establishes a task allocation model for container transportation operations and reduces the invalid empty load of the container trucks, to improve its transportation efficiency, reduce transportation costs and reduce environmental pollution.

2. Literature review

Domestic and foreign scholars have done a lot of research on the problem of Inter-Terminal Transportation (ITT) [1]. ZHANG [2] proposes that container hauling is the short-distance transportation of containers between the seaport and the inland terminal by container trucks. However, such operation modes have various disadvantages. For example, a large number of such transportation operation modes between ports will cause road congestion, empty vehicles, etc., thus affecting the timeliness of transportation operations, resulting in a series of unnecessary sacrifices such as high operation costs, invalid loss of vehicles, environmental pollution, etc. To reduce the above disadvantages of container transportation and improve its operation efficiency, scholars gradually began to explore and study the optimization methods of collaborative container transportation. HE [3] proposed the strategy of internal container sharing among multiple terminals, established an integer programming model for container transportation task allocation, and solved it by combining a genetic algorithm and simulation optimization method, to minimize the total workload and total transportation cost of vehicles. ZENER et al. [4] put forward the mechanism of shippers' alliance, that is, under the same logistics network, the transportation needs of all tasks of shippers are unified, and the transportation tasks are assigned to corresponding carriers according to the different scales of shippers. GHAERHGOZLI [5] compared various modes of container transport between terminals and applied the method of the game to determine the operation alliance of container transport between terminals between multiple container truck companies.

The research on the cooperation mode between carriers is as follows: ERGUN et al. [6] studied how carriers cooperate to minimize the repositioning of vehicles, thus reducing the invalid empty load of the truck. They use a path covering the problem to express this problem. In this problem, they found a set of constraint rings covering arc subsets in the directed graph. The goal of the same author, ERGUN et al. [7], is to reduce transportation costs by defining the repeated movement of the truck. In repeated movement, the route duplication of vehicles can be reduced by using the cooperation of the carrier. YILMAZ and SAVASANERIL [8] studied another form of this problem. They assume that a vehicle ownership contract has been signed between the shipper and the carrier, and each carrier will hand over a diversity card of its fleet to the shipper for operation. KRAJEWSKA et al. At the same time, we use cooperative game theory to study the cost of horizontal cooperation and the allocation of savings. KIM [10] uses the integer programming model to define the transit container transportation scheduling problem and gives the corresponding mathematical formula. It is assumed that the carriers cooperate to reduce empty travel by sharing delivery orders.

The change in each carrier’s total cost and profit after cooperation is studied through numerical experiments. CABALLINI [11] proposed an optimization model aiming at maximizing the total profit of cooperation for the cooperation planning of multi-carriers in the port environment and introduced a compensation mechanism to ensure that the sharer and the shared can obtain corresponding benefits and maintain the cooperation relationship between carriers. STER ZIK et al. [12] proposed that carriers can cooperate by sharing empty containers from the perspective of empty containers, which not only reduces the idle cost of containers but also promotes cooperation between carriers.

The research on the stability of long-term cooperation between carriers is as follows: CAVALLINI et al. [13] proposed a simple multi-carrier cooperation planning method and introduced a key aspect of the cooperation scheme, that is, an appropriate form of cooperation ensures fair cost distribution and savings between participants, and prevents each participant from losing customers related to orders shared with other carriers. LI et al. [14] made further research on the stability of customers in the process of cooperation between carriers and established a two-stage mixed integer programming model to maximize the profits of carriers. To solve the problem of task allocation in the process of cooperation between carriers, the stability of cooperation was guaranteed by considering the sharing of part of the information between carriers. VERDONCK et al. [15] to ensure that the carriers deal with the problem of cost allocation fairly and reasonably in the cooperation mechanism, introduced the shared warehouse mechanism, that is, the carriers share the same warehouse to allocate task orders, and analyzed the impact of this mechanism on the durability of carrier cooperation and the advantages and disadvantages of various cost allocation methods on carrier cooperation from the perspective of game theory.

It can be seen from the analysis of the existing documents that the current research on the optimization of multi-terminal container transportation mainly focuses on reducing transportation costs and time, optimizing the vehicle route, and reducing road traffic congestion to reduce carbon emissions [16]. The existing documents do not consider the actual busy degree of the terminal operation, and the carrier arranges the pickup and delivery of containers according to the busy situation of the terminal; Some truck carriers are worried about customer loss and are unwilling to participate in the cooperation. Therefore, how to effectively encourage the truck carriers to cooperate needs to be further explored, and the stability of the cooperation mode between multiple truck carriers also needs to be further studied.

