Distribution Route Planning of Clean Coal Based on Nearest Insertion Method

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Abstract. Clean coal technology has made some achievements for several ten years, but the research in its distribution field is very small, the distribution efficiency would directly affect the comprehensive development of clean coal technology, it is the key to improve the efficiency of distribution by planning distribution route rationally. The object of this paper was a clean coal distribution system which was built in a county. Through the surveying of the customer demand and distribution route, distribution vehicle in previous years, it was found that the vehicle deployment was only distributed by experiences, and the number of vehicles which used each day changed, this resulted a waste of transport process and an increase in energy consumption. Thus, the mathematical model was established here in order to aim at shortest path as objective function, and the distribution route was re-planned by using nearest-insertion method which been improved. The results showed that the transportation distance saved 37 km and the number of vehicles used had also been decreased from the past average of 5 to fixed 4 every day, as well the real loading of vehicles increased by 16.25% while the current distribution volume staying same. It realized the efficient distribution of clean coal, achieved the purpose of saving energy and reducing consumption.

1. Overview

Clean coal refers to the total number of products that can reduce pollution and improve the efficiency of processing, combustion, transformation and pollution control during the whole process from coal development to utilization. Clean coal technology is an important energy science technology, but also a significant part of the strategic new industry. The focus of the clean coal technology is improve the quality of coal and coal utilization efficiency, minimize pollutant emission from coal development to utilization through developing advanced technology and equipment [1]. After decades of development, there has made some progress in areas such as clean coal mining, combustion power generation [2-4], which play some role in improve the coal utilization efficiency and reduce atmospheric pollution, but there are few studies on clean coal distribution. In recent years, some clean coal distribution center has established by local government, people also pay more attention in the equipment of distribution center, while care less the distribution path and plan from the distribution center to each network, and this link will directly affect the efficiency of clean coal distribution, related to the overall development of clean coal technology.
In this paper, the optimization theory of distribution path applied to the process of clean coal distribution. According to the distribution center and networks that have been built in a county, the mathematical model of distribution is established based on the coal demand in past years, and planning the distribution path using improved nearest-insertion method, achieving the purpose of shortening the transport route and energy saving and consumption.

2. Current status of clean coal distribution centre in a county

2.1. Construction status
In order to strengthen the work of loose coal management, reduce the air pollution caused by coal bulk burning, and improve environmental quality, a distribution center of clean coal was been built in 2016 in a county. It locates in a village which away from the crowded area, covers an area of about 10 acres, a total investment of more than 200 million yuan, and now has 7 distribution networks, 5 trucks load 4 ton. The center transports clean coal to the rural villages directly in accordance with the principle of manufacturer distribution, delivery to the village, closed operation.

2.2. The status of distribution research and analysis

2.2.1. The usage of distribution vehicle. The distribution center is constructed in basis of an original coal transportation company, the main service object of the company was also the county's villages in the past, so the customer demand, on the whole, do not make a bi
g change. Through the field survey, the distribution center has been dispatched its vehicles according to experience in 2013 to 2016, the number of trucks used every day is not same. Table 1 is the number of days to use different number of vehicles.

| Year | 7 | 6 | 5 | 4 | 3 |
|------|---|---|---|---|---|
| 2013 | 53 | 81 | 95 | 71 | 65 |
| 2014 | 73 | 62 | 64 | 81 | 85 |
| 2015 | 93 | 79 | 63 | 77 | 53 |
| 2016 | 87 | 59 | 78 | 68 | 73 |

The average trucks used per day has calculated based on the actual number, which in 2013 is:

\( \frac{53 \times 7 + 81 \times 6 + 95 \times 5 + 71 \times 4 + 65 \times 3}{365} = 4.96 \)

The same method have been used in calculating the others number from 2014 to 2016, they are 4.88, 5.22, 5.05, and the average number of trucks per day in the past four years is:

\( \frac{4.96 + 4.88 + 5.22 + 5.05}{4} = 5 \)

Therefore, the average daily number of trucks used by the distribution center is 5.

