Research on Route Optimization of Coal Multimodal Transport in China

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Abstract: Transportation is the main way to solve the regional separation of supply and demand of China's coal resources. Aiming at the problem of coal transportation path selection, this paper constructs a comprehensive coal transportation path selection model, and selects ant colony algorithm as the main algorithm tool to solve the problem based on the actual coal transportation network in China. The model finds the optimal path and minimizes the transportation cost of the whole network under the condition that the supply of node is limited and the demand of each consumer place is satisfied. Therefore, it is of great practical and theoretical significance to improve the division and layout of the coal transportation market, make full use of the existing transportation conditions and reduce the logistics cost by studying the multimodal transport route selection of China's coal resources.

Keywords: Coal transportation, multimodal transportation, route optimization, ant colony algorithm

1 INTRODUCTION

Coal transportation is an important issue for energy transportation and energy development. In 2021, the total coal production of provinces and cities in China will be about 4.07 billion tons, and the total consumption will be about 3.96 billion tons. The total supply and demand will be roughly balanced. However, the regional distribution of supply and demand is uneven. The coal production is mainly concentrated in Shanxi, Shaanxi and Inner Mongolia, and the coal demand of most other provinces in the country needs to be transferred from other provinces. It can be seen that China's overall coal transportation market is huge, and transportation is the main way to solve the regional separation of coal supply and demand. At the same time, as a single mode of transportation is difficult to meet the huge transportation demand, the coal transportation is mainly undertaken by multimodal transport. Therefore, through the study of coal transportation, there will be formed a scientific coal multimodal transport organization scheme. This will help to make full use of the transportation conditions between different production and consumption places and realize the rational division of labor among different transportation modes, which is of great significance to build a low-cost and efficient comprehensive coal transportation system.

Scholars have made rich research achievements on coal transportation. Chang et al. (1981) Designed a two-stage regional railway network model, which selects the coal source, transportation mode, route and transfer station for each coal demand unit in the study area to minimize the overall cost and delay. Mou et al. (2012) Used the linear programming method to study the direction and volume of coal flow in China, and further analyzed the possibility of

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using the Yangtze River transport capacity for coal transportation. Clott et al. (2016) Analyzed the supply chain integration in Chicago metropolitan area. The results show that the regional supply chain planning must consider the utility of the freight channel from the national level, improve the service response capacity of the freight channel, and avoid the congestion of the freight channel. Li Y. et al. (2020) combed the experience of the United States and the European Union in developing coastal transport, analyzed the key cargo categories of coastal transport, and found that the advantages of large transport volume and low emissions still exist. Wang et al. (2020) Constructed a bi objective hub and spoke coal transportation network optimization model from a micro perspective, which takes into account both economic and environmental factors. The model can greatly reduce the total carbon dioxide emissions. Li et al. (2021) Built a multi-objective decision-making model for the selection of large-scale freight transport channels, which can provide a basis for the decision-making of route schemes for large-scale freight transport channels.

2 MODEL CONSTRUCTION

2.1 Problem description

The multimodal transport organization of coal mainly includes two ways: ① Direct transportation from the production place to the demand place via railway or highway; ② From the production site, it is transported to the port for launching by railway or highway, and then transported to the coal port by sea or inland river, and then transported to the destination by highway or railway. The whole transportation process involves iron, water and highway transportation, and the process is very complex. Moreover, in the actual coal transportation network, many production and consumption places are often involved. According to the supply and demand pattern of China's coal and the main transportation channels of coal, this paper will build a comprehensive transportation network of coal and a path selection model for comprehensive transportation of coal. It will also consider the transportation cost and carbon cost, and optimize the transportation path between the supply and demand places under the condition that the supply of different production places and the consumption of consumption places are clear, and determine the transportation route and allocation amount of coal. In order to facilitate the abstraction of practical problems into mathematical models, the following assumptions are made. The description of model parameters and variable definitions are shown in Table 1.:

① Considering that the research on the coal multimodal transport route in this paper takes the year as the cycle for static analysis, the coal delivered in the research year is regarded as being delivered to the destination within the year, and the situation that it is delivered across years is not considered.