Based on ITT research, this paper considers the busy degree of terminal operations, sets corresponding reward values according to different busy levels, encourages the carrier to avoid the operation peak hour, reduces the waiting time of the truck, and obtains higher rewards. At the same time, the paper introduces the carrier cooperation mechanism to discuss the optimization of multi-terminal container transportation. Through the cooperation of multi-carriers, the empty journey of container trucks between terminals is reduced, and the use of container trucks is also reduced. In addition, this paper designs an improved genetic algorithm based on the problem scenario. Compared with the Gurobi solver, it can obtain a higher quality solution in a shorter time.

3. Mathematical model

Literature [14] proposes a mathematical model based on a Time-Space diagram to minimize the empty load of trucks and the delay of transportation tasks. The model considers different sizes terminal nodes and carriers, the planning time is 12 hours, and the time step is 15 minutes. In this paper, a new integer programming model based on carrier cooperation is proposed to optimize the multi-terminal container transshipment problem. Compared with the model proposed in document [14] and other documents, this model can meet the actual transportation scenario in the ITT problem, and model the container transshipment between terminals, task processing time window, and terminal busy degree. At the same time, the model considers the rental cost, idle cost, transportation cost, delay cost of container transportation, the reward value of the carrier under different busy factors of the terminal, and the income of the container transportation, to maximize the total profit of the carrier.

3.1 Parameters

The model parameters are defined as follows: N: set of container terminals, $n \in N$; P:set of carrier, $p \in P$; K:set of Container transportation task; $A(i,j)$:set of transportation tasks for containers from the terminal i to the terminal j; T, T_0 :set of time node; $T= \{1,2,3,\ldots,t_{max}\}$, $T_0= \{0,1,2,3,\ldots,t_{max}\}$, $t,t_1 \in T$; C^P: set of initial task order of carrier p; Dp, Sp, Fp: represent the location node, task start node and task end node of the carrier`s truck company respectively; Lp :set of location nodes of container terminals and carrier companies, $Lp=N \cup \{Dp\}$;Lsp: set of location nodes and order starting points of container terminals and carrier companies, $Lsp=N \cup \{Dp,Sp\}$; e_k:revenue of transporting one container for task k; w_k:umber of containers to be moved in task k; l_{jt1}:reward value for the carrier to transport containers i to the terminal j at time-period t_1, (s_k,f_k):time window of transportation task k;$c_1{}^p$: operation cost of carrier p unit time-period,include the operating costs arising from empty truck driving, waiting for operation and carrying out transportation tasks;c_{2k}:delay cost of carrier p unit time-period;$c_3{}^p$:idle cost of the carrier p truck at the terminal:$c_4{}^p$:rental cost of a truck of the carrier p; Z^p: number of trucks available to the carrier during the planning period.

The decision variables are defined as follows:$x_{kt}{}^p$:number of containers transported by the carrier p at time-period t; $y_{kt}{}^p$: number of carrier trucks that the carrier sails from terminal i to terminal j; z^p: number of trucks that the carrier leaves (or returns) the warehouse at time-period 0 (or the end of the task period).

$$Max\ Sp = \sum_{n\epsilon N} e_k w_k + \sum_{p\epsilon P}\sum_{k\epsilon A(i,j)}\sum_{\substack{s_k \le t_1 \le f_k \\ t_1 = t + d_{ijt}}} l_j t_1 x_{kt}^p - \sum_{p\epsilon P}\left[(c_{1p})\sum_{i,j\epsilon A}\sum_{t\epsilon T} s_{ijt}\, y_{ijt}^p + c_{3p}\sum_{i,j\epsilon A}\sum_{t\epsilon T} y_{ijt}^p + \sum_{k\epsilon A(i,j)}\sum_{t > f_k - d_{ijt}} c_{2k}\left(t - f_k + d_{ijk}\right) x_{kt}^p + c_{4p} z^p\right] \quad (1)$$

