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An Optimization Model of Coal Allocation in a Group

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Abstract

The frame of an optimization model of coal alloction in a power generation group was introduced in present study. The influence of multi-coals blending and transportation were all considered in the model. Firstly, the impact of each process of coal using on the cost of power generation and boiler safety in the combustion process were analyzed, and the detailed mathematical descriptions were given. A multi-coals blending mathematical model based on safty, environmental protection and cost was proposed. The optimization model of coal transportation in the power generation group to achieve the most benefit was established. The algorithms of these models were studied and found that the genetic algorithm is one of the suitable methods to solve the models. An optimaiztion system for the coal allocation in the power generation group was developed based on the models and algorithms. The system adopts friendly software structure and can provide personalized functions for the power generation group and power plants.

Keywords*: power generation group, multi-coals blending, coal allocation, multi-objective optimization model*

1. Introduction

In China, coal is the primary energy used in the industry production, and the power industry is a large cousumer of coal resources. However, the distribution imbalance of coal resources and power generation enterprises is very serious in Chian. The long term performance of electrical coal supply and demand is that the coal should be transported from the west to the east as well as from the north to the south [1].

On the other hand, with the increasing of coal price and the shortage of the coal transportation, more and more thermal power plant has no longer singly used the designed coal, but adopted the multi-coals blending technology to sovle these problems. According to the operation experiences from many thermal power plants, the technology can expand the extension of purchasing coal sources, optimize the coal transport, then achieve the goal of reducing the operation cost of thermal power plants and power generation group [2].

For a power generation group, coal supply is a large system and involves a number of different areas, including coal supplier, logistics enterprise, transit logistics center and each power plant in the group. Scientific and efficient coal allocation should predict coal demand based on the “Coal-furnace" coupling, coal storage situation and load trend in each power plant in the group, integrate the coal sources information of coal supplier,optimizethe deployment of various transportation means, and make coal supplier, logistics provider and thermal power plant form a closed cycle [3].

In order to improve the competitiveness of a power generation group, an optimization model of coal allocation based on multi-coals blending techonolgy is a necessity [4-5]. Jin and Kwang[6] presented a methodology, multiagent-system-based intelligent reference governor (MAS-IRG), to realize the optimal mapping by searching for the best solution to the multi objective optimization problem that tackles conflicting requirements and found that MAS is an efficient methodologies to design the IC system for a complex large-scale power plant. A novel plant optimization technique was developed using genetic algorithms (GA) to maximize the overall revenue generated by a coal preparation plant by searching the best possible combination of overall yield and multiple product quality constraints [7]. Experimental investigations into the ignition behaviors of pulverized coals and coal blends in a drop tube furnace using a flame monitoring system were carried out. The ignition behaviors of a coal blend

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are found to have similar characteristics as the coal of higher volatile matter in the blend and depend on its proportion in the blend.The results from this study are used to predict the operation of a coal fired power plant in terms of fuel selection, fuel blending, and flame stability [8].

Based on thermal power industry SO_2 emission data from state department authorities, considering the main factors of China's thermal power industry SO_2 predicted emission, a combination prediction model was established, connecting gray prediction model with BP neural network model to predict SO_2 emission [9]. A study presented an investigation on the influence of hydrothermally treated municipal solid waste(MSW) on the co-combustion characteristics with different rank coals, i.e. Indian, Indonesian and Austra-lian coals. These experimental results help to understand and predict the behavior of coal and MSW blends in practical applications [10]. A numerical solution was presented to the constrained non-linear optimization of a multivariable objective function utilizing Excel spreadsheet. The method is capable of handling any number of source coals with different size fractions [11]. Comparative combustion studies were performed on particles of pulverized coal samples from three different ranks: a high-volatile bituminous coal, a sub-bituminous coal, and two lignite coals [12].

Siti et al. [13] investigated the behaviour of Malaysian sub-bituminous coal (Mukah Balingian), oil palm biomass (empty fruit bunches (EFB), kernel shell (PKS) and mesocarp fibre (PMF)) and their respective blends during pyrolysis using thermogravimetric analysis (TGA). The study investigated the combustion profiles of tobacco stem, high-sulfur bituminous coal and their blends by thermogravimetric analysis. Ignition and burnout performances, heat release performances, and gaseous pollutant emissions were also studied by thermogravimetric and mass spectrometry analyses [14]. The combustion behavior and excess heat release during the oxy-fuel combustion of blended coals were investigated experimentally using a non-isothermal thermogravimetric analyzer. For interaction behaviors on characteristic temperatures, the volatile release temperature shows an additive behavior; however, ignition and burnout temperatures show non-additive behaviors for blended coals [15].