② The transportation network is undirected, that is, if there are transportation routes from node i to node j, there are also transportation routes from node j to node i;

③ Transportation mode conversion only occurs at nodes, and at most one transportation mode conversion occurs at each node on a path;

④ Do not consider the difference in the demand for coal types in the demand area;

⑤ The price difference among coal production and marketing places is not considered;

⑥ The loss caused by transportation or loading and unloading is not considered;

Table 1. Description of model parameters and variable definitions

Name	Symbol	Explain
Decision variables	x_{ij}^{k}	Take 1 when k transportation mode is adopted from city i to city j, otherwise take 0
	y_{i}^{kl}	Take 1 When the transportation mode at node i is changed from k to l; otherwise take 0
Set	N_O, N_D	Set of starting and ending points of transportation network
	N_{DT}	Transit node and other nodes of transportation network
	N	Collection of transportation network node cities, $N=\{i \mid i=1,2,3,\cdots,\|N\|\}$
	K	Transport mode set $\mathrm{K}=\{k \mid k=1,2,3,\cdots,\|K\|\}$
Parameter	c_{ij}^{k}	Unit price from city i to city j with k transportation mode
	d_{ij}^{k}	Transportation distance from city i to city j in k mode
	q_{ij}^{k}	Transportation volume between nodes i and j using k transportation mode
	c_{i}^{kl}	Unit processing cost of transportation mode conversion from k to l at node i
	λ	Time value coefficient
	t_{ij}^{k}	Transportation time of k mode from city i to city j
	e_{ij}^{k}	Unit emission generated by k transportation mode on section i and j (kg/km)
	e_{i}^{kl}	Carbon emission coefficient of transportation mode from k to l at node i
	a	Number of nodes in the production site
	b	Number of nodes in consumption area
	O_i	Transfer out quantity of production site i
	D_j	Transfer in demand of consumption place j
	μ_{ij}^{k}	Transportation capacity limit of k transportation mode between nodes i and j

2.2 Model construction

Based on the model assumptions and relevant parameter descriptions in Section 2.1, the model of multimodal transport route selection is constructed as follows:

① Objective function:

$$\min f = \sum_{i\in N}\sum_{j\in N}\sum_{k\in M} x_{ij}^k c_{ij}^k d_{ij}^k q_{ij}^k + \sum_{i\in N}\sum_{k\in M}\sum_{l\in M} y_i^{kl} c_i^{kl} q_{ij}^k + \sum_{i\in N}\sum_{j\in N}\sum_{k\in M} \lambda t_{ij}^k + \sum_{i\in N}\sum_{j\in N}\sum_{k\in M} x_{ij}^k d_{ij}^k e_{ij}^k q_{ij}^k + \sum_{i\in N}\sum_{k\in M}\sum_{l\in M} y_i^{kl} e_i^{kl} q_{ij}^k \quad (1)$$

② Constraints:

$$\sum_{j}^{b} q_{ij} \le O_i \quad (2)$$

$$\sum_{i}^{a} q_{ij} \ge D_j \quad (3)$$

$$\sum_{k} q_{ij}^k = q_{ij} \quad (4)$$

$$q_{ij}^k \le \mu_{ij}^k \quad (5)$$

$$\sum_{k\in K} x_{ij}^k \le 1, \forall i, j \in N \quad (6)$$

$$\sum_{k\in K}\sum_{l\in K} y_i^{kl} \le 1, \forall i \in N \quad (7)$$

$$\sum_{j\in N}\sum_{k\in M} x_{ij}^k - \sum_{j\in N}\sum_{k\in M} x_{ji}^k = \begin{cases} 1, i = O \\ -1, i = D \\ 0, i \ne O, D \end{cases} \quad \forall i \in N \quad (8)$$