It is clear, the number of trucks used daily in the distribution center is 3 to 7 from 2013-2016. Figure 1 is the histogram of distribution usage trucks in 2013-2016. Among of them, use 5 trucks have 95 days in 2013, with 3 trucks for 53 days in 2015, balance is terrible. The number of delivery vehicle shows irregular change, which gives a lot of trouble to vehicle arrangement and configuration [5-6].

2.2.2. Distribution distance. The distribution center is responsible for the daily delivery of seven networks, each of which is located in the township of the county, the vehicle start from the distribution center and eventually return to it. For the convenience of the subsequent calculation, the branches are represented by 1-7, and the distribution center is represented by 0. The distance between the distribution center and the branches as shown in table 2.
2.2.3. Distribution demand of each branch. Calculating the average daily demand by surveying the requirement every year of 1-7 branch in 2013-2016 as shown in Table 3.

Table 3. Distribution demand per day for each branch in 2013–2016 Unit: t

| branch year | 1  | 2  | 3  | 4  | 5  | 6  | 7  |
|-------------|----|----|----|----|----|----|----|
| 2013        | 470| 698| 822| 469| 694| 336| 698|
| 2014        | 495| 720| 870| 494| 722| 358| 729|
| 2015        | 580| 748| 938| 531| 741| 379| 736|
| 2016        | 645| 760|1020| 665| 763| 388| 758|
| average     | 1.5| 2.0| 3.0| 1.5| 2.0| 1.0| 2.0|

2.3. The current distribution route analysis

According to the research, the distribution center has 5 distribution routes at present: 0-1-2-0, 0-4-0, 0-3-0, 0-5-0, 0-6-7-0, and the quasi-load capacity of all trucks are 4t. The distribution distance of each path Li, actual load Ri, actual load rate [7] etc. can be calculated separately, as shown in Table 4.
Table 4. Distribution path information before planning

| Distribution path | Distribution distance Li(km) | Actual load Ri(t) | Quasi-load(t) | Actual load rate (%) |
|-------------------|------------------------------|-------------------|---------------|----------------------|
| 0-1-2-0           | 11                           | 3.5               | 4             | 87.5%                |
| 0-3-0             | 90                           | 3                 | 4             | 75%                  |
| 0-4-0             | 64                           | 1.5               | 4             | 37.5%                |
| 0-5-0             | 70                           | 2                 | 4             | 50%                  |
| 0-6-7-0           | 338                          | 3                 | 4             | 75%                  |
| Total             | 573                          | 13                | 20            | 65%(average)         |

In the current distribution path, the total vehicle distance is 573 km, total demand of average daily is 13 tons. There are five distribution routes, that is, the average need 5 trucks and 5 drivers, average loading rate lower to 65%.

2.4. The problem exist in distribution path

The distribution system has the following several problems at this stage:

(1) Distribution path is unreasonable because of without scientific planning

Make the distribution plan and vehicle scheme, the key, is select the distribution path correctly. At present, the distribution path is set by manager from the map the location of each branch, and then according to the principle of dropping in or nearby into a line, and then the driver choose the optimal route depends on experience, which is not justified.

(2) The choice of distribution vehicle no quantitative calculation

Due to the uncertainty of the distribution path, the truck cannot reach its planning capacity. The low actual load rate causes the waste of vehicles and personnel, the increase of energy consumption.

3. Distribution route planning modelling and solution

3.1. Build the distribution route model

We usually convert some elements such as time, distance, cost and others into transportation cost, and scheduling vehicle is reducing transportation cost to realize the reasonable allocation of resources. There are two main models: one is using a loop representation and another is using transportation cost. According to the actual distribution of clean coal, we build the model of transportation cost as objective function, where is realized by the shortest path [8].

For modeling easily, it is necessary to consider the following hypothetical conditions:

(1) Distribution center will not show the possibility of shortage, the basic distribution information (demand, geographical location) of every branch has known, and the location of the distribution center has known.

(2) Without consider the distribution time limit, which means, the customer demand for goods without the time regulations.

