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Improving Economic Benefits through Coal Products Optimization in a Given Group

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ABSTRACT

Improving economic benefits from a large coal mining group with several operations is always the first objective of its operator. More concerns are usually focused on the unit operations and their cost. An optimization model for coal products and production rate based on Simplex Method(SM) and Algorithm of Universal Global Optimization(AUGO) approach is established in order to maximize the economic benefits of a given mining group in its existing cost construction. The result shows that the total economic return of the group could be improved a lot through optimization of its coal products and production rather than the summation of its every single mine's coal products and production rate, each operation of the group should do its best to produce as more as possible high quality products it can produce, and the mines with inferior quality of products should excavate their deposit according to the optimized production rate to make the whole system profit maximum rather than its own designed production.

Keywords: *Coal products, Production rate, Optimization, A given group, Simplex method.*

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1. INTRODUCTION

Coal is a major natural energy resource in China, which is about more than 70% of its total energy consumption and it is expected that the nation's energy structure will not be changed much in the next 50 years. It is estimated that coal will still be more than 50% in China's energy consumption in 2050. As a major coal producing and consuming country, how to increase its total economic return while decrease greenhouse gas emission from its coal burning with the production of coal is really a good concern (Organization for Economic Co-Operation and Development, 2003).

Recent years in China, some small and medium operations are being combined into large coal groups with the development of science and technology as well as market demand increasing, and some superior quality energy resources are concentrated into large complexes with higher management abilities. The resulted conditions from such combined enterprises give rise to such situation that several operations are operated by a large group with multi-commercial coal products. Take Xingdong mining area as an example, after 6 underground operations being mergered into the same group, the commercial coal products can be produced from the group include coking coal, metallurgical coal, steaming coal, coal for power generation, etc. with quite deferent coal prices.

In the period of planned economy in China, coal production was usually determined according to market demand, mine life and some other constraints, optimization work was rarely conducted in the original stages, so that its coal products; for a developed or existing mine, it is usually the more production rate, the more profit; for an active operation, if the market demand is high enough, the mine is typically try to produce more products to get a maximum financial return from its own; with the increasing large groups, the objective is to get maximum profit from its production of operations, so that the question is arising, if the group's maximum financial return is the sum of its every single operation; and if the group's maximum profit is related to their products of different operations.

The end objective of any coal mining company is to get maximum profit from its operation. For a single mine engaged in coal extraction, coal quality and ranks are usually determined, no need to optimize its coal products. As a big coal mining group, several mines maybe owned with different production rate and commercial coal products, and more concerns are usually focused on the unit operations and their cost, under this circumstance, if the optimization work can be made to make maximum profit from its production under the existing cost construction. As a result, a project is proposed to optimize total economic return in a given group with several operations under certain cost, coal production and coal products to seek a new approach.

Xingtai Mining Area is a major coal mining area in Jizhong Energy Group with 6 underground coal mines under operation, several kinds of coal products can be processed from its run-of mine coal. In order to improve the Group's benefits in the increasing market competition, a project focus on coal products and total production rate optimization is proposed to seek some better management approaches.

2. OPTIMIZATION MODEL FOR COAL PRODUCTS

For a given mining operation, its coal rank is usually determined, and coal products also depend on its coal deposit conditions. In a given conglomerated coal mining Group, several mines may be operated in a given period, so that its coal ranks and commercial coal products.

A coal mining group can be described as a big system in which the production rate, coal products be elements in it, the system optimization objectives can be decided according to the research objectives of the project, and then the sequences of the system optimization could be done as follows.

2.1. The Optimization of Objective Function and its Criterion (Operations Research Teaching Material Compiling Group, 1990; Wayne *et al.*, 2002; Qian, 2010)

