Study on dynamic multi-objective approach considering coal and water conflict in large scale coal group

Qing Feng¹, Li Lu²,*
¹Business School, Sichuan University, Chengdu, China
²Tourism School, Sichuan University, Chengdu, China

*Corresponding author e-mail: luli_rudy@126.com

Abstract. In the process of coal mining, destruction and pollution of groundwater in has reached a imminent time, and groundwater is not only related to the ecological environment, but also affect the health of human life. Similarly, coal and water conflict is still one of the world's problems in large scale coal mining regions. Based on this, this paper presents a dynamic multi-objective optimization model to deal with the conflict of the coal and water in the coal group with multiple subordinate collieries and arrive at a comprehensive arrangement to achieve environmentally friendly coal mining strategy. Through calculation, this paper draws the output of each subordinate coal mine. And on this basis, we continue to adjust the environmental protection parameters to compare the coal production at different collieries at different stages under different attitude of the government. At last, the paper conclude that, in either case, it is the first arrangement to give priority to the production of low-drainage, high-yield coal mines.

1. Introduction

As one of the most utilized energy sources, coal accounts for 29.2% of global primary energy consumption and is ranked second of all known energy sources, with total consumption being 3839.9 Mtoe (million tons of oil equivalent) and China possessed approximately 114.5 billion tons of proved coal reserves in 2015 according to the BP energy statistical report [1]. Water is also a resource that nobody can live without [2]. In the recent years, due to the development of society and economy, the demand of energy is increasing. Excessive mining of coal fields in China has resulted in a series of serious environmental pollution problems, such as groundwater table depression and regional water quality deterioration, and especially the quantities of groundwater produced by coal mining are very tremendous, which has many pollutants and bring further damage to local ecological environment [3,4]. However water is very important for the sustainable development coal fields, so the local government have to think about the future and manage the waste water and its treatment methods through relevant policies.

Fortunately, society has begun to pay more attention to this problem, and many relevant scholars have done a great deal of research on this issue. Younger and Wolkersdorfer studied the mining impacts on the fresh water environment deeply and proposed the technical and Managerial Guidelines [5]. Baker et al. used an ecologic-economic modeling approach based on a created wetland to reduce and control coal mine drainage and developed an optimal model to apply to a real world case in
Tennessee and Alabama, USA [6]. Many policies and legal provisions have also been specified by the government around the world, such as the Mineral Resources Law of the People's Republic of China, the National Environmental Policy Act of the United States and Japan's Mining Law. More recently, Xu et al. proposed a bi-level optimization model based on the Stackelberg-Nash equilibrium strategy with fuzzy coefficients to deal with environmental water problems in large scale coal fields, in which both the economic development and environmental protection are concerned [7,8]. These excellent studies have different views to protect the water resources produced by coal mining in coal fields and had already achieved remarkable results. However, in fact, the coal mining drainage has still not been fully resolved and further research by scholars is needed.

Previous coal mining drainage studies have only considered the single periodic decision maker situation. however, in fact, the manager needs to consider the long-term survival and development of the company and the long-term interests of the company cannot separate into the single cycle decision making due to the decision of the latter cycle is affected by the end of the previous cycle state. According to this situation, therefore, dynamic programming model, which has been shown to be one of the most efficient tools for representing multi-stage decision making problem, has the ability to describe this situation. But an enterprise, the main goal of the production plan of coal mining enterprises is to maximize of economic benefit. Therefore, this paper develops a dynamic balance strategy to solve the conflict between the economy and the ecology in the coal mine group to improve production and sales plan.

2. Key Problem Statement
To develop a dynamic balance based multi-objective optimization model to balance the conflicts between the economy and the ecology, some necessary background knowledge needs to be introduced.

In the coal mining industry, there are some small scale enterprises, but the coal group is still in the absolute dominant position. Coal groups often have multiple mining area, which each mining area has different characteristics so that the drainage in different mining areas is not the same. On the one hand, the government should improve local economic development and at the same time they make every effort to protect the environment, especially mine waste, through a variety of scientific and rational policy measures. On the other hand, for coal companies with multiple mining areas, they also have the responsibility and obligation to protect the environment while developing their economy. As all collieries are independent of each other, indeed, the different mining area is not the same as the drainage coefficient, drainage capacity, cost of mining, maximum available amount and maximum storage capacity, so the market demand and price vary. Based on these facts, how to arrange coal mining plan to become one of the problems that the head office must face.

Based on what we discussed above, a dynamic multi-objective programming model was developed in the next section to study on the environmentally regional development of coal mining industry.