Subject to

$$\sum_{k\epsilon A(i,j)} x_{kt}^p \le y_{ijt}^p \quad p\epsilon P, i, j\epsilon N, t\epsilon T \quad (2)$$

$$\sum_{p\epsilon P}\sum_{t:(s_k - d_{ijt} \le t)} x_{kt}^p = r_k \quad k\epsilon A(i,j)\ i, j\epsilon N \quad (3)$$

$$\sum_{p\epsilon P} x_k^p \le 1, k\epsilon A(i,j) \quad (4)$$

$$\sum_{\substack{t_1\epsilon T \\ t_1 = t - s_{ijt1}}} \sum_{\substack{i\epsilon L_{sp} \\ i \ne j}} y_{ij(t-1)}^p + y_{ij(t-1)}^p = \sum_{i\epsilon L_F} y_{ijt}^p \quad p\epsilon P, j\epsilon N, t\epsilon T \quad (5)$$

$$\sum_{j\epsilon L_p} y_{s_p jt}^p = z^p \quad p\epsilon P \quad (6)$$

$$\sum_{i\epsilon L_p}\sum_{t=T} y_{iF_p t}^p = z^p \quad p\epsilon P \quad (7)$$

$$\sum_{p\epsilon P} z^p \le Z^P \quad p\epsilon P \quad (8)$$

$$x_{kt}^p,\ \ y_{kt}^p,\ z^p \ge 0 \quad integer \quad (9)$$

(1) is the objective function, which is calculated from the income obtained by the transshipment container, the reward obtained by the carrier from transporting the container to the terminal at different busy levels at the terminal, and the various costs generated by the container transshipment by the truck. Its costs include the transportation cost of the truck, the idle cost of the truck, the delay cost of the truck operation, and the rental cost of the truck, to maximize the profit of the carrier; constraint; (2) ensure that the number of containers transferred from terminal *i* to terminal *j* does not exceed the number of trucks between the terminals; (3) ensure that the number of containers transferred between all terminals is equal to the total number of containers to be transferred; (4) ensure that all container transportation tasks can only be performed once; (5) ensure that the number of trucks entering the terminal i in each time period is equal to the number of trucks exiting. The number of inbound trucks includes empty and loaded trucks arriving at the terminal, as well as the trucks staying at the terminal in the previous period. Similarly, the outbound truck includes the empty truck and the loaded truck that leave the terminal, and the truck that stays at the terminal until leaving the terminal in the next time period; (6) indicates the number of trucks leaving the carrier warehouse at time zero and task time window; (7) indicates the number of trucks returned to the carrier warehouse at time zero and within the planned time window; (8) The number of transshipment containers between terminals deployed to the collection trucks shall not exceed the number of collection trucks available to the collection companies.

4. GA algorithm

The operation optimization problem of container sharing based on carrier cooperation established in this paper belongs to the NP-hard problem. Especially with the increase of the scale of the problem, the computational complexity tends to increase exponentially, and the optimal solution of the problem cannot be obtained in a limited time using the general small-scale optimization method. Therefore, this paper designs an improved genetic algorithm [17] to solve the problem, and its algorithm flow is shown in Figure 2.