In present study, the combined effect of transportation and multi-coals blending combustion on the total cost of power generation was investigated based on the method of coal management and allocation in a power generation group. The optimization coal purchasing and transportation paths for each power plant in the group were determined by the introduction of multi-coals blending combustion model and coal transportation and allocation model.

2. Framework of an Optimal Allocation Model

Traditional fuel coal transportation model often use the lowest transport cost as objective function. But for a power generation group, it is more complex due to many factors, such as delivery fee, arrival time, coal demand, coal species, auxiliary unit costs, and environmental requirements. It is a multi-objective optimal issue. The whole process of fuel coal production and using, from mining to combustion, involves many factors, and it is shown by Figure 1.

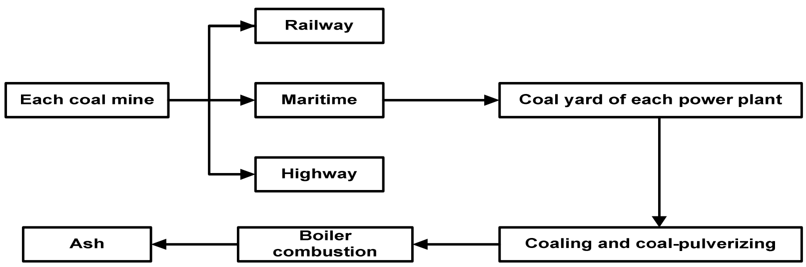

Figure 1. Flow Chart of Coal Flow Direction

For the process of coal combustion in a power plant, using multi-coals blending technology may affect combustion stability, erosion, fouling, overtemperature of heating surfaces, slagging in the furnace, unit operation efficiency and increasing electricity comsumption of auxiliary equipments. Thus, the coal species adaptability and the comprehensive benefits all should be considered in the model.

For the process of coal transportation, the final lowest comprehensive price at the entry of each plant is the main goal. According to the selected coal species by the allocation and blending system in each power plant, the optimal purchasing scheme can be achieved by filtering coal quality, selecting path, and predicting the additional cost.

So, for the whole process of coal allocation in a group, the model must consider the most suitable coal species and the best transportation path, and then obtain the biggest benefit for the power generation group. The optimal method route of coal allocation in a power generation group is shown by Figure 2.

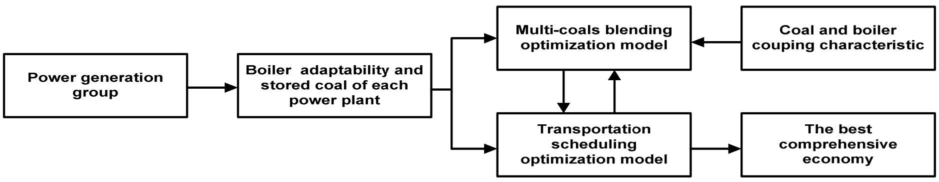

Figure 2. Optimal Method Route of Coal Allocation in a Group

3. Optimization Multi-coals Blending Model in a Power Plant

Multi-coals blending model need considering many factors, such as ignition, combustion, slagging characteristics, and is a multi-objective optimization issue [6]. The model can be described by,

$$\min\ \boldsymbol{y} = (f_1(\boldsymbol{x}), f_2(\boldsymbol{x}), \cdots, f_p(\boldsymbol{x}))\quad (p<K) \tag{1}$$

$$\textbf{Subject to:}\quad g(\boldsymbol{x}) = (g_1(\boldsymbol{x}), g_2(\boldsymbol{x}), \cdots, g_L(\boldsymbol{x})) \le 0 \tag{2}$$

Where, x is variable vector, $f(x)$ is objective function, y is objective function vector, $g(x)$ is constraint condition.

3.1. Objective Functions

The comprehensive economic indicators of power plant were used as objective functions, incluiding coal price cost, operation cost and environmental cost.

