Industry Science and Engineering Vol. 1 No. 12, 2024

Research on the Optimization of Electric Coal Transportation Routes Based on the Branch and Bound Method

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Abstract: This article focuses on the existing status in the process of electric coal allocation and transportation, considering how to reasonably integrate and optimize coal resources and transportation capacity to formulate the most economic resource allocation scheme and the most reasonable cross-regional allocation plan. By employing a series of theories and methods in logistics engineering, and based on the theory of cost minimization and the current characteristics of electric coal transportation, the research proposes optimization of electric coal transportation routes. This paper selects an appropriate modeling type for the specific scenario of large-scale transportation problems with interval parameters, multidimensionality, multiple constraints, multiple objectives, and considers the uncertainty of time in electric coal transportation. It establishes a transportation route planning model aimed at minimizing the delivered price during the electric coal allocation process, optimizing the many-to-many matching of coal mines and power plants, and the transportation routes. The Branch and Bound algorithm is used to solve and evaluate the problem, thereby verifying the feasibility of the electric coal transportation route optimization method based on minimizing the delivered price, and obtaining the scheme with the lowest delivered coal price and the transportation routes.

Keywords: Branch and Bound; Electric coal dispatch; Path Optimization; Mathematical Model; Python

1. Introduction

The distribution of coal resources in China is extremely uneven, with an overall trend of "more in the northwest and less in the southeast". On the other hand, the installed capacity of thermal power plants is the opposite, showing a trend of "less in the northwest and more in the southeast". This increases the proportion of the logistics cost of electric coal in the entire coal terminal selling price. When coal is transported from Shanxi, Shaanxi, and Inner Mongolia to the power plants in the southeast coastal area of Huadian Group, the highest logistics cost can reach about 60% of the factory cost [1]. The high or low cost of coal transportation directly affects the core competitiveness of enterprises [2]. There are problems in the current coal transportation mode, such as extensive coal transportation plans, outdated calculation methods for coal transportation balance, and a lack of effective consideration for the operational effectiveness of coal transportation.

2. The Current Situation Faced by Huadian's Intensive Regional Coal Transportation

Widely Distributed Allocation Mines: Domestic mines are mainly distributed in the vast regions of Shanxi, Shaanxi, Inner Mongolia, and Xinjiang. Due to inconsistent production conditions at each mine, there are significant differences in output and coal quality among different mines, often matching individual mines with multiple downstream power plants suitable for burning their coal [3].

Multiple Electric Coal Transportation Channels: At the national level, the transportation structure for transporting coal from west to east via railways and port terminals has been basically established. There are numerous transportation routes for allocating coal from multiple mines to multiple suitable power plants within the corporation.

Complex Costs of Electric Coal Transportation: There are numerous types and standards of fees for various stations, national railways, dedicated lines, etc. The national government stipulates long-term agreement prices for coal exports from each mine, but actual costs vary greatly depending on the transportation route and delivered prices.

Currently, the overall value role of the allocation process is not prominent enough. It mainly focuses on journal entries rather than value accounts, unable to provide references for targeted business value analysis and improvement activities by relevant departments within the company.

3. Research Significance

Firstly, it serves as a crucial foundation for the construction of the group's decision-making system for electric coal allocation. In the future, the group's cross-regional allocation network will further expand to Yunnan, Guizhou, and Sichuan. With the further increase in business volume and the complication of the business network, the allocation process, which occupies a key position in the production-transportation-sales supply chain, will become particularly complex. It is necessary to rely on the allocation decision-making system to make decisions on coal allocation plans in order to optimize the group's various business objectives. The research on the allocation model is the basic premise for building the coal allocation decision-making system. Only by first establishing the group's coal allocation model and studying the solution algorithm for the model can we establish a coal allocation decision-making system with the help of computers, perform calculations on large-scale business data, select the optimal coal allocation plan, and provide technical support for the group's operational decisions. Secondly, it is an effective means for the group to maximize the value of the electric coal supply chain. The focus of maximizing the value of the group's industrial chain lies in matching coal supply and demand and procuring and allocating coal at low cost while ensuring a certain level of customer satisfaction. The key point studied in the coal allocation model lies here. Based on different objectives and boundary conditions, the optimal coal allocation plan is calculated and selected to help realize the maximum value of the group's coal-fired power plants in specific environments. The optimization results of the allocation model can be directly applied to the group's actual business operations to guide the procurement and allocation of electric coal. Thirdly, it is an important guarantee for the successful implementation of the group's refined management. The refinement of allocation control and operation is a crucial shift for the group's business growth from an extensive to an intensive model. Only by doing so can we reduce ineffective and inefficient links in the production and operation process, increase the degree of collaboration among various links in the supply chain, make the supply chain operate more smoothly, and achieve rapid growth in economic aggregate and rapid expansion of the business network.