(3) Distribution center can responsible for multiple customers, namely, a center serves multiple clients.

(4) The vehicle is set out from the distribution center, arrives at the specified demand point and then go back. The demand points in the region are fixed and the location is known and unchanged.

(5) Distribution center has a certain number of distribution vehicle of the same type, and the capacity of each vehicle has known.

(6) The sum of the customer's demand on each route does not exceed the total capacity of the trucks.

The model can be described as: the distribution center is responsible for the delivery of clean coal to the n branches, the demand for each branch is \( r_i \) (i = 1, 2, 3 \ldots n), the center will send multiple
trucks to deliver goods. We want to know the lowest cost of vehicle transport path to meet the demand. Relevant variables meaning expressed by table 5.

**Table 5. Relevant variables meaning**

| Relevant variables | Meaning |
|--------------------|---------|
| $n$                | Total number of branches |
| $m$                | Total number of trucks used by distribution center |
| $r_i$              | The demand for goods in branch $i$, where $i = 1, 2, 3 \ldots, n$ |
| $d_{ij}$           | The distance from branch $i$ to $j$; $i, j = 0, 1, 2 \ldots n$; $i$ or $j$ as 0 indicate the distribution center. |
| $Q$                | Maximum load of vehicle |
| $R_i$              | The path $i$ load of vehicle |
| $L_i$              | The distance traveled of the vehicle $i$ |
| $T_i$              | The $i$ loop |
| $n_s$              | Total number of branches of vehicle $s$ distribution. $n_s = 0$ indicates the vehicle is not involved in distribution, $s = 1, 2, \ldots, m$ |
| $x_{ijs}$          | Equal to 0 or 1; 1 means the vehicle $s$ is driven from $i$ to $j$, 0 means others |
| $y_{is}$           | Equal to 0 or 1; 1 shows the distribution task of branch $i$ is completed by vehicle $s$, 0 means others |

Based on the distribution path optimization, the model is established [9-10]:

$$
\min Z = \sum_{i=0}^{n} \sum_{j=0}^{m} \sum_{s=1}^{m} (d_{ij} \cdot x_{ijs})
$$

(1)

$$
\text{s.t. } \sum_{s=1}^{m} y_{is} = 1, \ i = 1, 2, 3, \ldots, n
$$

(2)

$$
\sum_{i=1}^{n} r_i y_{is} \leq Q \quad i = 1, 2, 3, \ldots, n, s = 1, 2, 3, \ldots, m
$$

(3)

$$
\sum_{i=0}^{n} X_{ijs} = y_{js}, \ j = 1, 2, 3, \ldots, n, s = 1, 2, 3, \ldots, m
$$

(4)

$$
\sum_{j=0}^{n} X_{ijs} = y_{is}, \ i = 1, 2, 3, \ldots, n, s = 1, 2, 3, \ldots, m
$$

(5)

The meaning of each formula in the above model is as following: constraint condition (2) means the transport task of each branch complete by a truck only; the indication of constraint (3) is the demand for all branches on each route shall not exceed the vehicle load capacity; the constraints (4) and (5) Indicate that there is only one vehicle.

3.2. The nearest insertion method and solving model

The nearest insertion method can reduce the distribution path and improve the utilization rate of vehicle, which is ideal solution for simple planning problem, but it mainly focuses on the problem of
transport of single loop. For the multi-loop problem of clean coal distribution path planning, the improved nearest insertion method is used; the steps are [11]:

1. Find the smallest node \( v_i \) of \( C_0 \), form a sub-loop, \( T = \{ v_0, v_k, v_0 \} \);

2. Find a node from the sub-loop nearest node \( v_k \) in the remaining nodes. If the total freight volume of the loop does not exceed the vehicle load, proceed to step (3), otherwise, turn (1) to find a new loop.