$$y_i^{kl} = 0, \forall i \in \{O, D\}, \forall k, l \in M \quad (9)$$

$$x_{ij}^k \in \{0,1\}, \forall i, j \in N \quad (10)$$

$$y_i^{kl} \in \{0,1\}, \forall k, l \in M \quad (11)$$

Wherein, equation (1) is the objective function, equations (2)-(11) are constraints. The objective function (1) means the minimum total transportation cost, including the minimum sum of the transportation cost between the origin and destination points, the transshipment cost, the time cost, the carbon emission cost in the transportation process and the carbon emission cost in the transit process. Constraint (2) means that for any production place i, the transfer out quantity transported to any consumption place j cannot exceed the total production of the region; Constraint (3) means that for any consumption place j, the amount of coal transferred from each production place to the consumption place shall fully meet the demand of the region; Constraint (4) means that the sum of the transportation volumes of all transportation modes from the production place i to the consumption place j should be equal to the total dispatching volume from i to j; Constraint (5) means that the transportation volume between nodes i and j using the transportation mode in k shall not exceed the limit of corresponding transportation capacity; Constraint (6) means that at most one mode of transportation is selected between nodes i and j; Constraint (7) means that it is transported at most once on node i; Constraint (8) is a flow balance constraint; Constraint (9) indicates that the transportation mode conversion only occurs at the intermediate node, not at the start and end points; Constraint (10) indicates that the decision variable x_{ij}^k can only take 0 or 1; Constraint (11) indicates that the decision variable y_i^{kl} can only take 0 or 1.

3 ALGORITHM ANALYSIS

3.1 Algorithm solution idea

The coal transportation from different production places to different consumption places is a freight volume allocation problem considering multiple starting points to multiple terminals. The optimal optimization result is that each demand place selects the supply place with the lowest transportation cost for transportation. However, due to the limited output of each supply place, it is difficult to achieve the optimal situation. Therefore, the goal of this paper is to find the optimal path and minimize the transportation cost of the whole network under the condition that the supply of real estate is limited and the demand of each consumer place is fully satisfied.

3.2 Algorithm design process

Ant colony algorithm (ACA) is a bionic algorithm based on the simulation of ant routing in nature. As an intelligent algorithm, ant colony algorithm has achieved good results in solving path planning problems and allocation problems. The flow of algorithm design is as follows:

Step1: define the distance matrix between nodes in different transportation modes;

Step2: determine the start point set and end point set of the integrated transportation network;

Step3: initialize parameters to assign equal values to the pheromone quantity on each road segment: $\tau_{ij}(0) = C \quad \Delta\tau_{ij}(0) = 0$;

Step4: select the starting city for each ant;

Step5: calculate the ant transfer probability, and select the next passing node by roulette;

Step6: calculate the path length of each ant, record the optimal path in the current cycle, and update the pheromone concentration on different transport paths between OD pairs according to the formula;

Step7: judge whether the iteration termination conditions are met. If yes, proceed to the next step. Otherwise, repeat step4-6;

Step8: record the optimal path between OD pairs;

Step9: calculate the target values of all paths and sort them in descending order;

Step10: select the path with the lowest target value to allocate the freight volume under the constraints of meeting the supply of real estate and the demand of consumer places;

Step11: output results;

4 EXAMPLE ANALYSIS

4.1 Basic data preparation

The data used in this paper comes from the public information on the Internet. The distances of different transportation modes between the nodes in the coal transportation network come from relevant information websites and China coal information network. The coal supply and demand data of each node are based on the China energy statistical yearbook, and then summarize and sort out the shipping volume and arrival volume of each coal production base and demand area and its surrounding radiation areas, and predict the demand of each main origin and sales area, Then, according to the principle that the coal production of each production place gives priority to ensuring the coal demand in the region, the coal transfer out volume of each production place in the network and the coal transfer in volume of each consumption place are obtained. The total transfer out volume is about 2.16 billion tons and the total transfer in volume is about 2.09 billion tons. The supply and demand are roughly balanced.

Based on the pattern of transporting coal from the north to the South and from the west to the East, this study builds a model of China's coal comprehensive transportation network. There are three modes of transportation between nodes in the network. The transportation costs, reloading costs and carbon emission costs of various modes of transportation are shown in the table 2 and table 3:

Table 2. basic parameters

	Rail	ocean shipping	Inland river	Road
Transportation cost per ton kilometer (yuan)	0.20	0.02	0.03	0.48
Transportation speed (km/h)	55	28	19	80
Carbon cost (yuan / ton km)	0.00596	0.00307	0.00307	0.0296

Table 3. transshipment cost between different transportation modes (yuan / ton)

	Rail	water	Road
Rail	0	26	12.3
Water	34.68	0	26.1
Road	20.1	17.2	0

4.2 Result analysis

① Analysis of coal transportation direction and coal source in main transfer areas

