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A study on iron ore transportation model with penalty value of transportation equipment waiting

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ABSTRACT: As some steel enterprises are at a disadvantage in the choice of the mode of transportation, this paper made further studies of the characteristics of the iron ore logistics, taking comprehensive consideration of optimizing the waiting time under the conditions with limited loading capacity and setting up a procedural model of the iron ore logistics system with minimum cost of transportation, storage, loading, unloading, and transportation equipment waiting. Finally, taking the iron ore transport system of one steel enterprise as example, the solution and the validity of the model were analyzed and verified in this paper.

Keywords: iron ore; transportation model; waiting penalty

1 INTRODUCTION

As the steel industry has entered low-profit era, the steel enterprises pays more attention and puts more energy to the logistics management and the cost reduction of steel materials in circulation. It can maximize the profits by means of implementing refined management of the supply chain [1]. The iron ore supply has direct impact on subsequent production process in the steel enterprise because of the continuity of production process. Once the continuous production process was broken, it will result in huge losses. So the procurement and transport linking of iron ore is the key point to ensure the normal operation of steel companies. Gao and Tang [2] have solved these problems and determined the optimal order quantity by an weighted multi-objective linear programming model (MOLP). Although this model has determined the order quantity, it has not provided the selection method of optimal transportation. Gao Zhen and Tang Lixin [3] have built and solved the raw material procurement plan model for large steel companies, which is based on steel raw material logistics processes. This model has practical value, but it is from the standpoint of the supply chain, whereas, not for the specific steel companies. Moreover, Zhang Di [4] has built the decision making model including integrated inventory and transportation multistage transport modes, which taking minimizing inventory costs into account and applying to production.

As for iron ore procurement, the majority of iron ore comes from foreign mining and is shipped to domestic ports by a large ocean liner, and then gets allocated. On the one hand, to prevent unexpected factors, steel enterprises would set a safety inventory. On the other hand, there would be a trade-off when controlling transportation costs and inventory costs. High consumption of enterprise procurement leads to high transportation and inventory costs when the logistic management is poorly controlled. In the context of the general rise in international ore and shipping prices, how to reduce procurement costs becomes the puzzle for domestic steel enterprise logistics sectors. According to the survey, several inland steel enterprises are far from rivers and seas. They could only depend on rail and highway transport. It results in higher transportation costs than these enterprises that are near rivers or seas. Although the rail transport cost is far less than highway transport, considering the continuity of supply and the limit of route transport capacity and pick-up capability of the stations, they should select the right means of transportation.

There are two methods to load and unload raw materials for these steel enterprises: Tipper loading and unloading, and manual handling. On the one hand, the waiting of transportation equipment might incur fees, called transport equipment waits penalty value (referred to “punish wait”).The more waiting time is, the

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higher waiting costs rates take. On the other hand, manual handling costs is far higher than the tipper loading and unloading costs. So a balance must be formed between the two methods.

This article studies the method to choose best mode of transport, which make the total costs of transportation from the suppliers to the production site minimized. In addition, the equipment waiting time and higher labor costs are considered under the limit of train transport capacity, iron ore storage capacity and tipper loading and unloading capability.

2 PROBLEM DESCRIPTION

2.1 *Problems to be solved*

In order to improve the management quality of iron ore transportation, the paper has developed the logistics schematic of iron ore transportation (as shown in Figure 1) and the iron ore diversion schematic in the factory (as shown in Figure 2). Then further study was made on the integrated supply which related to multi-suppliers, multi-species, multi-ports and single customer. The optimal mathematical model could ensure