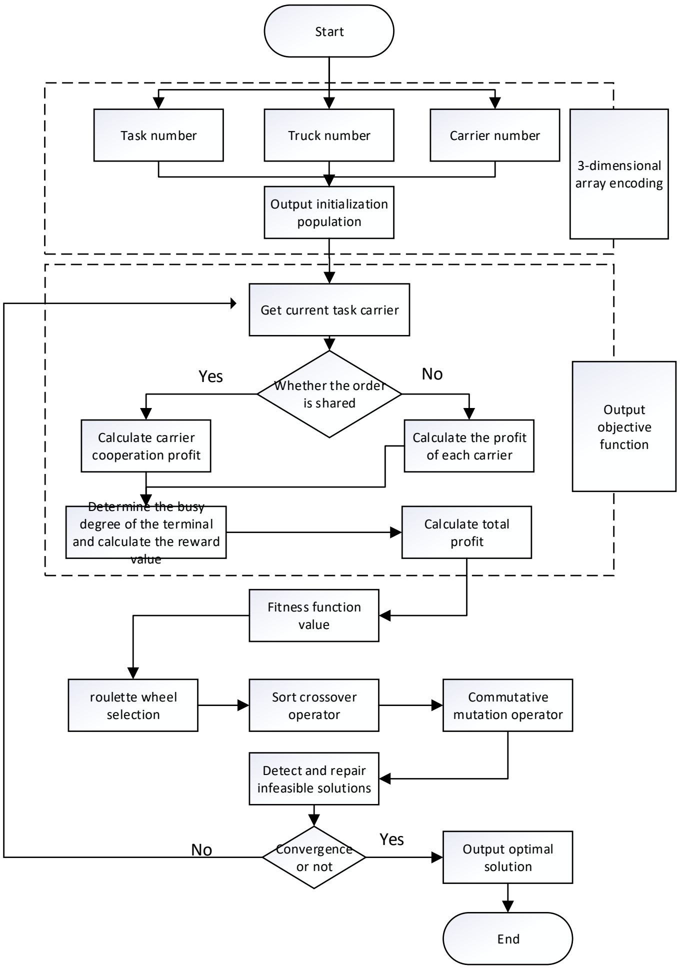

Figure 2. Algorithm Flow Chart

The main steps of the improved genetic algorithm to solve the multi-terminal container transportation optimization problem based on carrier cooperation are as follows:

1. Gene coding: The problem in this paper can be coded in the form of a three-dimensional array. The first dimension array represents the task sequence. The task sequence here is a little different from the task in the model. The combination of task number and box is used as a task. For example, the first box of task T1 is coded as "T1-C1", and then the newly coded task number is used as the task sequence, Therefore, the length of the task sequence is the sum of the number of tasks multiplied by the number of boxes corresponding to the task. The second dimension array is the car number, which is numbered from the beginning of the first car. The car number will be added every time a car is used. The third array represents the carrier corresponding to the second vehicle sequence. Suppose there are two tasks, the first task needs to carry four boxes, the second task needs to carry three boxes, and there are two carriers, each carrier only uses one transport vehicle to carry.

2. Decoding: A three-dimensional array is obtained according to the above encoding method and then decoded. The decoding method is a task-vehicle-carrier one-to-one correspondence. That is, the correspondence is obtained and the sequence is also obtained.

3. Calculate fitness function: for maximization problems, the larger the objective function, the higher the fitness. Generally speaking, when the solution does not meet the constraint conditions, it will be reflected in the objective function in the form of punishment. For this model, according to the gene coding described in step 1, after decoding, the task information of each truck can be obtained, and then the time of each task after each truck departs can be calculated. When the truck arrives early, the waiting time of the truck will be generated, and when the truck arrives late, the delay cost will be generated. Finally, when the truck operation is completed, the latest time of the time window will be exceeded, which will cause this solution to be infeasible, at this time, punishment should be given, that is, reduce the objective function value of the solution to reduce the fitness of the solution. In

addition, the transportation cost, stay cost, waiting cost, delay cost, and terminal reward value can be calculated according to the task information performed by the truck.

After initializing the population, the objective function of the model is obtained according to the input experimental parameters. The objective function of this paper is to maximize the total profit of the carrier, so the larger the objective value is, the greater the fitness function value is. The fitness function of this paper can be expressed as:

$$f_i = O_i \tag{10}$$

4. Roulette selection operator: The purpose of seethe lection operation is to allow individuals with high fitness to participate in the reproduction process, but also to give individuals with poor fitness opportunities to achieve a balanced effect. Common selection operations include roulette and competitive bidding mechanism. In this paper, roulette is selected, that is, to divide a disk according to the size of the individual objective function, and then rotate the disk each time to see which interval the stop position is exactly in, In this way, individuals with large objective function can be selected with a higher probability. It represents the population size and individual fitness. The probability of a dividual being selected can be expressed as:

$$P_i = f_i / \sum_{k=1}^{Q} f_k \tag{11}$$

5. Sorting crossover: The crossover operation is the process of two parents generating children. That is, after the intersection is selected, the information after the intersection of child 1 comes from parent 2, and the information after the intersection of child 2 comes from parent 1. Because each task can only be performed once, the crossover operation in this paper is designed in a sequence-based way, that is, when the offspring obtain the information of their parents, they use the sequence of genes for reference, which can ensure that the generated offspring are feasible.

6. Variation: Since the number of the used collection cards is a key inform this paper, the variation part is based on the heuristic rules to design the conditions for the number of collection cards, that is, when the number of collection cards in the solution is closer to the maximum number of collection cards, the easier it is to trigger the operation of reducing the number of collection cards, and the farther it is from the maximum number of collection cards, the easier it is to trigger the operation of increasing the number of collection cards.