4. Introduction to Basic Theories

Model Introduction: Path Optimization: The path planning problem is generally defined as designing a reasonable transportation route for goods from the origin to the destination through different route options [4]. Under certain constraints, such as cargo demand, transportation time, vehicle loading capacity constraints, mileage constraints, and other conditions, the objective is to minimize total transportation costs, shorten transportation routes, and reduce transportation time, thereby optimizing the overall transportation scheme [5].

5. Construction of a Multimodal Allocation Path Optimization Model for Electric Coal

The electric coal allocation scheme involves multiple logistics processes and nodes, including various transportation modes and transfer node selections. Most of these issues belong to the category of allocation problems with determined transportation processes. This paper proposes a selection model for electric coal allocation schemes aiming to minimize the delivered coal price at power plants [6]. By using a virtual allocation network, the original problem is transformed into an equivalent shortest path problem, involving a corresponding algorithm for solution.

5.1 Problem Description: Electric Coal Allocation Features Cross-Regional, Long-Distance, and Large-Scale Characteristics, Requiring the Analysis of Numerous Factors [7]

This paper focuses on studying the changes in delivered prices at power plants for various allocation routes during the transportation of electric coal. Assuming a batch of electric coal is transported from a mine to a power plant through various transportation links, it is necessary to conduct a techno-economic analysis of the transportation route attributes to obtain parameter values for different transportation routes. By analyzing the total delivered coal price to the plant, incorporating the balance of electric coal supply and demand as a constraint, and using these conditions as constraint parameters for modeling, all routes involved in the paper are virtualized as transportation network nodes to establish a transportation network. The objective is to identify the weekly transportation routes and reasonable mine-to-plant contract matches adopted in the transportation scheme with the lowest delivered coal price at power plants for given starting and ending points [8].

5.2 Model Assumptions [9]

1. The route from the starting mine to the power plant node in the transportation path is determined, and alternative routes for a single mine are given, requiring only the selection of different power plant nodes.
2. The costs of various allocation links, such as pithead prices, railway freight, sea freight, river freight, and various miscellaneous fees in all route allocation paths, have already been calculated and provided in the delivered prices at all routes to power plants.
3. Road loss is not considered.
4. The quality of electric coal only considers the impact of calorific value, with 5000 kcal selected as the standard product for analysis.

5.3 Notation Explanation

The symbol description is shown in the table 1 below.

Table 1. Table Symbol Description

Parameter Category	Parameter Name	Meaning of Parameter
Known Parameters	i	The number of coal mines, totaling m
	Si	Total annual supply of coal mines
	j	The number of power plants, totaling n
	Dj	Total annual demand of power plants
	k	Mode of transportation: 1 for railway, 2 for water transportation
	Cijk	Unit transportation cost from coal mine i to power plant j
	Wmax	Maximum inventory capacity of power plants
	Qijk	Decision variable: transportation quantity from coal mine i to power plant j using transportation mode k
	Ej	Weekly coal consumption of power plant j
	Xjk	Maximum receiving and unloading capacity of power plant using transportation mode k

5.4 Mathematical Model Establishment

To establish a function with the objective of minimizing the delivered coal price at power plants:

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{2} C_{ijk} \times Q_{ijk}, \forall j, k \tag{1}$$

The objective function aims to optimize the resource allocation scheme by calculating the lowest delivered coal price at power plants through both land and water transportation modes.

Constraint 1

$$\sum_{j=1}^{n}\sum_{k=1}^{2} Q_{ijk} \ll S_i, \forall_i \tag{2}$$

Constraint related to annual coal supply: The transported amount of coal for power generation cannot exceed the supply capacity of the respective coal mine.

Constraint 2

$$\sum_{i=1}^{m}\sum_{k=1}^{2} Q_{ijk} \ll D_j, \forall_{j,k} \tag{3}$$

Constraint related to annual power plant receipt: The transported amount of coal for power generation cannot exceed the demand of the respective power plant.

Constraint 3

$$\sum_{i=1}^{m}\sum_{k=1}^{2} Q_{ijk} \leq X_{jk}, \forall_{j,k} \quad (4)$$

Constraint of power plant's receiving and unloading capacity balance: The transportation volume of each mode for a power plant shall not exceed its weekly receiving and unloading capacity for that mode.