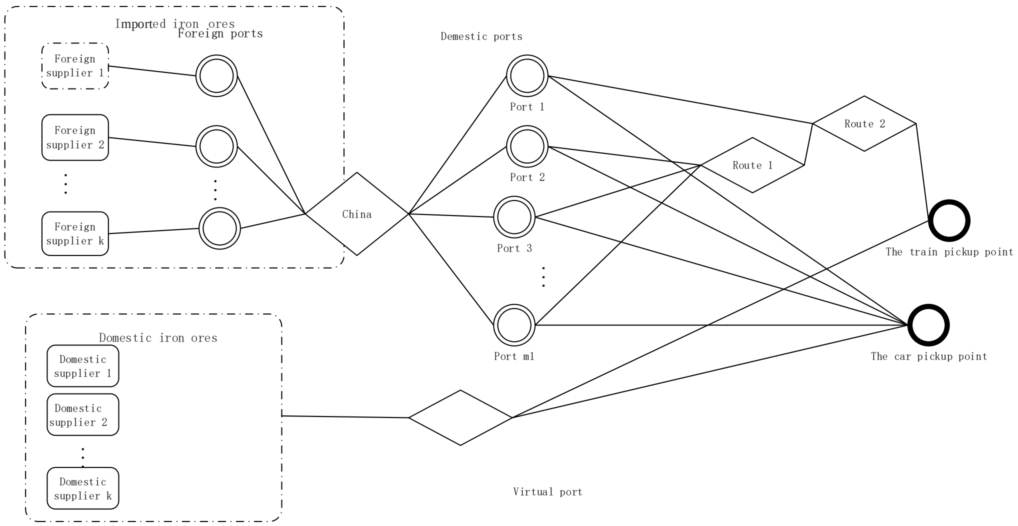

Figure 1. The logistics schematic of iron ore transportation

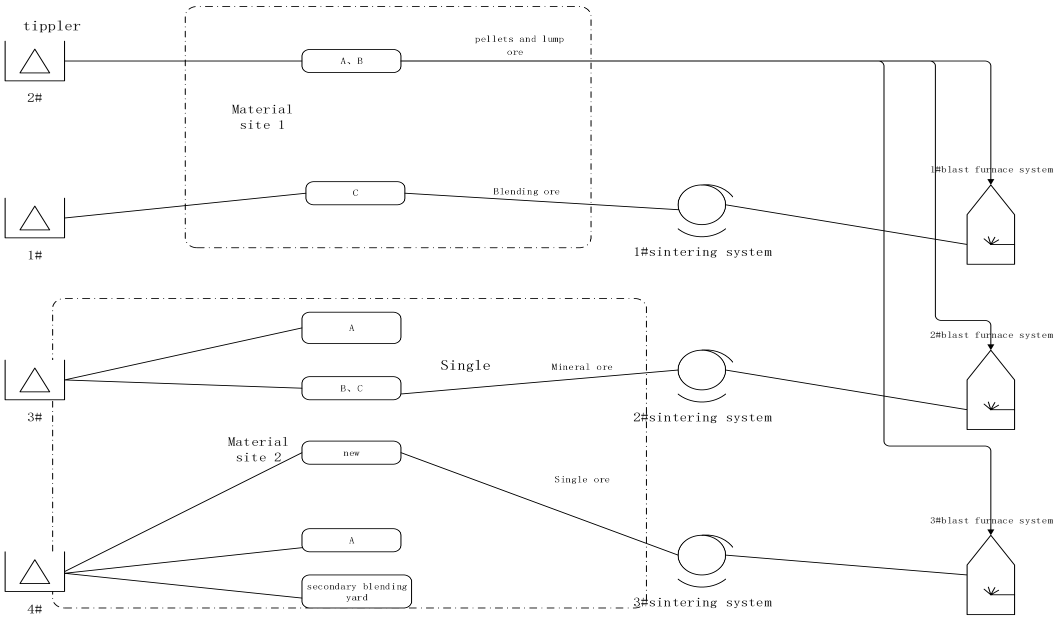

Figure 2. The iron ore diversion schematic in the factory

the lowest total cost of iron ore supply processes, and it is established under the premise of ensuring the steel production of the factory. The equipment waiting penalty value is added into the model and the capacity of the nodes and line in transportation chains is also considered. Then this model would be solved in stage by the software MATLAB. Finally, the optimal solutions would be found. The optimal train waiting time, suppliers, supply varieties, choice of ports, supply quantity, transportation way (car and train transportation quantity) will be available. It could provide decision-making basis for managers.

2.2 *Transport equipment costs and waiting penalty value*

Due to the capacity constraints of tipper, the train transport generates delay-fee. It is called as the train transportation waiting penalty value. Production materials transported by train are unloaded by tipper and enter into the raw materials site. This process mainly generates waiting costs, delivery costs, unloading costs, labor costs and freight and so on.

This article treats the delivery costs, unloading costs, labor costs and freight as the train unloading costs, while train waiting costs is calculated separately. Train waiting costs is related to the time period between the trains go in and out of the factory. The cost varies in steps; the longer the waiting time is, the more it costs. When train waiting costs and tipper unloading costs are higher than the costs of manual unloading, decision makers will choose the latter, instead of still waiting.

