Optimization of Empty Pallets Dispatching Based on Different Transportation Modes

Kang ZHOU

School of Traffic and Transportation, Beijing Jiaotong University, Beijing 100044, China
E-mail: zhoukang@bjtu.edu.cn

Shiwei HE

School of Traffic and Transportation, Beijing Jiaotong University, Beijing 100044, China
E-mail: shwhe@bjtu.edu.cn

Rui SONG

MOE Key Laboratory for Urban Transportation Complex Systems Theory and Technology, Beijing Jiaotong University, Beijing 100044, China
E-mail: rsong@bjtu.edu.cn

Weichuan YIN

School of Traffic and Transportation, Beijing Jiaotong University, Beijing 100044, China
E-mail: 13120924@bjtu.edu.cn

Lingyan CHENG

School of Traffic and Transportation, Beijing Jiaotong University, Beijing 100044, China
E-mail: 13120824@bjtu.edu.cn

Abstract In the pallet pool system, the differentiation of palletized freight volumes in different regions and seasonal transport of certain goods lead to the imbalance of pallets distribution among regions. It is necessary to improve the utilization of pallets through dispatching. The paper analyzes the factors which affect empty pallets dispatching, it includes carbon emission, transportation time and pallet type based on the pallet pool mode of enterprise alliance. On this basis, the optimization model is established with the goal of minimum total dispatching cost. Then, according to the different influences of railway and highway in transportation cost, the dispatching scheme is analyzed and the transportation mode of empty pallets dispatching is determined. Considering the characteristics of model, Cplex is used to solve it. Finally, a case is used to verify the feasibility and superiority of reasonable empty pallets dispatching in different transportation modes, and the transport characteristics of two transportation modes are analyzed. Moreover, the costs of pallets leasing and dispatching are compared.

Keywords freight; dispatching optimization; ILOG Cplex; pallets; pallet pool; stochastic constraint

---

Received March 1, 2016, accepted May 19, 2016

Supported by the National Natural Science Foundation of China (61374202), the “Fundamental Research Funds for the Central Universities” (2014YJS071)

1 Introduction

Since Ansoff proposed the concept of collaborative management, supply chain collaboration has been popular in academia^[1]. With the development of global logistics technology, traditional mode of cargo loading and transportation is gradually replaced by modular mode. Through packaging the scattered goods into container by cargo units, loading and securing by mechanical operation mode, the efficiency of loading and unloading, transport efficiency can be improved, the cost of transport, carbon emission and damage or lose of goods also would be reduced. Present, as a cheap, high-efficiency and convenient mode, pallets are widely adopted in unit logistics. The use of pallets not only facilitates the transport of goods and improves the transport efficiency, but also reduces transportation cost. Especially the establishment of pallet pool system, the efficiency of pallet is greatly enhanced^[2]. Murray and Anon studied the mode of pallet using^[3,4]. Jouglard, et al. studied the relationship between productivity and pallet pool while using horizontal machining centers to manufacture small lot sizes^[5]. Ray, et al. studied the benefits of using pallet^[6]. Mckerrow, Lacefield and Raballand described the pallet recovery problem from different aspects^[7–9]. Currently, pallet pool mode is mainly performed as leasing. Pallets rental companies distribute and recycle their own pallets, but this would reduce the utilization of pallet to some extent.

The unbalanced demand of goods which are carried by pallets among areas will always cause disequilibrium of goods distribution, and lead to the pallets excess in some regions but shortage in other regions. In order to balance the demand and supply of pallets distribution among regions, reduce superfluous waste of resources, it is necessary to dispatch the empty pallets^[10]. Up to now, the research of empty pallets dispatching is still less. However, the theories of empty container allocations can be referred. Leung, et al. presented a stochastic model for dynamic empty container allocations^[11]. Lam, et al. showed a dynamic stochastic model for a simple two-ports two-voyages system, and provided an exact optimal solution^[12]. Ren, et al. introduced the research status of pallet pool system, put forward a improved pallet pool system, and established the stochastic optimization model aiming at the pallet pool system^[13–15]. However, in the research of dispatching optimization, the influence factors such as pallet type, transportation mode and time constraint are ignored. Damage in the transportation of pallets has been an important problem for the pallet pool system managers. Due to the difference of damage rate in different transportation modes, it is necessary to take it into account in the process of empty pallets dispatching.