Constraint 4

$$T_{ijk}、Q_{ijkz} \in N \quad (5)$$

Shipping time and shipping volume are integers.

Constraint 5

$$Z - T_{ijk} \leq 0,\ Q_{ijkz} = 0 \quad (6)$$

If both water transportation and railway transportation methods are unavailable, the result of Qijk should be 0.

Output: Contract plan. Under the condition that total supply and total demand remain unchanged, which power plant should sign for how much quantity.

5.5 Model Solving

5.5.1 Construction of a virtual transportation network

Utilizing the concept of transformation, a virtual transportation network is created to convert the original problem into a shortest path problem with capacity constraints. Subsequently, the optimized network is solved using a branch-and-bound algorithm, and the obtained solution is then translated back to the solution for the original problem. There are multiple origin points i and destination points j, with several transportation channels connecting each pair of i and j nodes based on contract signing. Each pair of nodes is connected by an arc, and the attributes on each arc include transportation volume, price to the plant, and so on.

5.5.2 Solving with branch and bound method

The Branch and Bound Method is one of the most commonly used algorithms for solving integer programming problems. This method can solve not only pure integer programming problems but also mixed integer programming problems. It systematically searches through the entire feasible solution space of a constrained optimization problem (whose feasible solutions are finite in number) through branching and bounding. The entire solution space is repeatedly divided into smaller subsets, known as branching. For each subset, a lower bound (for minimization problems) of the objective function is calculated for the solution set within that subset, known as bounding. After each branching, if the objective value of a known feasible solution set cannot meet the current bound, that subset is discarded. In this way, many subsets are not considered, which is known as pruning. This is the basic idea of the Branch and Bound Method.

The specific steps are as follows.

We can use tools in Python to solve linear programming problems. Due to its popularity and convenience, we will introduce the use of the pulp package here. Pulp is capable of solving most linear programming problems, including Integer Programs (IPs), Binary Programs, and Mixed Integer Linear Programs (MILPs), with great effectiveness [10].

6. Empirical Analysis

China Huadian Corporation signed 83.793 million tons of annual long-term contracts for single orders exceeding 100,000 tons in its centralized procurement regions. The coal is transported from the Shanxi-Shaanxi-Inner Mongolia region via railway and Northern Ports for shipment. The challenge faced is: how should the fuel logistics company choose a transportation plan to transport coal produced in mining areas (from the Shanxi-Shaanxi-Inner Mongolia mining areas, which are the coal supply points) to eastern China's Shandong and Jiangsu provinces, central China's Anhui, Hunan, and Hubei provinces, and southern China's Guangdong and Guangxi regions. With the origin and destination points determined, the intermediate resource transportation methods are full of uncertainties. How to choose the appropriate transportation methods and routes are the main research contents.

Between transportation nodes, there can be different transportation modes with varying transportation times, costs, capacities, and node inventory capacities. Therefore, the transportation optimization problem to be solved is how to select the appropriate combination of transportation modes to optimize the overall benefits of multimodal transportation of thermal coal for power supply. This chapter selects the annual long-term contract mining areas as the transportation origin and the centralized procurement regions as the power supply areas (coal consumption bases) to design the transportation plan [11].

6.1Selection of Coal Mines. Based on the actual coal consumption of the enterprise, 110 contracted mines were selected. The mines and their production numbers are shown in Table 2 below.

Table 2. Mineral Production

mine site	Contracted Volume (in 10,000 tons)	mine site	Contracted Volume (in 10,000 tons)	mine site	Contracted Volume (in 10,000 tons)
1	20	38	20	75	20
2	32	39	40	76	35
3	22	40	30	77	90
4	70	41	210	78	20
5	30	42	40	79	30
6	58	43	200	80	335
7	163	44	220	81	50
8	40	45	72	82	102
9	10	46	300	83	45
10	116	47	10	84	40
11	211	48	11	85	48
12	58	49	30	86	220.5
13	40	50	105	87	15
14	70	51	15	88	85
15	70	52	200	89	27
16	25	53	10	90	20
17	60	54	20	91	20
18	20	55	217	92	40
19	20	56	10.8	93	10
20	80	57	10	94	35
21	52	58	120	95	240
22	30	59	650	96	500
23	20	60	100	97	30
24	30	61	200	98	40
25	20	62	65	99	20
26	20	63	20	100	80
27	20	64	40	101	85
28	20	65	10	102	30
29	14	66	34	103	10
30	100	67	40	104	80
31	130	68	20	105	10
32	30	69	10	106	50
33	20	70	50	107	30
34	60	71	550	108	26
35	14	72	20	109	35
36	80	73	30	110	120
37	24	74	77		

6.2 Selection of Thermal Power Plants

This paper selects 38 major coal-fired power plants of the group, including those located in Shandong, Jiangsu, Fujian, Guangdong, Guangxi, Hunan, Hubei, and Anhui regions. The power plants and their demand numbers are shown in Table 3 below.