Given that annual profit of a coal operation is P, i is the number of its mines, j denotes the number of coal products, and there are n mines in the coal operation, m coal products. The x_{ri} refers raw coal production rate of the i^{th} mine, y_{ji} the production of the j^{th} coal products of the i^{th} mine, p_{ri} is the raw coal price of the i^{th} mine, c_{ri} is the raw coal production cost of the i^{th} mine(i=1, 2, ..., n); p_{ji} is coal price of the j^{th} coal products in the i^{th} mine, c_{ji} is the production cost of the j^{th} coal products of the i^{th} mine (j = 1, 2, ... , m). The objective function is to achieve the maximum profit of the operation, so the optimization equation of coal products can be set up as follows:

$$\mathrm{Max}\, P=\sum_{i=1}^{n}(p_{ri}-c_{ri})x_{ri}+\sum_{i=1}^{n}\sum_{j=1}^{m}(p_{ji}-c_{ji})y_{ji} \tag{1}$$

2.2. The Constraints of the Objective Function

1) The Market Demand

Market demand must be considered at first for the production of coal products (Qian *et al.*, 2003; Qian *et al.*, 2008) only the marketable products are the sources of profits. If D_p is the total market coal product demand for the operation, k_{cj} the total market demand for the j^{th} coal product, the coal production rate is subject to:

$$\sum_{i=1}^{n}x_{ri}\le D_{p} \tag{2}$$

$$\sum_{i=1}^{n}y_{ji}\le k_{cj},\quad (j=1,2,...,m) \tag{3}$$

The market demand of coal can be forecasted according to the statistics of the several years before by different forecasting methods.

2) Designed Coal Production Rate (Miao and Qian, 2009)

The quantity of coal products is determined by its designed raw coal production rate.

$$x_{ri}\le A_{dpi}\quad (i=1,2,\ \dots,\ n) \tag{4}$$

Where A_{dpi} refers to designed annual production rate of coal in the i^{th} mine.

3) The Quality of the Coal to be Mined

The quality of commercial coal is really a good concern to the end users, especially the sulfur content, ash content and calorific value etc. (Deng *et al.*, 2013; Golshani *et al.*, 2013) If, S_i, A_i, T_i are the sulfur content, ash content and thermal value of the i^{th} mine, respectively; A_{max}, S_{max} refer user commercial coal ash, sulfur content requirement limit respectively; T_{max}, T_{min} is user requirements on upper and lower thermal value of coal products, then the constraint equations are shown as follows:

$$\sum_{i=1}^{n}S_{i}x_{ri}\le S_{max}\sum_{i=1}^{n}x_{ri} \tag{5}$$

$$\sum_{i=1}^{n}A_{i}x_{ri}\le A_{max}\sum_{i=1}^{n}x_{ri} \tag{6}$$

$$T_{\min}\sum_{i=1}^{n}x_{ri} \leq \sum_{i=1}^{n}T_i x_{ri} \leq T_{\max}\sum_{i=1}^{n}x_{ri} \qquad (7)$$

4) The Breakeven Point of Coal Production

Any coal operation must take into account its economic conditions, keep the production rate higher than its break-even point of production rate in order to get minimum profit. If B_e is the break-even point of an operation's annual production rate with zero profit, the raw coal or/and commercial coal products should be,

$$\sum_{i=1}^{n}p_{ri}x_{ri} + \sum_{i=1}^{n}\sum_{j=1}^{m}p_{ji}y_{ji} \geq B_e \qquad (8)$$

5) Transport Capacity

Coal transportation capacity from a mine to its end users is often an important factor for its designed production rate since a coal mine is usually located at a distant area. If T_0 represents the maximum annual transport capacity of a coal mine, the total production must be

$$\sum_{i=1}^{n}x_{\mathrm{ri}} + \sum_{i=1}^{n}\sum_{j=1}^{m}y_{ji} \leq T_0 \qquad (9)$$

6) Nonnegative of the Variables

All the variables involved in the model must be non-negative.

3. THE ESTABLISHMENT OF OPTIMIZATION MODEL (Peter, 2011)

Xingdong mining area (XMA) is a major coal production area of Jizhong Energy Group, six underground mines are operated under the mining area. The coal ranks mined in the area include coke oven coal, steaming coal, metallurgical coal etc. in the early stages, XMA's coal products were only sold according to the products produced by every single mine. With the development of market demand, it is found that it be better to sell more qualified higher price coal products to get higher profit. A project aimed to optimize the XMA's total financial return is proposed to see if the financial situation could be improved.