(1) Coal price cost

If the standard coal price is P_0 (Yuan/ton), the average calorific value of blended coal is Q_{avg}(kCal/kg), the price is P_{avg}, the saving cost under a certain multi-coals blending method is expressed as,

$$\Delta P_1 = P_0 - \frac{7000}{Q_{avg}} P_{avg} \tag{3}$$

(2) Operation cost

The operation cost mainly includes the power consumptions of coal pulverizing system and fan system. Assuming the power comsumption per weight pulverized coal for each kind of fuel coal all is s (kWh/ton), the increasing of operation cost is calculated by,

$$\Delta P_2 = s \cdot (\frac{7000}{Q_{avg}} - 1) \cdot P_y \tag{4}$$

Where, P_y denotes the price of electricity to power grid, Yuan/kWh.

(3) Environmental cost

Environmental costs consist primarily of desulfurization costs, limestone costs and sewage charges. Assuming the desulfurization efficiency is same for different units. The environmental costs can be expressed as:

$$\Delta P_3 = U_{SO_2} S_{avg} \cdot (7000 / Q_{avg}) \quad (5)$$

Where, U_{SO_2} (Yuan/ton) denotes the fixed desulfurization cost including limestone slurry cost and emissions environmental charge. S_{avg}(%) is the average sulfur.

Based on the above three sides, the objective function of multi-coals blending optimization model is as following:

$$\boldsymbol{min} \quad F = \Delta P_1 - \Delta P_2 - \Delta P_3 \quad (6)$$

3.2. Constraint Conditions

The main constraint conditions are all come from coal quality. The nonlinear relatinships are used to calculate coal quality, and are experessed as following:

Calorific value: $Q_A \le f_q\left(X_i, Q_i, M_i, A_i, V_i, F_i\right) \le Q_B$ (7)

Sulfur: $S_A \le f_s\left(X_i, S_i\right) \le S_B$ (8)

Moisture: $M_A \le f_m\left(X_i, A_i, V_i, F_i\right) \le M_B$ (9)

Volatile matter: $V_A \le f_v\left(X_i, M_i, A_i, V_i, F_i\right) \le V_B$ (10)

Ash: $A_A \le f_a\left(X_i, A_i, V_i, F_i\right) \le A_B$ (11)

Ash melting point: $ST_A \le f_{st}(X_i) \le ST_B$ (12)

Where, *A* is lower limit, *B* is upper limit, *i* is each coal sample. And *f* is nonlinear function of each variable, and can be calculated by the neural network method.

4. Transportation Model

4.1. Objective Functions

In order to obtain the objective functions of coal transportation model, the following factors should be considered.

(1) Transportation distance

The transportation distance impacts directly on transportation cost and transportation time, which were generally a linear relationship with transport distance.

(2) Transportation costs

For the economic interest of the power generation group, reducing the cost of transportation will bring coal cost reduction.

(3) Transportation time

Coal needs to be delivered to power plant within the stipulated time; otherwise it will affect the normal power generation. Meanwhile, the shortening of the transport time will reduce the cost of the whole transport process.

The optimal objective is the minimum total cost and the shortest transport time, and is expressed as:

$$\begin{aligned} Min Z &= \alpha\left(\sum_i \sum_k x_{i,i+1}^k C_{i,i+1}^k + \sum_i \sum_k \sum_l y_i^{kl} p_i^{kl}\right) \\ &+ \beta\sigma\left(\sum_i \sum_k x_{i,i+1}^k H_{i,i+1}^k + \sum_i \sum_k \sum_l y_i^{kl} t_i^{kl}\right) \end{aligned} \quad (13)$$

Where, α and β are weighing coefficients, σ is adjusting coefficient, $C_{i,i+1}^k$ is the transportation expense from node i to node $i+1$ by transportation model k. p_i^{kl} is the transportation expense at node i by the transportation model converting from k to l;when $x_{i,i+1}^k$ is 1, it means the transportation model used is k from node i to node $i+1$;when $x_{i,i+1}^k$ is

0, it means not using transportation model k ;when y_i^{kl} is 1, it means the transportation model converts from k to l at node i; when y_i^{kl} is 0, it means the transportation model k will convert to another or not coverting.