Based on the researches above, it is necessary to optimize the pallets dispatching to realize circulation of pallets with the lowest cost. The paper considers the difference of freight rates, transport distance, carbon emissions and damage rates between railway and highway transportation mode, and then establishes the empty dispatching optimization model, taking the minimum total dispatching cost as the object to meet the demand of pallets. Through solving the model, the rational way of empty pallets dispatching is analyzed under the influence of various factors in the region, and some theoretical guidance for the dispatching of empty pallets are provided.

2 Pallet Pool Mode of Enterprise Alliance

There are three main modes of pallets circulation: exchange mode, rental mode and combination mode of rental and exchange. Based on the analysis of modes above, relying on the information platform, Zhou, et al. determined the pallet pool mode of enterprise alliance which includes transportation enterprises and pallet rental enterprises (as shown in Figure 1)^[16]:

- 1) Transportation enterprises and pallet rental enterprises form alliance mode of consultation and cooperation;
- 2) Transportation enterprises provide the pallet rental (or exchange) service to customers, and the pallets provided are only for goods circulation;
- 3) Terminal stations of transportation enterprises in the pallet pool system are responsible for the pallets recycling according to the situation of production and sales of customers;
- 4) Empty pallets recycled from terminal stations will be provided to the pallet demand enterprises in the service scope and circulating can be realized;
- 5) According to the demand of pallets, the terminal station transports pallets from surplus points to demand points in the pallet pool system.

In this mode, alliance enterprises are mutually beneficial. Pallet rental enterprises can use the space of transportation enterprises to store a certain empty pallets. And transportation enterprises can quickly provide pallets and give priority to the customers which use pallets, in order to encourage qualified enterprises to use pallets. This can improve transport efficiency, shorten handling time and save handling fee, especially in the busy shipping period, it is beneficial to promote the development of unit logistics. And it is conducive to allocate empty pallets in different areas.

Figure 1 Pallet pool mode of enterprise alliance

3 Formulation of Empty Pallet Dispatching

The main goal of empty pallets dispatching is to achieve the empty pallets moving from supply points to demand points with the minimum allocation cost and reasonable allocation

time. When the cost of transportation and loading is more than the rental cost for demand points, they will replace dispatching with leasing pallets. As the difference of carbon emissions for different transportation modes, considering the impact of transportation to the environment, the carbon emissions cost should be taken to the objective function as one of factors. In addition, the inventory costs of empty pallet supply points will also affect the empty pallets dispatching. Like other goods, there will be a certain damage rate during the transport of empty pallets, so the damage rate should be considered in the process of dispatching, in order to satisfy the empty pallet demand as more as possible.

3.1 Basic Assumptions

- 1) Empty pallets demanded of pallet demand points on the various types can be satisfied, if it cannot be met through transportation, pallet demand points can lease pallets from pallet rental enterprises (all costs are passed to the rental fee);
- 2) The origin of each transport path is empty pallet supply point, destination is pallet demand point, and there are only one supply point and one demand point of each path;
- 3) The routes of different transportation modes between the supply point and demand point are all known, each kind of transportation mode corresponds to a transport path, all costs associated with transportation are converted to freight rates;
- 4) Transport capacity is only related to transportation modes between empty pallet supply point and demand point, when highway transportation mode or railway transportation mode is not available between supply point and demand point, the transport capacity is set to 0;
- 5) In the decision-making period, the unit costs associated with empty pallets dispatching are unchanged.

3.2 Notations Definition

3.2.1 Sets

O is set of pallet supply points, o is one element of the set, $o \in O$;
 D is set of pallet demand points, d is one element of the set, $d \in D$;
 V is set of pallet types, v is one element of the set, $v \in V$;
 K is set of transportation modes, k is one element of the set, $k \in K$.