The 6 underground mines in the XMA are Dongpang (DP), Gequan (GQ), Xiandewang (XDW) , Xingdong (XD), Xingtai (XT), and Zhangcun (ZC) mines. Coal products of the Group are mainly classified into coking coal, coal for power generation (power coal) and steaming coal for other uses.

The purpose of the XMA's optimization is to get the maximum profit from its coal production, the optimization criteria of the project are set up as follows:

1) the total group annual profit should be maximized;

2) the supply of coal products should be kept stable;

3) the quality of coal products be in line with the market demand.

Given that group's profit value is P, p_{1i} is coking coal price of the i^{th} mine, c_{1i} is coking coal production cost of the i^{th} mine; p_{2i} is power coal price the of the i^{th} mine, c_{2i} is power coal production cost of the i^{th} mine, p_{3i} is steaming coal price the of the i^{th} mine, c_{3i} is steaming coal production cost of the i^{th} mine. The x_i is coking coal production from the i^{th} mine, y_i is power coal output from the i^{th} coal mine, z_i the steaming coal production from the i^{th} mine. Then

1) Function equation of the Group's objective,

$$\operatorname{Max} P = \sum_{i=1}^{6}(p_{1i} - c_{1i})x_i + \sum_{i=1}^{6}(p_{2i} - c_{2i})y_i + \sum_{i=1}^{6}(p_{3i} - c_{3i})z_i \qquad (10)$$

2) The objective function is subject to

(1) The market demand

Given that the biggest market demand for coking coal, power coal and steaming coal is K_{max}, P_{max}, D_{max} respectively, then the market demand for coal production will be,

$$\sum_{i=1}^{6} x_i \le K_{max} \qquad (11)$$

$$\sum_{i=1}^{6} y_i \le P_{max} \qquad (12)$$

$$\sum_{i=1}^{6} z_i \le D_{max} \qquad (13)$$

(2) The production rate of coal products

The maximum raw coal production rate of the i^{th} mine is a_i, recovery rate of the commercial coal in the i^{th} mine is r_i,

$$r_i = \frac{\text{commercial coal production of the } i^{th} \text{ min e}}{\text{raw coal production of the } i^{th} \text{ min e}},$$

$$x_i + y_i \le r_i a_i, \quad (i = 1, 2, ..., 6) \qquad (14)$$

(3) Processing capacity of washing plants

If the maximum processing capacity of washing plants in the Group is W, then

$$\sum_{i=1}^{6}(x_i + y_i + z_i) \le W, \qquad (15)$$

(4) Non-negative of the whole variables

All the variables used in the model should be nonnegative, that is

$$x_i \ge 0,\ y_i \ge 0,\ z_i \ge 0,\ i = 1, 2, ..., 6 \qquad (16)$$

(5) All the other constraints related to the model will be taken into consideration, including the breakeven point of production rate, transportation capacity, resource recovery rate so on and so like.

4. SOLUTION TO THE OPTIMIZATION MODEL

Since in the optimization model of commercial coal products, the objective function $f(x)$ and the constraint set functions $g(x)$ are all linear or first-order, the programming problem can be solved as a linear programming (Wayne *et al.*, 2002).

In the light of the XMA's related data , the coal price, production cost and profit are listed in Table 1(the price and cost data are estimated from the statistics of the last 5 years production of the XMA), production rate and recovery rate of commercial coal of different mines are listed in Table 2.

Table-1. Estimated price of coal products and operating cost* (RMB ￥/t)

Mine name	Coking coal price	Coking coal cost	Coking coal profit	Power coal price	Power coal cost	Power coal profit	Steaming coal price	Steaming coal cost	Steaming coal profit
DP	1060.97	617.82	443.15	697.96	393.56	304.40	334.95	169.30	165.32
GQ	1205.27	701.85	503.42	732.46	416.75	315.71	259.65	131.65	128.00
XT	1134.08	660.39	473.69	679.56	387.18	292.38	225.03	113.96	111.07
XD	0.00	0.00	0.00	0.00	0.00	0.00	684.77	346.79	337.98
XDW	806.22	469.47	336.75	600.95	334.93	266.02	395.68	200.39	195.29
ZC	1032.00	600.95	431.05	0.00	0.00	0.00	342.00	200.77	141.23

*Courtesy of XMA's statistics.