Table 3. Thermal Power Plant and Demand

power plant	demand volume	power plant	demand volume	power plant	demand volume
1NG	157	14CD	200	27YH	131
2ZQ	203	15HS	53	28SLQ	358

3XX	187	16LK	190	29SZ	226
4WH	459	17KM	280	30JLC	242.8
5JREQ	261.5	18ST	60	31LC	200
6SW	90	19GG	100	32ZB	224
7PJ	130	20WF	210	33ZX	950
8LZ	669	21QD	190	34TZ	187
9WT	299.5	22PS	110	35LH2	177
10JRYQ	241.5	23SG	100	36YZ	50
11JL	225	24XSS	183	37QD	110
12XY	369	25LA	200	38YA	20
13CS	193	26LH1	143		

6.3 Model Solution

The programming is as follows:

```
prob = LpProblem ("Coal_ Transportation_ Problem", LpMinimize)
Q = LpVariable. dicts("Q", [(i, j, k) for i in range (1, 111) for j in range (1, 39) for k in range (1, 3)], lowBound=0, cat='Continuous')

prob += lpSum(Q[(i, j, k)] * (Cij1[i-1][j-1] if k == 1 else Cij2[i-1][j-1]) for i in range(1, 111) for j in range(1, 39) for k in range(1, 3)), "Total_ Cost"

for i in range (1, 111):
    for j in range (1, 39):
        if Cij1[i-1] [j-1] == 0:
            prob += Q [(i, j, 1)] == 0, f"Qij1_Zero_When_Cij1_Zero_{i}_{j}"

for i in range (1, 111):
    for j in range (1, 39):
        if Cij2[i-1] [j-1] == 0:
            prob += Q [(i, j, 2)] == 0, f"Qij2_Zero_When_Cij2_Zero_{i}_{j}"

for i in range (1, 111):
    prob += lpSum (Q [(i, j, k)] for j in range (1, 39) for k in range (1, 3)) >= Si[i-1], f"Annual_ Transportation_ Lower_ Constraint_{i}"
    prob += lpSum(Q[(i, j, k)] for j in range(1, 39) for k in range(1, 3)) <= Si[i-1], f"Annual_ Transportation_ Upper_ Constraint_{i}"

for j in range (1, 39):
    prob += lpSum (Q [(i, j, k)] for i in range (1, 111) for k in range (1, 3)) >= Dj[j-1], f"Weekly_ Coal_ Demand_ Lower_ Constraint_{j}"
    prob += lpSum (Q [(i, j, k)] for i in range (1, 111) for k in range (1, 3)) <= Dj [j-1], f"Weekly_ Coal_ Demand_ Upper_ Constraint_{j}"

prob. Solve ()

print ("Status:", LpStatus[prob.status])

for v in prob. Variables ():
    if v. varValue >0:
        print (v.name, "=", v. varValue)

print ("Total Cost =", value (prob. objective))


for j in range (1, 39):
    total_ coal_ transport = sum (value (Q [(i, j, k)]) for i in range (1, 111) for k in range (1, 3))

    if total_ coal_ transport < Dj [j-1]/2:
        print (f"Constraint not satisfied for power plant {j}. Total coal transportation: {total_ coal_ transport}, Demand: {Dj [j-1]/2}")

print ("Total Trans value sum of Q:", sum (value (Q [(i, j, k)]) for i in range (1, 111) for k in range (1, 3) for j in range (1,39)))

total_ cost = 0
for i in range (1, 111):
    for j in range (1, 39):
        for k in range (1, 3):
            if k == 1:
                total_ cost += Qij1[i-1] [j-1] * Cij1[i-1] [j-1]
            else:
                total_ cost += Qij2[i-1] [j-1] * Cij2[i-1] [j-1]
```

```
print ("Origin Total Cost:", total_ cost)
# print (len (Qij1[0]), len (Qij1))
# print (len (Qij2[0]), len (Qij2))

for j in range (1, 39):
    total_ coal_ transport = sum (Qij1[i] [j-1] +Qij2[i] [j-1] for i in range (110))
    if total_ coal_ transport < Dj [j-1]/2:
        print (f" Constraint not satisfied for power plant {j}. Total coal transportation: {total_ coal_ transport}, Demand: {Dj [j-1]/2}")
```