4.2. Constraint Conditions

$$\sum_k x_{i,i+1}^k = 1 \ \forall i \quad (14)$$

$$\sum_k \sum_l y_i^{kl} = 1 \ \forall i \quad (15)$$

$$x_{i-1,i}^k + x_{i,i+1}^l \geq 2y_i^{kl} \ \forall i,k,l \quad (16)$$

$$\alpha + \beta = 1 \ \alpha \geq 0, \beta \geq 0 \quad (17)$$

$$\sum_i \sum_k x_{i,i+1}^k H_{i,i+1}^k + \sum_i \sum_k \sum_l y_i^{kl} t_i^{kl} \leq T \quad (18)$$

$$x_{i,i+1}^k, y_i^{kl} \in \{0,1\} \ \forall i,k,l \quad (19)$$

Where, Equation (14) indicates only one mode of transportation can be used between two transportation nodes; Equation (15) indicates only one transfer model can be used in one node; Equation (16) is used to ensure the consistency of the whole transport process, if the transportation model converts from *k* to *l* at node *i*, the transportation model use *k* from the node *i*-1 to node *i*; Equation (17) indicates the sum of the weight coefficients is 1; Equation (18) indicates the total transportation time should be less than the specified latest arrival time; and Equation (19) means that the values of variables are limited to 0 or 1.

5. Optimization Model and Software System of Coal Allocation in a Group

Based on the above mentioned models, an optimization model of coal allocation in a power generation group can be obtained. In order to provide support and guideline of engineering practice, a software system is desined based on the optimization model. The software system using B/S structure, users can easily visit it by using a web browser. And the network topology diagram of it is shown in Figure 3. The software system was designed using modularization method, and the main modules are shown in Figure 4.

The main functions of the system are as followings:

(1) Group unified deployment module. It is a key decision-making process and is divided into the multi-coals blending decision and transportation route optimization decision.