3 MODEL FORMULATION

Iron ore logistics transportation system model for a steel enterprise belongs to multiple suppliers-a single customer model, which includes a series of parts such as demand, production, ordering, shipping, port stocks, and inland transport. The waiting penalty value of transport equipment is also added into the model. Before building the transportation model, some decisions about waiting time of train entering the factory must be made. These decisions in various stages of waiting time would have an influence on the total cost of the entire logistics system. Overall logistics and transport model should be established according to different waiting time.

3.1 *Assumptions*

Suppose that decision-making period is a month. In the premise of meeting the production needs of this month, the quantities of various types of iron ore transported into the factory by train and truck are optimized. Next it is to choose the suitable monthly iron transport ratio. Assumptions:

(1) Production materials transport by train should be unloaded by the tipper during the waiting time;

(2) Production materials transport by cars should be unloaded manually;

(3) The tipper's capability is limited and with flexibility;

(4) The manual capability is without restriction;

(5) The pickup capability of train station is limited;

(6) Do not consider the transit loss and empty rate of cars and trains;

(7) Do not consider the order cost and price volatility of iron ore.

3.2 *Parameters and variables*

Define the following parameters:

A_{ij}—the maximum quantity of *j* material supplied by *i* supplier;

Dj—the month requirements of *j* material;

C_{im}—the maritime transportation cost from *i* supplier to m port (yuan/ ton). Note: If it's impossible for supplier *i* to arrive port m, then $C_{im} = \infty$; If supplier *i* arrives virtual port m, then $C_{im} = 0$;

B_m—the port surcharge of port m (Yuan/ton), and for virtual port $B_{m = 0}$;

Q_m—the maximum capability to accept goods of port m (For example, the maximum storage capacity of a steel plant);

X_m^p—the railway transportation costs from port *m* to the steel plant (Yuan/ton), and if the rail transport is impossible, then $X_m^p = \infty$;

Y_m^p—the highway transportation costs from port m to the steel plant (Yuan/ton), and if the highway transport is impossible, then $Y_m^p = \infty$;

C_{im1}—the total cost from *i* supplier to *m* port, then to the steel plant selecting rail transport (Yuan / ton);

C_{im2}—the total cost from *i* supplier to *m* port, then to the steel plant selecting motor transport (Yuan / ton);

S—the maximum traffic capability of the first route;

E—the maximum traffic capability of the second route;

F—the maximum pickup capability of the train pickup point;

G—the unloading costs of tipper (Yuan / ton);

H—the costs of the manual unloading (Yuan/ton);

I—the penalty value of train waiting (Yuan/train);

f_0—the tipper capability of the train without waiting (train per mouth);

W—the average daily waiting time of the trains;

Model variables are as follows:

X_{jim}—the quantity of material *j* transported from mine *i* to port *m* by rails;

Y_{jim}—the quantity of material *j* transported from mine *i* to port *m* by trucks.

3.3 *The decision-making process of the train waiting time*

The standard of the delay cost of train is as follows:

During (0, n) hour, the delayed cost is r_1 Yuan per hour for a train;

During (n, 2n] hour, the delayed cost is r_2 Yuan per hour for a train;

During (2n, 3n] hour, the delayed cost is r_3 Yuan per hour for a train;

During $(3n,+\infty)$ hour, the delayed cost is r_4 Yuan per hour for a train.

So, the function of penalty waiting value of the train in different time is defined as following:

$$\mathrm{I}(\mathrm{w})=\begin{cases} 0 & w=0 \\ r_1 w & 0<w\le n \\ r_2 w+n(r_1-r_2) & n<w\le 2n \\ r_3 w+n(r_1+r_2-2r_3) & 2n<w\le 3n \\ r_4 w+n(r_1+r_2+r_3-3r_4) & w>3n \end{cases}$$
$$(r_4>r_3>r_2>r_1)$$

The month tipper capability under the condition of different waiting time, *f (w)* is as following:

$$f(w)=\begin{cases} f_0 & w=0 \\ f_0+aw & 0<w\le n \\ f_0+na+b(w-n) & n<w\le 2n \\ f_0+na+nb & w>2n \end{cases}$$
$$(a>b>c>0)$$

In which, the parameters, n, r_1, r_2, r_3, r_4 are determined by the specific train delay fee charging standard; the parameters, *a, b, c* are determined by the effect of train waiting time on the tipper capability.