3.2.2 Parameters

l_{od} expresses distance from supply point o to demand point d ;
 a_o^v expresses empty pallets quantity of v type supplied by supply point o ;
 d_d^v expresses empty pallets quantity of v type demanded by demand point d ;
 c_o^v expresses unit inventory cost of supply points;
 c_d^v expresses price of leasing one pallet for pallet demand point d ;
 g^v expresses weight of one empty pallet of type v ;
 c^v expresses unit loss cost of pallet v because of damage or lose in the process of transportation;
 c^k expresses unit cost of transportation mode k ;
 v^k expresses average speed of transportation mode k ;

β^k expresses average carbon emission per ton per kilometer of transportation mode k ;

c_0 expresses the cost of unit carbon emission;

m_{od}^k expresses maximum transport capacity of transportation mode k from supply point o to demand point d ;

ρ^k expresses the damage rate of pallets when transportation mode k transporting pallets, it is a stochastic variable, $E(\rho^k)$ is the expected value of ρ^k .

3.2.3 Decision Variables

x_{od}^{kv} is the positive integer decision variable, it presents the quantity of v type pallets carried by transportation mode k from supply point o to demand point d ;

r_d^v is the quantity of leasing pallets in pallet demand point d ;

s_o^v is the remaining quantity of v type pallets in pallet supply point o , once dispatching.

3.3 Objective Function and Constraint Conditions

3.3.1 Function of Dispatching Costs

Based on the assumptions and parameters above, take the minimum total costs which include transportation and carbon emission costs of pallets carriage, inventory cost, leasing cost and damage cost due to damage and lose in the transportation process as object, the following mathematical models are constructed:

$$\min C_1 = \sum_{o \in O} \sum_{d \in D} \sum_{v \in V} \sum_{k \in K} (c^k + \beta^k c_0) l_{od} x_{od}^{kv} g^v + \sum_{o \in O} \sum_{v \in V} s_o^v c_o^v, \quad (1)$$

$$\min C_2 = \sum_{d \in D} \sum_{v \in V} r_d^v c_d^v + \sum_{o \in O} \sum_{d \in D} \sum_{v \in V} \sum_{k \in K} E(\rho^k) x_{od}^{kv} c^v, \quad (2)$$

$$\min C = \min C_1 + \min C_2. \quad (3)$$

3.3.2 Constraint Conditions

1) Supply constraint:

$$\sum_{d \in D} \sum_{k \in K} x_{od}^{kv} \leq a_o^d, \quad \forall o \in O, v \in V. \quad (4)$$

$\sum_{d \in D} \sum_{k \in K} x_{od}^{kv}$ is the quantity of v type pallets transported from supply point o to each demand point, it should not exceed the total quantity a_o^d of v type pallets supplied by supply demand o .

2) Chance constraint of stochastic demand:

$$\Pr \left\{ \sum_{o \in O} \sum_{k \in K} x_{od}^{kv} (1 - \rho^k) \geq d_d^v - r_d^v \right\} \geq \delta^k, \quad \forall d \in D, v \in V. \quad (5)$$

$\sum_{o \in O} \sum_{k \in K} x_{od}^{kv} (1 - \rho^k)$ represents the quantity of intact pallets of type v that arriving at the demand point d , it should not be less than the quantity that the deterministic demand quantity d_d^v of demand point d subtracts the leasing quantity r_d^v . Chance constraint methods

impose a fixed maximum probability that a given restriction (or sets of restrictions) will be violated^[17].

3) Transport capacity constraint of different transportation modes:

$$\sum_{v \in V} x_{od}^{kv} \leq m_{od}^k, \quad \forall o \in O, d \in D, k \in K. \quad (6)$$

$\sum_{v \in V} x_{od}^{kv}$ represents the quantity of v type pallets carried by transportation mode k from supply demand point o to demand point d , it can't exceed the transport capacity of determination m_{od}^k .