2.1. Model assumption
(1) The mining capacity of each colliery is unlimited.
(2) Coal over the minimum demand part can be sold.

2.2. Symbol Description
\( i \): Index for colliery, \( i = \Psi = 1,2,...,I \).
\( t \): Index for decision stage, \( t = \Theta = 1,2,...,T \).
\( X_i^t \): The production quantity of colliery \( i \) at stage \( t \).
\( Y_i^t \): Quantity that colliery \( i \) coal sales at the stage \( t \).
\( P_i^t \): Price that colliery \( i \) coal sales at the stage \( t \).
\( C_i \): Cost of coal products at colliery \( i \) at the stage \( t \).
\( h \): Unit storage charge of all collieries and all stage.
$S_i^t$: The storage quantity of colliery $i$ at the stage $t$.

$U_i$: Unit cost of waste water treatment of colliery $i$.

$E_i$: Per tonnes coal drainage coefficient for exploitation at colliery $i$.

$R_i^u$: The recoverable quantity of coal at colliery $i$ in the planning cycle.

$CS_i^\text{max}$: Maximum storage capacity of colliery $i$ at each stage.

$SS_i^\text{min}$: Safe stock quantity of colliery $i$ at each stage.

$D_i$: The number of market demand that colliery $i$ needs to meet at the stage $t$.

$EP_i$: Maximum waste water processing ability at colliery $i$ at the stage $t$.

$\alpha$: Attitude of the head office towards the waste water discharge reduction.

3. Mathematical Model

The dynamic multi-objective optimization model for balancing the conflicts between the economy and the ecology can be mathematically formulated as following model 1.

$$\text{max } F1 = (1 - \tau) \sum_{t=1}^{T} \sum_{i=1}^{I} P_i Y_i - \sum_{t=1}^{T} \sum_{i=1}^{I} C_i X_i - h \sum_{t=1}^{T} \sum_{i=1}^{I} S_i - \sum_{t=1}^{T} \sum_{i=1}^{I} U_i X_i E_i$$

$$\text{min } F2 = \sum_{t=1}^{T} \sum_{i=1}^{I} X_i E_i$$

$$\text{Subject to}$$

$$\sum_{i=1}^{T} X_i^t \leq R_i^u, \forall i \in \Psi$$

$$S_i^t = S_{i,t-1} + X_i^t - Y_i^t, \forall i \in \Psi, \forall t \in \Theta$$

$$S_i^t \geq R_i^u, \forall i \in \Psi, \forall t \in \Theta$$

$$Y_i^t \leq D_i^t, \forall i \in \Psi, \forall t \in \Theta$$

$$X_i Y_i \leq EP_i, \forall i \in \Psi, \forall t \in \Theta$$

$$X_i E_i \geq 0, \forall i \in \Psi, \forall t \in \Theta$$

$$Y_i^t \geq 0, \forall i \in \Psi, \forall t \in \Theta$$

$$Y_i^t \geq 0, \forall i \in \Psi, \forall t \in \Theta$$
Object function (1-1) represents the maximum economic benefits that the difference between the income of each coal mine and the consumption during the planning cycle, which includes the mining cost of various coal mines, inventory costs and waste water treatment costs. Object function (1-2) represents the total drainage which are the sum of the drainage at all stages of all coal mines. Constraint condition (1-3) shows that the amount of coal that can be mined by each coal mine during the planning cycle. Formula (1-4) is the state transition equation which represents the coal storage amount at the end of each stage of each colliery. Constraint condition (1-5) indicates that the sum of the inventory amount of last stage and the number of mining at current stage cannot exceed the maximum storage capacity. Constraint condition (1-6) indicates that the current number of sales of coal can not exceed the existing number. Constraint condition (1-7) indicates that the number of ending stocks should be above the number of safety stocks. Constraint condition (1-8) indicates that all types of coal sales at each stage must meet market demand. Constraint condition (1-9) indicates that the number of waste water treatment of each colliery at each stage of does not exceed their own processing capacity. Constraint condition (1-11) and (1-13) are the non-negative constraint of variable.

4. Case Study
To demonstrate the efficiency of the proposed method, a real world case study is given as follows.

4.1. Presentation of case problem
Founded in 1982, China Coal Pingshuo Group Co., Ltd is China's coal energy group limited company's core business, is China's largest coal production enterprises of a number of indicators ranked the leading level, is China's major thermal coal base and billion tons of coal Production base in the northwest of Shanxi Province established by state. Pingshuo Group is located in Shuozhou city, Shanxi Province and has a number of mining areas, this paper selected four major coal mines (i.e., i=1,2,...,I) as a research object: Jinggong(Jg) colliery, Antaibao(Atb) colliery, Anjialing(Ajl) colliery, Donglu(Dl) colliery).