Under 5 types of conditions below, we calculate the transportation cost entering into the factory, the handling charges (the costs of tipper unloading + the costs of manual unloading) and the waiting costs with different waiting time:

(1) There is no waiting time for trains and the trains that exceed the rollover capability of tippers are transferred to manual unloading directly;

a. If $\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{i=1}^{I}X_{jim}\le f_0$, the costs entering into the factory C_e is $\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{i=1}^{I}X_{jim}G$.

b. If $\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{i=1}^{I}X_{jim}>f_0$, the costs entering into the factory C_e is $\left(\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{i=1}^{I}X_{jim}-f_0\right)H+f_0G$.

(2) The daily average waiting time of the trains entering into the factory exceeds the rollover capability of tippers $w\in(0,n]$;

a. If $f_0<\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{i=1}^{I}X_{jim}\le f_0+aw$, the entering costs C_e is $\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{i=1}^{I}X_{jim}G+r_1aw^2$.

b. If $\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{i=1}^{I}X_{jim}>f_0+aw$, the entering costs C_e is $\left[\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{i=1}^{2}X_{jim}-(f_0+aw)\right]H+(f_0+aw)G+r_1aw^2$.

(3)The daily average waiting time of the trains entering into the factory exceeds the rollover ability of tippers $w\in(n,2n]$;

a. If $f_0+aw<\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{i=1}^{I}X_{jim}\le f_0+na+bw-nb$, the entering costs C_e is

$$\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{i=1}^{I}X_{jim}G+nr_1(na+bw-nb)+r_2(na+bw-nb)(w-n).$$

b. If $\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{i=1}^{I}X_{jim}>f_0+na+bw-nb$, the entering costs C_e is

$$(f_0+na+bw-nb)G+\left[\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{i=1}^{I}X_{jim1}-(f_0+na+bw-nb)\right]H+nr_1(na+bw-nb)+r_2(na+bw-nb)(w-n).$$

(4) The daily average waiting time of the trains entering into the factory exceeds the rollover capability of tippers $w\in(2n,3n]$;

a. If $\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{i=1}^{I}X_{jim}\le f_0+na+nb$, the entering costs C_e is

$$\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{i=1}^{I}X_{jim}G+nr_1(na+nb)+nr_2(na+nb)+r_3(na+nb)(w-2n).$$

b. If $\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{i=1}^{I}X_{jim}>f_0+na+nb$, the entering costs C_e is

$$(f_0+na+nb)G+\left[\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{i=1}^{I}X_{jim}-(f_0+na+nb)\right]H+nr_1(na+nb)+nr_2(na+nb)+r_3(na+nb)(w-2n).$$

(5)The daily average waiting time of the trains entering into the factory h exceeds the rollover capability of tippers $w\in(3n,+\infty)$;

a. If $\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{i=1}^{I}X_{jim}\le f_0+na+nb$, the entering costs C_e is

$$\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{i=1}^{I} X_{jim}G + nr_1(na+nb) + nr_2(na+nb) + nr_3(na+nb) + r_4(na+nb)(w-3n).$$

b. If $\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{i=1}^{I} X_{jim} > f_0 + na + nb$, the entering costs C_e is

$$\left[\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{i=1}^{I} X_{jim} - (f_0+na+nb)\right]H + (f_0+na+nb)G + nr_1(na+nb) + nr_2(na+nb) + nr_3(na+nb) + r_4(na+nb)(w-3n).$$

3.4 *Objective function*

Objective function is the minimum sum of marine freight, inland transportation charge, the port surcharge (handling charges, storage charges), and the costs entering the factory (handling charges, the waiting cost of the train), namely:

$$\text{Min} \sum_{m=1}^{M}\sum_{i=1}^{I}\sum_{j=1}^{J}(X_{jim}+Y_{jim})C_{im} + \sum_{m=1}^{M}\sum_{i=1}^{I}\sum_{j=1}^{J}(X_{jim}+Y_{jim})C_m + \sum_{m=1}^{M}\sum_{i=1}^{I}\sum_{j=1}^{J}X_{jim}X_m^p + \sum_{m=1}^{M}\sum_{i=1}^{I}\sum_{j=1}^{J}Y_{jim}Y_m^p + \sum_{m=1}^{M}\sum_{i=1}^{I}\sum_{j=1}^{J}Y_{jim}H + C_e$$