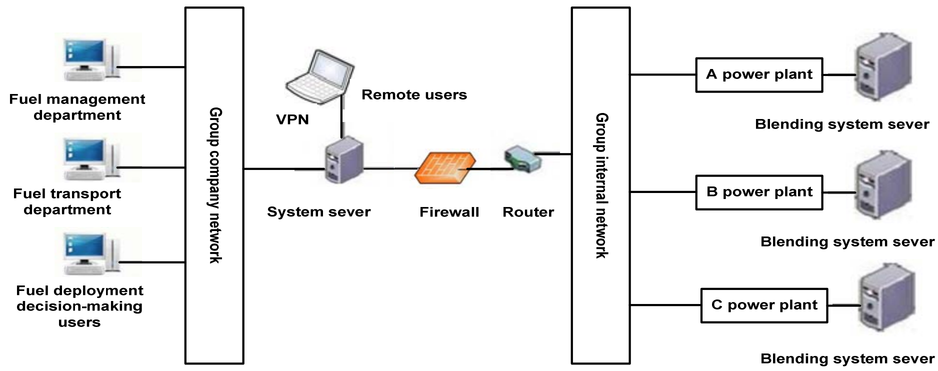

Figure 3. System Network Topology

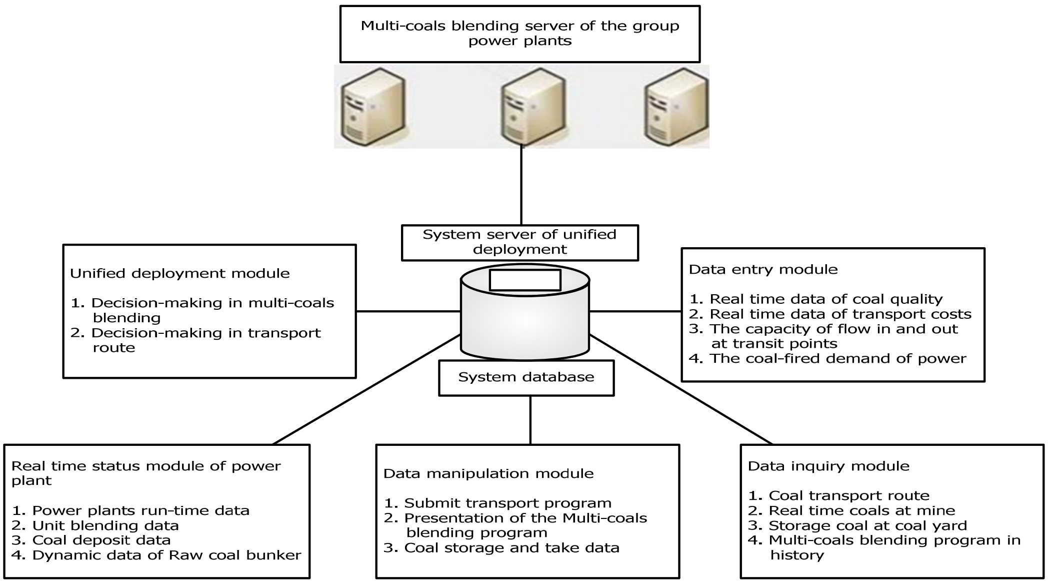

Figure 4. System Function Diagram

(2) Power plant real-time status module. It is used to show unit operation data, flow direction of coal, stored coal status in the coal yard and raw coal dynamic stratified information.

Unit operation parameters: displaying the main operating parameters, the current program of coaling, operation optimization parameters of coal pulverizer and providing alarm when there are exception data.

General situation of coal yard: displaying two-dimensional map and three-dimensional map of coal yard, and the name of coal, coal quality information, stored time, height, areas can be displayed on each coal dump. When the coal yard operators finish coal piling and coaling, they will update the stored coal data of coal yard.

Raw coal dynamic: real-time tracking of different kinds of coal entering into the coal yard, and calculating corresponding coal height, layers, weight and coal quality data. When the coal is about to change, this module can remind the field operator of operational state of the main coal pulverizer.

(3) Data entry module: this module is mainly used to provide group fuel department and power plant staff with entering channel of coal quality information and real-time transport cost. The users can enter corresponding information at specified location. The system will automatically update the database to ensure the accuracy of deployment results.

(4) Data querying model: this module is used to provide users with daily statisticalstatements, which includes historical coal transport route, historical coal purchasing amount, transport cost curve, pie chart of power plant stored coal amount and so on.

(5) Data set module: this module is mainly used to provide operation setup function for privileged users. It is used to set blending boundary conditions, transport optimization boundary conditions, operating parameter alarm value, user information permission and so on.

6. Results and Analysis

6.1. Information Database and Algorithm

The information about 20 kinds of coals is shown in Table 1, and it was used as a database to calculate the optimization model of coal allocation in a group. And the genetic algorithm [7] was used to solve the above mentioned models.

Three kinds of coal were selected to be blended in the optimization process, the searching range of the ratio is from 10% to 90% and the accuracy of the ratio is 1%.

The constraint conditions were set as following:

Calorific value：$5025 \le Q_{net} \le 5735 (kCal/kg)$ (20)

Moisture：$0<M\le 7(\%)$ (21)

Volatile：$23\le V\le 28(\%)$ (22)

Sulfur：$0<S\le 1.3(\%)$ (23)

Ash：$0<A\le 19(\%)$ (24)

The standard coal price is assumed as 1005 yuan/ton, the electricity consumption of auxiliary is 11.5kWh/t, the desulfurization fixed cost is 100 yuan/t, desulfurization efficiency is 90%, and the electricity price is 0.4 yuan/kWh.

Table 1. Coal Information Database

Coal Number	Heat (kCal/kg)	Moisture (%)	Volatile (%)	Ash (%)	Sulfur (%)	Price (Yuan/t)
01	5032	1.13	18.27	29.54	1.48	580
02	4398	13.53	35.84	2.02	0.41	450
03	4979	8.56	24.77	10.39	0.21	560
04	4843	9.69	27.43	8.70	0.25	530
05	4742	10.66	30.66	6.96	0.29	490
06	5539	9.76	29.27	7.56	0.27	630
07	5333	5.31	33.53	16.70	0.39	595
08	5433	5.08	25.45	16.61	0.87	610
09	5029	6.03	28.21	15.14	0.78	570
10	4572	11.70	41.99	4.73	0.10	460
11	5597	1.67	11.87	22.70	0.44	640
12	5825	1.43	14.93	21.50	0.35	670
13	5709	0.78	15.72	21.82	1.08	650
14	6167	1.36	18.79	20.25	1.16	750
15	4665	0.83	23.45	31.83	2.98	480
16	6150	2.06	10.00	17.39	0.25	690
17	4761	9.63	32.31	6.46	0.68	500
18	4780	8.07	29.14	13.79	0.25	520
19	4831	8.24	28.41	12.86	0.24	525
20	4924	8.43	26.77	11.40	0.22	540

6.2. Calculated Results of Optimization Multi-coals Blending Model

The genetic algorithm was used to solve the model and the Matlab software was applied in the process of calculation. The maximum number of iterations was selected as termination conditions. It was set as 500. Part of the computational results is shown in Table 2.