4) Inventory constraint:

$$\sum_{d \in D} \sum_{k \in K} x_{od}^{kv} = a_o^v - s_o^v, \quad \forall o \in O, v \in V. \quad (7)$$

After once distribution of empty pallets, the remaining inventory equals the quantity supplied by supply point o subtracting the quantity transported from this point.

5) Time constraint:

If the pallets of type v required by demand point d can't arrive at demand point on stipulated time, it should be punished by the function $f(t_{od}^{kv})$, the expression is

$$f(t_{od}^{kv}) = \begin{cases} M_1 (\theta_d^v - t_{od}^{kv}) & t_{od}^{kv} < \theta_d^v, \\ 0 & \theta_d^v \leq t_{od}^{kv} \leq \psi_d^v, \\ M_2 (t_{od}^{kv} - \psi_d^v) & t_{od}^{kv} > \psi_d^v, \end{cases} \quad (8)$$

where θ_d^v and ψ_d^v represent the shortest and longest carrying time of pallet demand point d expected, t_{od}^{kv} represents the real time of transportation from supply point o to demand point d by transportation mode k , M_1 is the penalty coefficient of cost if the pallets arrived early, M_2 is the penalty coefficient of cost if the pallets arrived later than the expected time. The additional cost C_e represents penalty cost if pallets can't arrive at the demand point on stipulated time, it should meet the following condition:

$$\min C_e = \sum_{o \in O} \sum_{d \in D} \sum_{v \in V} \sum_{k \in K} (t_{od}^{kv}) x_{od}^{kv}. \quad (9)$$

Based on the model (3), considering the time constraint, model (3) and the function (7) can be combined together, then the objective function is adjusted to:

$$\min C + \min C_e. \quad (10)$$

4 Solution Approaches

4.1 Determination Process of Random Constraint

Because there is a random variable ρ^k in the model, it couldn't be solved by optimization software and algorithm directly. Liu, et al. and Liu raised some theories and methods to deal with the chance constraint^[18–20]. According to these theories, the chance constraint (5) can be converted to equivalent determinate constraint.

For constraint (5), when $\sum_{d \in D} \sum_{v \in V} x_{od}^{kv} = 0$, the demand of pallets is met by leasing, so there is no damage rate caused by transportation; when $\sum_{d \in D} \sum_{v \in V} x_{od}^{kv} > 0$, constraint (5) is equal to $\Pr\{1 - \frac{d_d^v - r_d^v}{\sum_{o \in O} \sum_{k \in K} x_{od}^{kv}} - \rho^k \geq 0\} \geq \delta^k$. According to the related theorems of Liu^[18], for each given confidence level δ^k , there is an λ^k to meet $\Pr\{\lambda^k - \rho^k\} = \delta^k$. If and only if $1 - \frac{d_d^v - r_d^v}{\sum_{o \in O} \sum_{k \in K} x_{od}^{kv}} \geq \lambda^k$, $\Pr\{1 - \frac{d_d^v - r_d^v}{\sum_{o \in O} \sum_{k \in K} x_{od}^{kv}} - \rho^k \geq 0\} \geq \delta^k$ holds up. So chance constraint (5) can be convert to equivalent determinate constraint:

$$\sum_{o \in O} \sum_{k \in K} x_{od}^{kv} (1 - \Phi_k^{-1}(\delta^k)) \geq d_d^v - r_d^v, \quad (11)$$

where, $\lambda^k = \inf\{\lambda | \lambda = \Phi_k^{-1}(\delta^k)\}$. $\Phi_k^{-1}(\delta^k)$ is inverse function of distribution function Φ for random damage rate ρ^k .