3. Find an arc \( (i, j) \) in the sub-loop, make \( C_k + C_{i} - C_{j} \) minimum, and insert the node \( v_i \) into the node \( v_0, v_i \), with two new arc \( (i, k), (k, j) \) instead of the original arc \( (i, j) \) and add node \( v_k \) to sub-loop. If the total distance of the circuit at this time is not exceeding the travel limit of the vehicle, continue to step (4), otherwise go to step (1) and find a new circuit.

4. Repeat step (2) and (3) until every node is placed a sub-loop.

We plot the figure 2 according the average daily demand of each branch, the distance between the distribution center and branch, and the distance between each branch, then the improved nearest insertion method is applied to solve the model.

![Figure 2. Distribution distance and demand.](image)

Take \( t = \{0\} \), \( n = \{0, 1, 2\ldots 7\} \), compare all the paths from the distribution center 0. Because \( \min \{ C_{0i} | i \in N, 1 \leq i \leq 7 \} = C_{01} = 3 \text{km} \), the branch 0, 1 forms a sub-loop, \( T_1 = \{0, 1, 0\} \), now \( r_1 = 1.5t, l_1 = 6 \text{ km} \).

Then find the minimum distance between 0 and 1 in the remaining branches (2, 3, 4, 5, 7), \( \min \{ C_{0i}, C_{i} | i \in N, 1 \leq i \leq 7 \text{ and } i \neq 1 \} = C_{02} = 3 \text{ km} \), \( r_2 = 2t \).

Because \( r_1 + r_2 = 3.5t < 4t \), the breach 2 is inserted in the sub-loop \( T_1 = \{0, 1, 0\} \), regardless of the round trip between 0 and 1 due to symmetry, the result is same, thus forming a new sub-loop \( T_1 = \{0, 1, 2, 0\} \), \( R_1 = 3.5t, L_1 = 11 \text{ km} \).

In the remaining branch (3, 4, 5, 6, 7), looking for the nearest distance from 0, 1, 2, minimum distance is known as \( C_{41} = 30 \text{ km} \), the demand of branch 4 is \( r_4 = 1.5t \), but the 4 branch can't insert to \( T_1 \) because \( 1.5 + 3.5 = 5t > 4t \). So \( T_1 = \{0, 1, 2, 0\} \), \( R_1 = 3.5t, L_1 = 11 \text{ km} \), it become the first independence loop.
Repeat the steps above and the next a few loops are T2= {0, 4, 5, 0}, R2=3.5t, L2=69km; T3= {0, 3, 6, 0}, R3=4t, L3=220km; T4= {0, 7, 0}, R4=2t, L4=236km.

3.3. Planning result analysis

Four distribution paths are needed after using the improved nearest insertion method to the path planning of clean coal distribution, which namely 0-1-2-0, 0-3-6-0, 0-4-5-0, 0-7-0. The distribution distance of each path Li, actual load Ri, actual load rate etc. can be calculated separately, as shown in Table 6.

| Distribution path | Distribution distance Li(km) | Actual load Ri(t) | Quasi-load(t) | Actual load rate (%) |
|-------------------|------------------------------|-------------------|---------------|---------------------|
| 0-1-2-0           | 11                           | 3.5               | 4             | 87.5%               |
| 0-3-6-0           | 220                          | 4                 | 4             | 100%                |
| 0-4-5-0           | 69                           | 3.5               | 4             | 87.5%               |
| 0-7-0             | 236                          | 2                 | 4             | 50%                 |
| Total             | 536                          | 13                | 16            | 81.25%(average)     |

It is well shown that the distribution path after re-planning reduced from 5 to 4, which saving 1 truck and 1 driver. The vehicle's total driving distance is 536km, which saved 37km than before optimized system. Average real loading rate increase from 65% to 81.25%, which is 16.25% higher than that before planning.

4. Conclusion

The logistics of distribution center to each branch is a core in the clean coal distribution management, and selecting the ideal distribution path play an important role in improving the distribution efficiency. Through using scientific method in logistics distribution path planning, rationalize vehicle arrangement and staff scheduling, enhance the real load rate of the vehicle, reduce the transportation distance, and achieve the goal of improving logistics efficiency and reducing energy consumption.

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