7. Retain elite: copy the individuals with the highest fitness in the parent generation directly to the children. Retain elite strategy can ensure that the individuals with high fitness are not lost by random factors, and can make the algorithm convergence faster.

8. Termination rule: When the number of iterations of the algorithm reaches the set maximum number of iterations, stop the calculation to obtain the optimal transportation task allocation scheme, otherwise return to continue to execute Step 3.

5. Computational experiments

The optimization problem of container transportation between terminals based on container sharing established in this paper belongs to the NP-hard problem. With the increase of the scale of the problem, its calculation difficulty generally increases exponentially. To verify the applicability of the model built in this paper, the stability of the model is verified by solving numerical examples of different scales.

5.1 Comparative analysis of costs and benefits under multi-carrier cooperation

This section sets 18 task sequences (see Table I for details), including a different number of carriers and terminals to show the solution quality of the model under different problem scales. Figure 3 compares the carrier's independent transportation operation and the carrier's cooperative transportation from the number of trucks, the carrier's profit, the sum of various costs, and the reward value obtained by the carrier. The cost parameters of the carrier are shown in Table 2.

Table 1. Task number

No.	Number of terminal	Number of carrier	Average number of delivery tasks (per carrier company)	Average number of containers in a task	Average number of containers in a task
1	3	2	5	5	12
2	3	2	7	7	12
3	3	2	10	10	24
4	3	2	12	12	24
5	3	2	15	15	48
6	3	2	17	17	48
7	4	3	5	5	12
8	4	3	7	7	12
9	4	3	10	10	24
10	4	3	12	12	24
11	4	3	15	15	48
12	4	3	17	17	48
13	5	4	5	5	12
14	5	4	7	7	12
15	5	4	10	10	24
16	5	4	12	12	24
17	5	4	15	15	48
18	5	4	17	17	48

Table 2. Cost Parameters of Carrie

	Unit	Value
Truck transportation cost, c1	yuan/time-period	14
truck rental cost, c4	yuan/time-period	7.58
Truck idle cost	yun/time-period	0.07
delay cost	yuan/TEU/time-period	35
Truck transportation Revenue	yuan/TEU	[125, 210] random generation
Rewards for carriers under different busy factors of the terminal	yuan/TEU	[7, 21] random generation

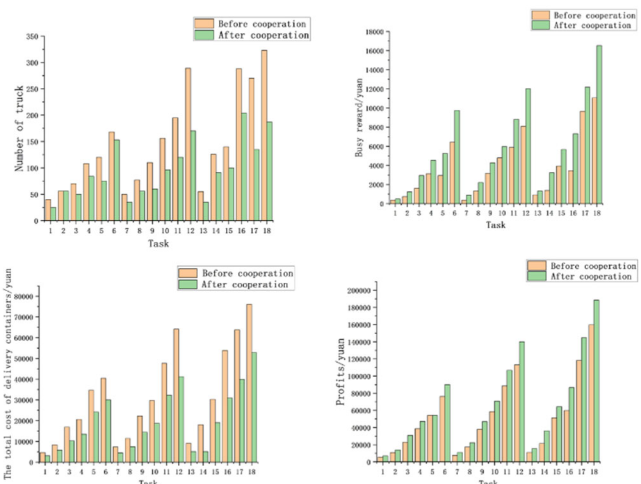

Figure 3. Changes of indicators before and after carrier cooperation under different scenarios

Figure 3 shows the changes in various scenes before and after carrier cooperation under different scenarios, including four indicators: the number of trucks, the reward value of trucks when they arrive at each busy level of the terminal, the sum of operating costs, and the carrier's profit. For the transportation problems of different scales, the final profit has been significantly improved by 18% at least, and the profit of task 14 has increased by 69%. In addition, under the cooperation mode, the number of trucks used to complete the transportation task is less than the number of trucks used by the carrier for independent transportation, which can be reduced by up to 50%. At the same time, it also shows that the carrier has significantly reduced the empty journey of the truck through cooperative transportation.

5.2 Algorithm validity verification

For the selection of genetic parameters of the GA algorithm, under the premise of ensuring the accuracy of the solution and the short running time of the algorithm program, several comparative experiments have been carried out successively. Finally, the population size is 500, the maximum number of iterations is 300, the crossover probability is 0.8, and the mutation probability is 0.3.