4.2 Solved by ILOG Cplex

When optimizing the dispatching of empty pallets in pallet pool system, first we should determine the feasible routes between supply point and demand point. If there are large-scale alternative routes, the feasible routes set should be determined as the initial network in the alternative set by k shortest route algorithm, the detailed acquisition method is shown in reference [21]. After the initial network is determined, the routes and arcs of initial network should be labeled. The parameters of initial network with routes and arcs number are calibrated. Then the problem is solved using optimization software ILOG Cplex v12.2 according to the characteristics of objective function and constraints. Without complex operations required by user, Cplex can quickly solve large-scale, complex problems such as linear problem, quadratic constraints, and mixed integer programming problems. ILOG Cplex v12.2 contains a series of configurable algorithm program: single optimization program, boundary optimization program as well as mixed integer optimization program. We can select the appropriate optimization program according to the characteristics of problems that will be solved. There, mixed-integer optimization program can provide fast and efficient solution for the majority of mixed-integer programming problem. In the set expression of Cplex code, relationship matrix is used to represent the relationship between routes and connection arcs, routes and flows of goods, time and arcs on the path. Specific model solving process could be referred to Luo's optimization software and applications^[22].

5 Computation Study

In a pallet pool system, there are nine pallet service points. Because of the imbalance of palletized goods distribution in the system, set three pallet supply points, expressed as (O_1, O_2, O_3) , and six pallet demand points, expressed as $(D_1, D_2, D_3, D_4, D_5, D_6)$. According to the demand, pallets specifications would be classified as 3 types: 1200mm $\times$ 1000mm, 1100mm $\times$ 1100mm, 1200mm $\times$ 800mm, that is $V(v_1, v_2, v_3) = 1, 2, 3$. The weights of a single pallet for each type are 20kg, 18kg, and 15kg. The specific data of supply and demand between the pallet supply points and the pallet demand points are shown in Table 1 and Table 2 (unit leasing price is the price of leasing one pallet in the decision period, inventory cost is the price of pallets per one ton). Other parameters are shown in Table 3. Because of space constraints, other unimportant data are not listed.

Table 1 Parameters of supply

Pallets type	Unit leasing price (yuan)	Supply points	Unit inventory cost (yuan)	Supply
		O_1	2	5 020
v_1	8	O_2	1.9	3 200
		O_3	1.5	2 480
		O_1	2	3 610
v_2	7	O_2	1.9	4 900
		O_3	1.5	2 010
		O_1	2	2 600
v_3	9	O_2	1.9	4 260
		O_3	1.5	2 100

If the pallets demanded arriving at the pallet demand points earlier than the expected transportation time, set the penalty coefficient M_1 to equal unit inventory cost; if later, the penalty coefficient M_2 equals unit lease price. According to past experience, assume that the confidence level $\delta^k=0.9$ of chance constrained conditions (5), then:

$$\Pr \left\{ 1 - \frac{d_d^v - r_d^v}{\sum_{o \in O} \sum_{k \in K} x_{od}^{kv}} - \rho^k \geq 0 \right\} \geq 0.9 \quad (12)$$

That is:

$$\sum_{o \in O} \sum_{k \in K} x_{od}^{kv} (1 - \Phi_k^{-1}(0.9)) \geq d_d^v - r_d^v \quad (13)$$

The damage rate ρ^k of pallets transported by highway transportation obeys normal distribution $N(0.001, 0.05^2)$, so $1 - \Phi_k^{-1}(0.9) = 1 - (1.282 \times 0.001 + 0.05^2) = 0.996$; while the damage rate ρ^k of pallets transported by railway transportation obeys normal distribution $N(0.002, 0.03^2)$, so $1 - \Phi_k^{-1}(0.9) = 1 - (1.282 \times 0.002 + 0.03^2) = 0.997$.

Table 2 Parameters of demand

Pallets type	Demand points	Demand	Expected transportation time (h)		
		Routes	Shortest	Longest	
v_1	D_1	1 050	O_1-D_1	0.5	1
	D_2	3 100	O_1-D_2	14	16
	D_3	2 080	O_1-D_3	2	2
	D_4	1 100	O_1-D_4	4	6
	D_5	620	O_1-D_5	5	8
	D_6	1 850	O_1-D_6	3	5
v_2	D_1	745	O_2-D_1	6	9
	D_2	1 620	O_2-D_2	14	18
	D_3	1 580	O_2-D_3	7	10
	D_4	2 270	O_2-D_4	12	15
	D_5	945	O_2-D_5	3	5
	D_6	1 020	O_2-D_6	13	17
v_3	D_1	1 620	O_3-D_1	16	19
	D_2	865	O_3-D_2	3	5
	D_3	2 310	O_3-D_3	2	9
	D_4	1 680	O_3-D_4	3	4
	D_5	795	O_3-D_5	6	8
	D_6	2 540	O_3-D_6	14	17