Market demand forecasting of coking coal, coal for power generation, steaming coal for the given year is 10.03, 6.35, 1.85Mt respectively, the objective function is given by

$$\text{Max } F = 443.15x_1 + 503.42x_2 + 473.69x_3 + 0.0x_4 + 336.75x_5 + 431.05x_6 +$$
$$+ 304.40y_1 + 315.71y_2 + 292.38y_3 + 266.02y_5 +$$
$$+ 165.32z_1 + 128.00z_2 + 111.07z_3 + 337.98z_4 + 195.29z_5 + 141.23z_6 \qquad (17)$$

Table-2. Mine production rate and recovery rate of coal products

Mine name	Max Designed production, Mt	Commercial coal recovery rate	Max Commercial coal production,/Mt
DP	6.50	0.80	5.20
GQ	1.84	0.93	1.71
XT	2.80	0.85	2.38
XD	1.73	0.83	1.44
XDW	2.80	0.81	2.27
ZC	2.40	0.85	2.04

*Courtesy of XMA's statistics.

Subject to

$x_1+x_2+x_3+x_4+x_5+x_6\leq 10.03$

$y_1+y_2+y_3+y_4+y_5+y_6\leq 6.35$

$z_1+z_2+z_3+z_4+z_5+z_6\leq 1.85$

$x_1+y_1+z_1\leq 2.38$

$x_2+y_2+z_2\leq 5.20$

$x_3+y_3+z_3\leq 1.71$

$x_4+y_4+z_4\leq 1.44$

$x_5+y_5+z_5\leq 2.04$

$x_6+y_6+z_6\leq 2.27$

$x_i\geq 0,\ y_j\geq 0,\ z_k\geq 0,\quad i, j, k = 1, 2, \ldots, 6 \qquad (18)$

In which x_i refers to the coking coal production from the i^{th} mine, y_j refers to the coal production for power generation from the j^{th} mine, and z_k the steaming coal production from the k^{th} mine.

Since the variants in the model are all first-order, and optimization model of the project is a linear programming problem which can be solved by different software with different advantages and disadvantages.

Simplex Method(SM) and Algorithm of Universal Global Optimization(AUGO) are selected in the process of optimization, and the 1stOpt 5.0 software is selected to search for its solutions. The 1stOpt 5.0 software has the advantages of using AUGO with higher numbers of repetition and iteration, and the more accuracy of the optimization results. After repeating and iterating the given times, the general global optimization results are shown in Table 3.

Table-3. Optimization results of coal products from different mines

Year 2013		DP	GQ	XD	XT	XDW	ZC
Designed production rate /Mt	Coking coal	3.80	0.50	2.35	0	0.81	0.80
	Coal for power generation	0.39	0.28	0.14	0.00	0.49	0.00
	Steaming coal	0.86	0.70	0.57	1.25	0.54	0.90
Optimized production rate /Mt	Coking coal	3.90	1.71	2.38	0	0	2.04
	Coal for power generation	1.30	0.00	0.00	0.00	2.27	0.00
	Steaming coal	0.00	0.00	0.00	1.44	0.00	0.00

Source:

5. CONCLUSIONS

To optimize coal products and production rate of different mines in a big group can offer an approach to getting maximum profit through optimizing designed production rate, coal products and increased market competency under certain cost construction. The project case study shows that optimization model of production rate and coal products in the XMA can bring more profit than that of the sum of designed production rate in every single mine, take the year of 2015 for example, if the XMA produce coal products according to optimization result, the total profit of the Group could be increased by 21.0% from 5.02 to 6.08 billion Yuan rather than by each mine's designed production.

From the case study, some conclusions could be drawn:

5.1. If the group organized its production rate according to the designed production rate of every mine, it is probably that the total profit of the group cannot be reached maximum.

5.2. Through optimization of the group's coal products under the original designed production rate, the group's financial return can be increased more than 20.0% in light of the ongoing coal products price and cost.

5.3. Under certain market demand, each operation of the group should do its best to produce as more as possible high quality products it can produce.

5.4. Those mines with inferior quality of products should excavate their minerals according to the optimized production rate to make the whole system profit maximum rather than its own designed production.

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