In order to verify the effectiveness of the improved genetic algorithm designed in this paper, the numerical examples of different sizes are analyzed and compared. For small-scale cases, the Gurobi solver is used to solve, and for large-scale cases, GA is used to solve. Each case is run 6 times, and the results are taken as the average value.

The solution results of the algorithm in different scale examples are shown in Table 3 and Table 4. It can be seen from Table 3 that when the number of container transportation tasks reaches 30, Gurobi can not find an accurate solution in a short time, while the genetic algorithm designed in this paper can obtain high-quality solutions in a relatively short time, which greatly improves the solution efficiency of the solution, with the average gap value of only 3.85%. Table 4 shows the calculation time and objective function value of the algorithm proposed in this paper when solving large-scale numerical examples. It can be seen from Table 4 that when solving large-scale examples, the calculation time difference of the genetic algorithm for solving problems is small. When the number of tasks reaches 80 and the number of carriers reaches 5, the algorithm designed in this paper only needs 13.46s to get the results, and the calculation time is relatively short. Thus, the GA algorithm designed in this paper is effective.

Table 3. Comparison and analysis of solution results of small-scale examples based on Gurobi and genetic

No.	Number of task(TEU)	Number of carrier	Gurobi		GA		Gap%
			Computer time/s	Profit/yuan	Computer time/s	Profit/yuan	
1	5	3	2.18	10458	1.52	10626	1.6
2	8	3	4.52	17560	1.64	18396	4.8
3	10	3	12.62	20452	4.67	21665	5.9
4	20	3	124.31	34526	5.52	35610	3.1
5	30	3	-	-	7.48	38420	-
Gap = 100% × (GA-Gurobi) / Gurobi							

Table 4. Comparison and analysis of solution results of large-scale numerical examples based on genetic algorithm

No.	Number of task(TEU)	Number of carrier	Computer time/s	Profit/yuan
6	40	5	7.85	42836
7	50	5	9.47	44257
8	60	5	10.53	53620
9	80	5	13.46	74358

5.3 sensitivity analysis

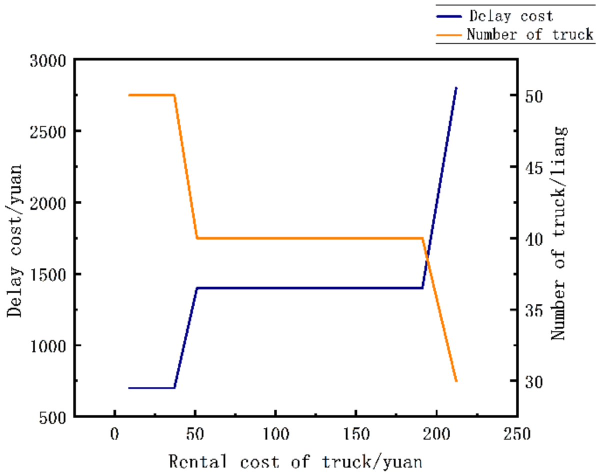

Figure 4. The influence of the change of truck rental cost coefficient on the number of trucks and the delay cost

Under the condition that other parameters remain unchanged, sensitivity analysis is carried out on the rental cost coefficient of the carrier's truck. By setting different truck rental cost coefficients, observe the impact of rental cost on the number of trucks deployed to the entire system and the delay cost. As can be seen from Figure 4, when the rental cost of the truck increased from 9.1 yuan to 212.1 yuan, the number of trucks deployed to the whole system decreased from 50 to 30, and the delay cost of transportation increased from 700 yuan to 2800 yuan. Therefore, when the cost coefficient of truck rental increases, the profit of the carrier will decrease, and the willingness of the carrier to cooperate will decrease, thus affecting the effect of cooperation.

6. Conclusion

In this paper, based on the problem of container transporting between terminals, considering the busy degree of terminals, an integer programming model is proposed based on the sharing of containers between carriers. According to the actual transportation demand between terminals, the optimal task allocation is determined, and the characteristics and impact of the ITT problem are studied. The results show that the truck sharing among carriers can effectively reduce the various costs of ITT and the use of collection cards. The research results of this paper can provide a theoretical basis for the problem of container truck scheduling between multiple terminals. At the same time, there are also shortcomings in this study. For example, in the ITT problem, the insufficient number of carriers' collecting cards is not considered, and the optimization algorithm is not carried out to carry out more in-depth research on the model. This is another direction of this kind of problem research.

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