Table 3 Related parameters of two transportation modes

Transportation modes	Highway	Railway
Average velocity (km/h)	80	40
Unit transportation cost (yuan/(t.km))	0.5	0.1
CO ₂ emission (kg/(100t.km))	79.6	2.8

Note: the data of carbon emission comes from the German Railway 2008 annual environmental report on CO₂ emission statistics.

5.1 Calculation

Use ILOG Cplex v12.2 software to solve the model. The dispatching optimization scheme is shown in Table 4. Because of the damage rate, the quantity of pallets transported including damaged pallets more than the demanded. The total cost of dispatching is 145 323.85 yuan, far less than the cost of leasing all pallets.

Table 4 Optimization results of dispatching

v_1	Modes	D_1	D_2	D_3	D_4	D_5	D_6
O_1	Highway	890	0	2 000	0	0	0
	Railway	0	0	0	970	0	1 160
O_2	Highway	0	0	0	0	0	0
	Railway	0	0	0	0	622	0
O_3	Highway	0	0	0	0	0	0
	Railway	0	1 472	0	0	0	0
Lease		164	1 633	88	133	0	694
v_2	Modes	D_1	D_2	D_3	D_4	D_5	D_6
O_1	Highway	140	0	140	0	0	0
	Railway	0	0	0	0	0	0
O_2	Highway	0	0	0	0	0	0
	Railway	0	0	0	0	630	0
O_3	Highway	0	0	0	0	0	0
	Railway	0	0	0	0	0	0
Lease		606	1 620	1 441	2 270	317	1 020
v_3	Modes	D_1	D_2	D_3	D_4	D_5	D_6
O_1	Highway	480	0	640	0	0	0
	Railway	0	0	0	1 480	0	0
O_2	Highway	0	0	0	0	0	0
	Railway	0	0	0	0	798	0
O_3	Highway	0	0	0	0	0	0
	Railway	0	868	1 120	0	0	0
Lease		1 142	0	556	205	0	2 540
Value of the function			145 323.849828003				

5.2 Analysis of Results

According to the calculation results, it is still difficult to meet the demand completely by transportation even the distance between pallet supply point and demand point is very close because of constraint conditions. As the carbon emissions and transportation expenses are far lower than ones of highway transportation, total pallets transported by railway is higher than highway. Through the solution of O_1-D_3 , it can reflect the function of time constraint to a certain extent. But as the punish coefficient increases, time constraint intensity will increase gradually. When the penalty coefficient is set to be infinity, time constraint would be changed into hard constraint.

Transport distance affects the transportation expenses directly. And carbon emission, transport time are important factors to decide the final optimization results, taking O_1-D_3 and O_3-D_2 as examples to analyze the relationship between distance and quantity of pallets transported (as shown in Figure 2). Highway has some advantages in short distance transport. With the

growth of distance, the cost increases faster than the railway transportation, so the quantity of carrying pallets falls sharply. Relatively speaking, the railway transportation has obvious advantages in long distance transport.

Figure 2 The relationship between the quantity of empty pallets carried and distance

Table 5 Optimization results of ignoring capacity constraints

v_1	Modes	D_1	D_2	D_3	D_4	D_5	D_6
O_1	Highway	1 055	0	1 005	0	0	0
	Railway	0	0	0	1 104	0	1 856
O_2	Highway	0	0	0	0	0	0
	Railway	0	0	0	0	622	0
O_3	Highway	0	0	0	0	0	0
	Railway	0	1 397	1 083	0	0	0
	Lease	0	1 708	0	0	0	0
v_2	Modes	D_1	D_2	D_3	D_4	D_5	D_6
O_1	Highway	309	0	0	0	0	0
	Railway	0	0	0	2 277	0	1 024
O_2	Highway	0	0	0	0	0	0
	Railway	0	0	0	0	948	0
O_3	Highway	0	0	0	0	0	0
	Railway	0	425	1 585	0	0	0
	Lease	438	1 197	0	0	0	0
v_3	Modes	D_1	D_2	D_3	D_4	D_5	D_6
O_1	Highway	0	0	0	0	0	0
	Railway	0	0	0	52	0	2 548
O_2	Highway	0	0	0	0	0	0
	Railway	0	0	0	0	798	0
O_3	Highway	0	0	0	0	0	0
	Railway	0	0	2 100	0	0	0
	Lease	1 620	865	217	1 629	0	0
Value of the function		92 206.49743					