By studying the optimal allocation and transportation path between od point pairs, it is found that the outward transportation of coal in Sanxi region can meet the coal consumption demand of most provinces in China. Among them, because Shanxi is closer to major coal transfer areas such as Beijing Tianjin Hebei, southeast coastal areas and central and southern regions, and has superior transportation conditions, its transportation cost has a strong advantage compared with other producing areas such as Shaanxi and Inner Mongolia. There are not only Shuohuang line, Daqin line, Wari line and other special railways supporting it, which can be directly transported to the demand areas along the line through the coal transportation channel, but also transported to the northern ports by railway, and can also be jointly transported to the demand areas along the line through the railway and the Beijing Hangzhou canal. However, due to its output constraints, the coal supplied by Shanxi was eventually mainly transferred to Henan, Shandong, Anhui and other places. Shaanxi has superior coal transportation conditions, second only to Shanxi, and its coal is mainly transported to Anhui, Shanghai, Jiangsu, Hunan, Guangdong and other places. In addition to meeting its own coal demand, Guizhou's remaining coal supply is mainly transported to nearby Chongqing, Sichuan, Yunnan and Guangxi. Northeast China and Beijing Tianjin Hebei region are closer to the west of Inner Mongolia, so the coal transportation volume of Beijing, Tianjin, Liaoning, Hebei, Heilongjiang and other places mainly comes from Ordos, Huolinhe, Chifeng and other places in Inner Mongolia. Due to the restriction of transportation conditions, Xinjiang is rich in coal resources, but it has not been over exploited. It is mainly used to meet the coal demand of the region and the adjacent areas along the Lanzhou Xinjiang Railway.

Among the main transfer in areas, Shandong, Jiangsu, Anhui and other places have rich transportation conditions, and there are many optional transportation organization modes. They can not only meet the transfer needs directly by railway, but also meet the transportation needs through the combined transportation of railway, sea transportation or inland river. Some cities have great advantages compared with other transportation schemes because inland water transportation is closer to the origin and the transportation cost is lower. According to the results of the example, it is found that most cities along the Beijing Hangzhou canal, such as Xuzhou and Nanjing, choose railway and inland river combined transportation. Shanghai, Ningbo, Fuzhou, Guangzhou and Beibu Gulf have good sea transportation conditions, and almost all coal transportation volume comes from rail sea combined transportation. Railway transportation is still the main mode of transportation in other inland areas.

The transfer in areas by province are derived from the transfer mode, as shown in Table 4:

Table 4. Main sources and modes of transport

Place of demand	Input volume/Kiloton	source	Transportation mode
Heilongjiang	87500	Inner Mongolia	Rail
Liaoning	155000	Inner Mongolia, Shanxi	Rail
Jilin	75000	Inner Mongolia	Rail
Beijing	1600	Inner Mongolia	Rail
Tianjin	38000	Inner Mongolia	Rail

Hebei	237000	Shanxi, Inner Mongolia	Rail
Shandong	321000	Shanxi	Rail
Jiangsu	241000	Shanxi, Shaanxi	Rail, rail- river, rail-sea
Zhejiang	139000	Shanxi	Rail, rail-sea
Anhui	57000	Shaanxi	Rail, rail- river
Shanghai	42000	Shaanxi	Rail-sea
Fujian	79000	Shanxi	Rail-sea
Jiangxi	75000	Shaanxi	Rail
Henan	92000	Shaanxi, Shanxi	Rail
Hubei	119000	Shaanxi	Rail, rail-river
Hunan	92000	Shaanxi	Rail
Guangxi	77000	Guizhou	Rail
Guangdong	168000	Shanxi	Rail-sea

This paper mainly considers the trunk transportation from production places to major cities of provinces and cities. Therefore, the transportation distance is generally long and the transportation volume is large. As a result, there is no road transportation mode in the final transportation path, which is also in line with the actual transportation situation. The unit cost of highway transportation is often several times or even dozens of times higher than that of railway and waterway transportation. Due to its high transportation cost and carbon emission cost, in practice, it is generally only used as a supplement to the transportation capacity from the trunk node to the final consumption place. Therefore, it is reasonable that there is no highway transportation mode in the network constructed in this paper.

② Analysis of dispatching scheme

Among the main coal transportation lines, except that some lines are dedicated freight channels, most of the other railways are mixed passenger and freight lines. When the passenger flow is in the peak period, the railway department often adopts the method of "suppressing goods and ensuring passengers" to reduce the coal railway transportation volume, thus aggravating the shortage of coal transportation capacity in a short time. When constructing the comprehensive coal transportation network, this paper not only considers the main sea launching and unloading ports of coal, but also takes into account the inland water transportation mode. Through the analysis of the transportation results, it is found that compared with the existing transportation schemes, the railway sea combined transportation has little change, but for the cities along the inland river, the railway inland river combined transportation can greatly reduce the carbon emission cost, reduce the transportation cost, release the railway capacity of some lines and share the transfer pressure of the northern ports.