The annual contract transportation path for the output result is shown in Table 4 below:

Table 4. Transportation Route

Status: Optimal	Q_ (30, _20, _1) = 15.0	Q_ (58, _38, _1) = 20.0	Q_ (85, _37, _1) = 48.0
Q (1, _1, _1) = 20.0	Q_ (30, _31, _1) = 50.0	Q_ (59, _26, _1) = 42.0	Q_ (86, _10, _2) = 3.0
Q_ (10, _13, _2) = 73.0	Q_ (31, _31, _1) = 90.0	Q_ (59, _28, _1) = 23.0	Q_ (86, _16, _2) = 160.0
Q_ (10, _15, _2) = 43.0	Q_ (31, _6, _1) = 10.0	Q_ (59, _29, _1) = 10.0	Q_ (86, _5, _2) = 57.5
Q_ (100, _11, _1) = 55.0	Q_ (31, _7, _1) = 30.0	Q_ (59, _33, _1) = 380.0	Q_ (87, _11, _2) = 15.0
Q_ (100, _12, _1) = 25.0	Q_ (32, _29, _1) = 30.0	Q_ (59, _34, _1) = 187.0	Q_ (88, _2, _1) = 85.0
Q_ (101, _17, _2) = 85.0	Q_ (33, _25, _1) = 20.0	Q_ (59, _35, _1) = 8.0	Q_ (89, _30, _1) = 27.0
Q_ (102, _1, _1) = 30.0	Q_ (34, _21, _1) = 60.0	Q_ (6, _8, _2) = 58.0	Q_ (9, _6, _1) = 10.0
Q_ (103, _6, _1) = 10.0	Q_ (35, _32, _1) = 14.0	Q_ (60, _9, _2) = 100.0	Q_ (90, _4, _2) = 20.0
Q_ (104, _4, _2) = 80.0	Q_ (36, _28, _1) = 80.0	Q_ (61, _10, _2) = 58.5	Q_ (91, _33, _1) = 20.0
Q_ (105, _8, _2) = 10.0	Q_ (37, _24, _1) = 24.0	Q_ (61, _36, _2) = 50.0	Q_ (92, _25, _1) = 40.0
Q_ (106, _22, _1) = 50.0	Q_ (38, _12, _1) = 20.0	Q_ (61, _9, _2) = 91.5	Q_ (93, _4, _2) = 10.0
Q_ (107, _4, _2) = 30.0	Q_ (39, _25, _1) = 40.0	Q_ (62, _25, _1) = 65.0	Q_ (94, _29, _1) = 35.0
Q_ (108, _29, _1) = 26.0	Q_ (4, _4, _2) = 70.0	Q_ (63, _30, _1) = 20.0	Q_ (95, _18, _2) = 60.0
Q_ (109, _8, _2) = 35.0	Q_ (40, _12, _1) = 30.0	Q_ (64, _1, _1) = 40.0	Q_ (95, _24, _2) = 139.0
Q_ (11, _17, _2) = 111.0	Q_ (41, _11, _1) = 135.0	Q_ (65, _32, _1) = 10.0	Q_ (95, _5, _2) = 41.0
Q_ (11, _19, _2) = 100.0	Q_ (41, _20, _1) = 75.0	Q_ (66, _35, _1) = 34.0	Q_ (96, _1, _1) = 67.0
Q_ (110, _13, _1) = 120.0	Q_ (42, _14, _1) = 40.0	Q_ (67, _2, _1) = 40.0	Q_ (96, _10, _2) = 108.0
Q_ (12, _4, _2) = 58.0	Q_ (43, _12, _1) = 165.0	Q_ (68, _31, _1) = 20.0	Q_ (96, _15, _2) = 10.0
Q_ (13, _20, _1) = 40.0	Q_ (43, _25, _1) = 35.0	Q_ (69, _28, _1) = 10.0	Q_ (96, _17, _2) = 84.0
Q_ (14, _22, _1) = 60.0	Q_ (44, _14, _1) = 160.0	Q_ (7, _5, _2) = 163.0	Q_ (96, _23, _2) = 40.0
Q_ (14, _23, _1) = 10.0	Q_ (44, _6, _1) = 60.0	Q_ (70, _28, _1) = 50.0	Q_ (96, _4, _2) = 191.0
Q_ (15, _7, _1) = 70.0	Q_ (45, _10, _2) = 72.0	Q_ (71, _33, _1) = 550.0	Q_ (97, _8, _2) = 30.0
Q_ (16, _12, _1) = 25.0	Q_ (46, _28, _1) = 151.0	Q_ (72, _31, _1) = 20.0	Q_ (98, _8, _2) = 40.0
Q_ (17, _21, _1) = 60.0	Q_ (46, _30, _1) = 149.0	Q_ (73, _16, _1) = 30.0	Q_ (99, _11, _2) = 20.0
Q_ (18, _26, _1) = 20.0	Q_ (47, _3, _1) = 10.0	Q_ (74, _28, _1) = 14.0	Total Cost = 6242313.812085778
Q_ (19, _26, _1) = 20.0	Q_ (48, _2, _1) = 11.0	Q_ (74, _9, _2) = 63.0	Total Trans value sum of Q: 8379.3
Q_ (2, _2, _1) = 32.0	Q_ (49, _26, _1) = 30.0	Q_ (75, _24, _1) = 20.0	Origin Total Cost: 6427134.586651272
Q_ (20, _20, _1) = 80.0	Q_ (5, _7, _1) = 30.0	Q_ (76, _35, _1) = 35.0	
Q_ (21, _8, _2) = 52.0	Q_ (50, _29, _1) = 105.0	Q_ (77, _8, _2) = 90.0	
Q_ (22, _28, _1) = 30.0	Q_ (51, _30, _1) = 15.0	Q_ (78, _8, _2) = 20.0	
Q_ (23, _21, _2) = 20.0	Q_ (52, _32, _1) = 200.0	Q_ (79, _12, _1) = 30.0	
Q_ (24, _21, _1) = 30.0	Q_ (53, _3, _1) = 10.0	Q_ (8, _12, _1) = 40.0	
Q_ (25, _29, _1) = 20.0	Q_ (54, _27, _1) = 20.0	Q_ (80, _30, _1) = 1.0	
Q_ (26, _30, _1) = 20.0	Q_ (55, _21, _1) = 20.0	Q_ (80, _8, _2) = 334.0	
Q_ (27, _31, _1) = 20.0	Q_ (55, _3, _1) = 135.0	Q_ (81, _23, _2) = 50.0	
Q_ (28, _12, _1) = 20.0	Q_ (55, _37, _1) = 62.0	Q_ (82, _26, _1) = 31.0	
Q_ (29, _12, _1) = 14.0	Q_ (56, _30, _1) = 10.8	Q_ (82, _27, _1) = 71.0	
Q_ (3, _3, _1) = 22.0	Q_ (57, _3, _1) = 10.0	Q_ (83, _9, _2) = 45.0	
Q_ (30, _2, _1) = 35.0	Q_ (58, _35, _1) = 100.0	Q_ (84, _27, _1) = 40.0	