In which,

(1) The marine freight is:

$$\sum_{m=1}^{M}\sum_{i=1}^{I}\sum_{j=1}^{J}(X_{jim}+Y_{jim})C_{im};$$

(2) The port storage fee is:

$$\sum_{m=1}^{M}\sum_{i=1}^{I}\sum_{j=1}^{J}(X_{jim}+Y_{jim})C_m;$$

(3) The railway transportation costs are:

$$\sum_{m=1}^{M}\sum_{i=1}^{I}\sum_{j=1}^{J}X_{jim}X_m^p;$$

(4) The highway transportation costs are:

$$\sum_{m=1}^{M}\sum_{i=1}^{I}\sum_{j=1}^{J}Y_{jim}Y_m^p;$$

(5) The handling charges trucks entering the factory are:

$$\sum_{m=1}^{M}\sum_{i=1}^{I}\sum_{j=1}^{J}Y_{jim}H;$$

(6) The handling charges trains entering the factory and the waiting costs are C_e.

Note: There exists corresponding C_e for *W* in different waiting time.

3.5 *Constraint conditions*

(1) The manufacture requirement constraints:

$$\sum_{m=1}^{M}\sum_{i=1}^{I}(X_{jim}+Y_{jim}) \ge D_j \quad (j = 1, 2, \dots, J) \qquad (1)$$

(2) The ability constraints of suppliers:

$$\sum_{m=1}^{M}(X_{jim}+Y_{jim}) \le A_{ij} \quad (i = 1, 2, \dots, I;\ j = 1, 2, \dots, J) \qquad (2)$$

(3) The ability constraints of ports:

$$\sum_{i=1}^{I}\sum_{j=1}^{J}(X_{jim}+Y_{jim}) \le Q_m \quad (m = 1, 2, \dots, M) \qquad (3)$$

(4) The traffic ability constraints of the first route:

$$\sum_{m=1}^{K}\sum_{i=1}^{I}\sum_{j=1}^{J}X_{jim} \le S \qquad (4)$$

(5) The traffic ability constraints of the second route:

$$\sum_{m=1}^{M}\sum_{i=1}^{I}\sum_{j=1}^{J}X_{jim} \le E \qquad (5)$$

(6) The pickup ability constraints of stations:

$$\sum_{m=1}^{M}\sum_{i=1}^{I}\sum_{j=1}^{J}X_{jim} \le F \qquad (6)$$

(7) The ability constraints on the tipper. For those constraints, there are two situations in this paper: in the first situation (7.1), the ability of tippers can meet the requirements of trains entering the factory in determined waiting time; in the second situation (7.2), the ability of tippers is unable to meet all the requirements of trains entering the factory in determined waiting time and some portion of the trains will be manually unloaded. The entering cost C_e is different under two conditions, thus the corresponding objective function is different. The constraints are expressed as follow:

a. If W=0, $\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{i=1}^{I}X_{jim} \le f_0$ (7.1)

or $\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{i=1}^{I}X_{jim} > f_0$ (7.2)

b. If $w \in (0, n]$, $f_0 < \sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{i=1}^{I}X_{jim} \le f_0 + aw$ (7.1)

or $\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{i=1}^{I}X_{jim} > f_0 + aw$ (7.2)

c. If $w \in (n, 2n]$,

$$f_0 + aw < \sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{i=1}^{I} X_{jim} \le f_0 + na + bw - nb \qquad (7.1)$$

or $$\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{i=1}^{I} X_{jim} > f_0 + na + bw - nb \quad (7.2) \qquad (7.2)$$

d. If $w \in (2n, 3n)$,

$$\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{i=1}^{I} X_{jim} \le f_0 + na + nb \quad (7.1) \qquad (7.1)$$

or $$\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{i=1}^{I} X_{jim} > f_0 + na + nb \quad (7.2) \qquad (7.2)$$

e. If $w \in (3n, +\infty)$,

$$\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{i=1}^{I} X_{jim} \le f_0 + na + nb \quad (7.1) \qquad (7.1)$$

or $$\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{i=1}^{I} X_{jim} > f_0 + na + nb \quad (7.2) \qquad (7.2)$$

4 APPLICATION TO THE STEEL ENTERPRISE

4.1 *Solution method of the model*

In this paper, when W under the condition with different value, the model is a linear programming model. Since the data size is bigger, it is feasible to use MATLAB to solve the model. Before carrying out the solution, the model must be transformed into standard form as follows:

$$\min_x f_x^T$$
$$AX \le b$$
$$AeqX = beq$$
$$lb \le x \le ub$$

(1) Model variables regularization: Put X_{jim} and Yj_{im} in the correct order. The total size of the variable is $J \times I \times M \times 2$;

(2) The coefficients of objective function regularization: the variable in the model is $J \times I \times M \times 2$ and the coefficient matrix should be $1 \times (J \times I \times M \times 2)$. The total costs of corresponding line and transportation mode need to be calculated. Take the ore transportation fee schedule of one steel enterprise in the model for example, conducting a specific cost calculation on the same. The calculations are as shown in Table 1.