In addition, if we only choose highway transportation mode and other conditions unchanged, the final cost would be 203 226.93 yuan, which is much higher than the optimal solution and also much higher than the number of railway transportation mode only (the cost is 157 438.24 yuan). If we don't consider the capacity, i.e., the transport capacity of transportation modes on the path is large enough, the final cost is 92 206.50 yuan. This is because most demand points are satisfied by allocation and transportation, the dispatching scheme is shown in Table 5 (the quantity of transported pallets includes the damaged pallets).

Damage rate of pallets can affect dispatching. Generally speaking, the lower ρ^k is, the smaller cost of dispatching. If we don't consider damage rate or assume the damage rate as 0, the total cost of dispatching is 144 478.64 yuan, and the dispatching scheme will change, as shown in Table 6.

Table 6 Optimization results of ignoring damage rate

v_1	Modes	D_1	D_2	D_3	D_4	D_5	D_6
O_1	Highway	1 050	0	1 710	0	0	0
	Railway	0	0	0	1 100	0	1 160
O_2	Highway	0	0	0	0	0	0
	Railway	0	0	0	0	620	0
O_3	Highway	0	0	0	0	0	0
	Railway	0	1 470	0	0	0	0
Lease		0	1 625	370	0	0	690
v_2	Modes	D_1	D_2	D_3	D_4	D_5	D_6
O_1	Highway	0	0	0	0	0	0
	Railway	0	0	0	280	0	0
O_2	Highway	0	0	0	0	0	0
	Railway	0	0	0	0	635	0
O_3	Highway	0	0	0	0	0	0
	Railway	0	0	0	0	0	0
Lease		745	1 620	1 580	1 990	310	1 020
v_3	Modes	D_1	D_2	D_3	D_4	D_5	D_6
O_1	Highway	460	0	1 070	0	0	0
	Railway	0	0	0	1 070	0	0
O_2	Highway	0	0	0	0	0	0
	Railway	0	0	0	0	795	0
O_3	Highway	0	0	0	0	0	0
	Railway	0	865	1 120	0	0	0
Lease		1 160	0	120	610	0	2 540
Value of the function				144 478.643828			

In addition, we try to increase the scale of the system. Increase supply points to 6 and de-

mand points to 10, except the quantity of supply and demand, distance and other values related with the new added points of supply and demand, the other parameters such as confidence level δ^k and pallets type are unchanged. Then solve it by Cplex. The result shows that the solving speed doesn't increase significantly (as shown in Figure 3). This is because the influence factor of affecting the solving speed is not only the system scale, but also the complexity of model.

Figure 3 The convergence speed after increasing scale of pallet pool system

6 Conclusions

Based on the pallet pool system of enterprise alliance type, and combining with the related research theory, the decision schemes of empty pallets dispatching in highway and railway transportation modes are analyzed. Through the analysis of relevant factors affecting the empty pallet dispatching, the model of empty pallets dispatching is determined with minimum cost which includes transportation cost, carbon emission cost, leasing cost, inventory cost and damage cost. As the different demand of enterprises for pallet specifications, the pallet types are taken into 3 kinds. In addition, according to the time requirements of pallet demand points for different types of pallets, the penalty function for the transport time is established, and the minimum cost is taken as the optimization objective. The damage rate of pallets in different transportation modes is uncertain, so a stochastic programming model is constructed. Since the objective function and constraint conditions have stochastic variables, in order to solve the model, chance constrained condition with stochastic variables is determined. Then the optimization model is solved using Cplex software. Finally, a case is shown in order to validate and analyze the model. Due to the difference of railway and highway transportation modes in the freight, transport capacity, carbon emission and other factors of influencing the empty pallet dispatching, the characteristics of two transportation modes in their own way are analyzed. And the results for different values of parameters are compared in order to prove the effectiveness of the proposed method further. Methods studied in this paper and the related theory can provide theoretical guidance for the actual dispatching of pallets and other carriers.