According to the results of the example, the direction of rail sea intermodal transport through the port has not changed much. The ports around Bohai Bay are still the main seaborne launching ports for coal, among which Huang Ye and Qinhuangdao rank first. Qinhuangdao port is mainly connected to the Daqin Railway, and the underground coal mainly comes from Datong, Baotou and other places; Huangye port is mainly connected to Shuozhou Huanghua railway, launching coal from Shuozhou and Yuanping. However, for cities along the inland river, the transportation cost of railway inland river combined transport is often lower than that of railway direct transport or railway sea combined transport, and then transported to the place of demand through the sea river channel. Among them, Xuzhou, Nanjing and other cities have the most significant changes in transportation costs. According to the calculation results, the coal transferred into Xuzhou mainly comes from Shuozhou, Shanxi Province. The shortest direct railway transportation path is Shuozhou Dingzhou Cangzhou Dezhou Jinan Jining Xuzhou. The railway transportation distance is 1048 kilometers, the transportation volume is 28.93 million tons, and the transportation cost is about 8.091 billion yuan. If the railway inland waterway combined transport mode is selected, it needs to be transferred in Cangzhou, and transferred from Shuohuang line to Beijing Hangzhou canal for transportation. The transportation distance is 503km by railway and 646km by waterway, with a total transportation cost of about 7.588 billion yuan. Compared with direct railway transportation, the annual transportation cost can be reduced by 503million yuan, saving about 6.63% of the transportation cost. The coal in Nanjing mainly comes from Luliang, Shanxi Province. In the calculation example, Nanjing's transportation demand is 60million tons. Usually, the transportation scheme is usually launched in Rizhao port through the Waziri railway, transported to Shanghai by sea, and then transported to Nanjing through the sea-river channel. After calculation, the transportation cost of this transportation method is about 30.643 billion yuan. However, the transportation cost can be significantly reduced by railway inland waterway combined transport, that is, it is transported to Dezhou by railway and then to Nanjing by Beijing Hangzhou canal. The transportation cost of this scheme is 24.732 billion yuan, and the annual transportation cost can be reduced by about 5.911 billion yuan, saving about 19.28% of the transportation cost.

In terms of railway transportation, according to the calculation results, it is found that the completion of Haoji railway has effectively reduced the transportation costs in Hubei, Hunan and Jiangxi. Before the completion of the Haoji railway, the railway transport capacity in the two lakes and one river region often could not meet the regional coal transport capacity demand, and a large amount of coal usually needed to be transported by the sea into the river channel. However, although the deep inland region is located along the Yangtze River and has favorable inland navigation conditions, the transportation distance from the coal dispatching place is too long, and it needs to be transported by railway and sea, Shipping and inland river transit for many times, the transportation cost and transit cost are too high, resulting in the high overall transportation cost of coal. After the completion of the Haoji railway, compared with the existing statistical data, the coal transportation volume through the Haoji railway has greatly increased, the transportation distance has been greatly shortened, and the transportation volume from Shaanxi Province to central China has been expanded. The coal resources can not only be directly transported to the two lakes and one River areas by railway, but also be combined with the Yangtze River by railway, effectively improving the transportation capacity, effectively shorten the transportation distance ,reduce the carbon cost and overall transportation cost.

5 CONCLUSIONS

Based on China's comprehensive coal transportation network, in this article, ant colony algorithm is selected as the main algorithm tool to solve the problem, and the results of the example are analyzed from the coal transportation route, coal source and transportation scheme. The results show that the coal transportation is mainly railway transportation and railway water transportation. Compared with the existing transportation schemes, the railway sea transportation has little change, but the inland river and railway have a significant impact on the coal transportation cost in some areas: considering the inland river transportation mode can effectively reduce the transportation cost of cities along the inland river, release some railway transportation capacity and relieve the transfer pressure of northern ports; In terms of railway transportation, Haoji railway is of great significance to the coal transportation in Central China. Through the comparative analysis of transportation schemes, the research value of this paper is enhanced. In the future, the transportation scheme can be further studied according to different types of coal, so as to provide further practical significance for coal transportation and production.

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