(3) The size of constraints is $J + I \times J + M + 3$. Coefficient of the condition function is set to $(J + I \times J + M + 3) \times (J \times I \times M \times 2)$ matrix in accordance with the law of (1).

The total cost of the transportation model is as shown in Table 1.

4.2 *Evaluation of the Result*

After normalization, the model has been solved by programming in MATLAB. According to the value of w (integer) from 0 to 30 and different constraint conditions of 7.1 and 7.2, the program need to be run 31×2 times. According to the result of model calculation, when w=10, the total logistics cost of ore entering into the factory has reached the minimum, and the cost is 220.65 million yuan. The obtained result of the model is consistent with the actual situation, and the overall logistics cost has been reduced.

(1) Before the optimization, the steel factory outputs about 7.3 million tons of iron, and the logistic cost of ore is 230.17 million yuan per month in 2010;

(2) After the optimization, the steel factory outputs about 7.9 million tons of iron, and the logistic cost of ore is actually decreased 9.52 million yuan per month in 2014;

(3) The unit logistics fees of iron ore entering the factory for iron production have been decreased by 11.4%;

(4) Based on the analysis of the result, the total

Table 1. The total cost of the transportation model

i	m	C_{im}	B_m	X_m^p	Y_m^p	G	H	C_{im1}	C_{im2}
Foreign suppliers 1	1	71.19	38.86	82.58	125.61	4.699	19.956	197.329	255.616
	2	71.19	30.66	86.29	142.37	4.699	19.956	192.839	264.176
	3	71.19	34.56	140.23	216.5	4.699	19.956	250.679	342.206
......									
Virtual		∞	∞	∞	∞	∞	∞	∞	∞
......									
Domestic supplier 1	1	∞	∞	∞	∞	∞	∞	∞	∞
	2	∞	∞	∞	∞	∞	∞	∞	∞
	3	∞	∞	∞	∞	∞	∞	∞	∞
......									
Virtual		0	0	180.37	242.54	4.699	19.956	185.069	262.496
......									

railway transport ratio of iron ore have been increased (as shown in figure 3): a. Railway transport ratio of domestic concentrate ores has been increased; b. The transportation of imported iron ore is realized all by railway transportation; c. The railway transportation ratio of the increased imported economic ores is 100%.

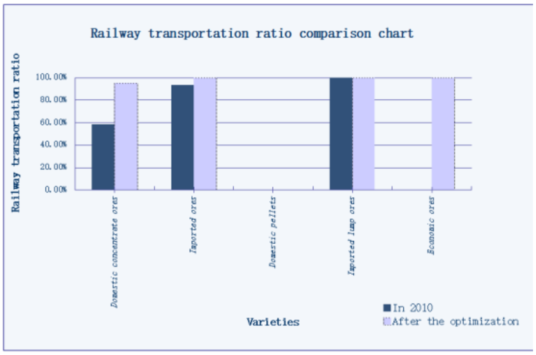

Figure 3. Railway transportation ratio comparison chart

5 CONCLUSIONS

This paper aimed at doing in-depth study about the characteristics of iron ore logistics of some large inland steel enterprises which can't rely on water transportation. Based on the process of iron ore entering this kind of steel industry, the penalty value of transportation equipment waiting (This paper considered the train waiting time) was taken into overall consideration when the condition of loading capacity was limited. The procedural model based on the total cost minimum of transportation, storage, loading and unloading, and transportation equipment waiting cost of the ore logistics system was constructed. This is a supply mode of one user with many suppliers, and it is an optimization model with a collection of multi-stage transportation, storage, loading and unloading process of iron ore supply. In this paper, we not only presented the data processing and solution of the model, but also made empirical verification to prove that this model can achieve overall balance with comprehensive consideration of various factors; the calculation also proved that overall iron ore logistics rate has been reduced, and the steel enterprise has achieved optimal effect.

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