References

- [1] Ansoff H I. Corporate strategy. McGraw-Hill Book Company, 1965.
- [2] Zhou K, He S W, Song R, et al. Chinese railway pallet pool system and its benefit analysis. Shandong Science, 2014, 27(5): 67–72.
- [3] Murray J. Pallet pool is key to Swedish cargo handling efficiency. The Journal of ICHCA, 1967, 3(3): 27–29.
- [4] Anon. Pallet pool: The hauliers speak out. Matls Handling and Mgmt, 1969(9): 30–32.

- [5] Jouglard M, Spink P. Pallet pools pump up productivity. *Manufacturing Engineering*, 2004, 132(2): 71.
- [6] Ray C D, Michael J H, Scholnick B N. Supply-chain system costs of alternative grocery industry pallet systems. *Forest Products Society*, 2006, 56(10): 52–57.
- [7] Mckerrrow D. What makes reusable packaging systems work? *Logistics Information Management*, 1989, 9(4): 39–42.
- [8] Lacefield S. What's more "palatable"-renting or owning? *Logistics Management*, 2004, 43(4): 63–66.
- [9] Raballand G, Aldaz-Carroll E. How do differing standards increase trade costs? The case of pallets. *The World Economy*, 2007, 30(4): 685–702.
- [10] Zhou K, He S W, Song R, *et al.* Optimization model of railway empty pallet dispatching based on the mode of pallet pool. *Journal of Beijing Jiaotong University*, 2014, 38(3): 22–26.
- [11] Leung C H, Lai K K, Wu Y. Stochastic Model for Dynamic Empty Container Allocations. *Industrial Engineering and Management Systems*, 2003(2): 113–120.
- [12] Lam S W, Lee L H, Tang L C. An approximate dynamic programming approach for the empty container allocation problem. *Transportation Research Part C*, 2007(15): 265–277.
- [13] Ren J W, Zhang X Y. Pallet recovery stochastic programming model of pallet pool system. *Control and Decision*, 2010, 25(8): 1211–1214.
- [14] Ren J W, Zhang X Y. Two stage stochastic chance constrained programming model of pallet pool system dispatch. *Control and Decision*, 2011, 26(9): 1353–1357.
- [15] Ren J W, Zhang X Y, Zhang J, *et al.* A multi-scenario model for pallets allocation over a pallet pool. *Systems Engineering — Theory & Practice*, 2013, 33(1): 1–10.
- [16] Zhou K, He S W, You L J. Study on palletized share mode based on railway transportation. *Railway Transport Economy*, 2013, 35(10): 83–87.
- [17] Miranda P, Garrido R, *et al.* Multidepot vehicle routing with uncertain demands. *Transportation Research Record*, 2004, 1882: 150–158.
- [18] Liu B D, Zhao R Q, Wang G. *Uncertain programming with applications*. Tsinghua University Press Ltd, 2003.
- [19] Liu B D, Iwamura K. Chance constrained programming with fuzzy parameters. *Fuzzy Sets and Systems*, 1998, 94(2): 227–237.
- [20] Liu Y H. Uncertain random variables: A mixture of uncertainty and randomness. *Soft Computing*, 2013, 17(4): 625–634.
- [21] Wang B H, He S W, Song R, *et al.* Multi-modal express shipment network routing optimization model and algorithm. *Journal of the China Railway Society*, 2009, 31(2): 12–16.
- [22] Luo X G. Optimization software and application. <http://wenku.baidu.com/view/f3954605b52acfc789ebc95d.html>.