Table 2. The Operation Results of Genetic Algorithm

No.	Individual code						Heat value (kCal/kg)	Water content (%)	Fugitive constituent (%)	Ash content (%)	Sulfur content (%)	Target value
1	1	19	11	34	33	33	5151	3.66	19.504	21.78	0.72	115.1
2	20	19	1	30	27	43	4943	5.24	23.588	19.59	0.767	111.1
3	11	7	2	40	40	20	5252	5.498	25.328	16.17	0.412	170.2
4	10	16	1	34	37	29	5290	5.068	23.275	16.61	0.555	162.7
5	2	20	6	39	22	39	4957	10.94	31.282	6.244	0.314	196.2
6	17	4	3	35	47	18	4838	9.566	28.659	8.22	0.393	186.6
7	11	20	1	38	36	26	5209	3.964	18.898	20.41	0.631	127.9
8	20	8	13	34	31	35	5357	4.714	22.493	16.66	0.723	124.8

6.3. Calculated Results of Transportation Model

The genetic algorithm was also used in the solving of the model. For example, the transportation network of coal to a power plant is assumed as Figure 5. There are three modes of transport options: rail transportation, road transportation and sea transportation. The costs of various transportation modes are shown in Table 3, the need times of various transportation modes are shown in Table 4, the fee of transshipment between various transportation modes are shown in Table 5, and the tansshipment times between various transportation modes are shown in Table 6.

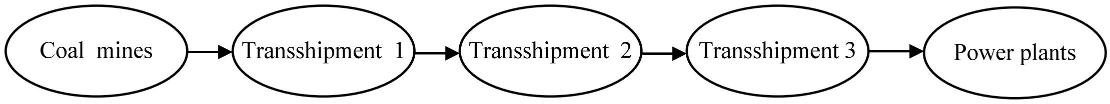

Figure 5. Transportation Network

Table 3. Unit Transportation Costs of Various Transport Modes (yuan/t)

Transportation Mode	Coal mine - 1	1-2	2-3	3-4	4- power plant
Rail	62	39	40	45	53
Road	80	24	36	51	70
Sea	M	35	37	48	49

Where, 1, 2, 3, 4 all respect different transshipment points. M mens that the sea transportation cannot be used.

Table 4. The Transportation Times of the Various Transportation Modes (days)

Transportation Mode	Coal mine - 1	1-2	2-3	3-4	4- power plant
Rail	1.6	1.0	1.5	1.8	2.0
Road	2.3	0.8	1.2	1.5	2.0
Sea	M	1.1	1.3	1.7	1.8

Table 5. Transshipment Charges between Various Transportation Modes (yuan/t)

Transportation Mode	Rail	Road	Sea
Rail	0	5	4
Road	5	0	4
Sea	4	4	0

Table 6. The Times of Transshipment between Various Transport Modes (days)

Transportation Mode	Rail	Road	Sea
Rail	0	0.7	0.5
Road	0.7	0	1
Sea	0.5	1	0

The Matlab software was used to accomplish the optimization process. The conditions were set as following:

$$\alpha=0.7 \tag{25}$$

$$\beta=0.3 \tag{26}$$

$$\sigma=10 \tag{27}$$

And the crossover probability was set as 0.8, mutation probability was set as 0.005, and the whole transportation coal was set as 15,000 tons.

The optimization result of the transportation path is 1-1-2-3-3. That means that the rail transportation is used from coal mine to point 2, the road transportation should be used from point 2 to point 3, and the sea transportation is applied from point 3 to the power plant. The total optimization goal value is 197.1, the frequency of operation iteration is 51, the total transportation cost is 243 yuan/ton, and the total transportation time is 9 days.

7. Conclusion

An optimaiztion system for the coal allocation in a power generation group was developed based on the multi-coals blending technology model, coal transportation model and the relevant algorithms. The system adopts friendly software structure and can provide personalized functions for the power generation group and power plants. A computational example show that the optimization results can be searched out by the genetic algorithm in a very short period of time, but the results contain some suboptimal solutions. In the practical application, the balance between search speed and precision can be achieved by choosing a more appreciate algorithm according to the requirements of computing time.

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