After optimizing the transportation routes in this annual contract, the calculated cost of coal delivered to the power plants amounted to 62.423 billion yuan, compared to 64.143 billion yuan based on the original transportation routes. With the existing signed resources, by changing the transportation flow direction and optimizing the routes, we can improve efficiency and reduce the unit price of standard coal delivered to the plants by 2.8%. This provides new methods and insights for creating value for the enterprise.

7. Conclusion

Based on the coal transportation route optimization model, this paper verifies the feasibility of utilizing the branch and bound algorithm for optimizing the transportation routes of thermal coal for power enterprises, according to the characteristics of the model. Through calculations and analyses of the case study model, an annual contract transportation plan is obtained, which effectively assists power enterprises in cost savings.

The limitation of this paper lies in its simplification of the model establishment and solution process. The flow direction from mine sites to all power plants has been fixed, and the routes from mine sites to all power plants have not been included in the analysis. Additionally, fluctuations in transportation volumes between summer and winter, coal calorific value uniformly constrained at 5000 kcal, power plant unloading capacity, and secondary port inventory have all been simplified and not considered. In future research, in addition to addressing the aforementioned issues, the operating capacity of the group's power plants should also be included in the analysis to construct an analysis model for optimizing the total profit of coal-fired power plants across the entire group through thermal coal transportation. This will maximize the benefits of coal-fired power plants at the group level.

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