4.2. Model Transformation
As Shuozhou city is a developing city in China, local governments need to make decision to ensure economic development. However, in the long run, economic development can not be at the expense of the environment. So the environment must be protected and the coal group has the responsibility to make a certain contribution to the protection of the environment. Pingshuo Group as a large coal mining enterprises in Shuozhou city, of course, need to make its own contribution to the local environmental protection.

Consequently, the Pingshuo Group need to put environmental protection targets into constraints to protect environment. Therefore, model 1 is transformed into the following model 2:

$$\begin{align*}
\max F1 &= (1 - \tau) \sum_{t=1}^{T} \sum_{r=1}^{I} P_{r} Y_{r} - \sum_{t=1}^{T} \sum_{i=1}^{I} \sum_{r=1}^{I} C_{i} X_{i} - \sum_{t=1}^{T} \sum_{i=1}^{I} S_{i} - \sum_{t=1}^{T} \sum_{i=1}^{I} U_{i} X_{i} E \\
\text{s.t.} & \sum_{t=1}^{T} \sum_{r=1}^{I} X_{r} E_{r} \leq F2^* \\
& (X,Y) \in \Pi
\end{align*}$$

where, $\pi$ is the flexible region of model 1, $\alpha$ is the attitude of the head office towards the waste water discharge reduction and $F2$ is the maximum drainage due to the optimal solution of the total drainage constraint is not taken into account in model 1. Therefore, the model 1 is already transformed into a single target model.
4.3. Data collection
Before we can calculate the model, we need the specific data of the parameters in the model, so we get the data according to the historical data of the coal mining group and by scientific prediction. Detailed data for this paper are given in the table 1, table 2 and table 3.

Table 1. The basic parameters of coal group.

|    | \( \tau \) | \( h \) (RMB / tonne) | \( SS_{i}^{\text{min}} \) (10^6 tonnes) |
|----|------------|------------------------|---------------------------------------|
|    | 0.17       | 0.1                    | 0.15                                  |

Table 2. Other parameters of different collieries of coal group.

| colliery | \( R_{i}^{u} \) (10^6 tonnes) | \( CS_{i}^{\text{max}} \) (10^6 tonnes) | \( E_{i} \) (m^3 / tonne) | \( U_{i} \) (RMB / m^3) | \( C_{i} \) (RMB / tonne) | \( EP_{i} \) (10^6 m^3) |
|---------|-----------------|----------------------------------|-----------------|-----------------|-----------------|-----------------|
| 1       | 4.03            | 1.5                             | 1.12            | 5               | 219             | 0.85            |
| 2       | 10.66           | 3.3                             | 1.02            | 4               | 213             | 1.98            |
| 3       | 13              | 4.2                             | 1.06            | 6               | 206             | 2.43            |
| 4       | 5.2             | 1.8                             | 1.13            | 7               | 197             | 1.22            |

Table 3. Coal prices and demand at different stages of different coal mines.

| month | demand (10^6 tonnes) | price (RMB / tonne) |
|-------|-----------------------|---------------------|
|       | colliery 1 | colliery 2 | colliery 3 | colliery 4 | colliery 1 | colliery 2 | colliery 3 | colliery 4 |
| demand (10^6 tonnes) | 0.7 | 0.6 | 0.5 | 0.8 | 0.4 | 0.5 | 1.7 | 1.5 | 1.2 | 1.4 | 1.3 | 1.4 | 0.9 | 0.7 | 0.6 | 0.8 | 0.6 | 0.7 |
| price (RMB / tonne)   | 594 | 589 | 575 | 599 | 591 | 580 | 545 | 538 | 535 | 549 | 547 | 528 | 529 | 515 | 510 | 540 | 532 | 526 |
|                       | 485 | 476 | 473 | 495 | 484 | 467 |      |      |      |      |      |      |      |      |      |      |      |      |      |

5. Results and Discussion
By entering the data into the proposed dynamic model and use lingo to find the solution of the model. First, without considering the effect of model 1's second target (total drainage) and the result of the model are shown in table 4.
Table 4. Result of the model 1 without considering objective of the total drainage.

| month | 1  | 2  | 3  | 4  | 5  | 6  |
|-------|----|----|----|----|----|----|
| \(X^t_i\) (10^6 tonnes) |    |    |    |    |    |    |
| colliery 1 | 0.76 | 0.76 | 0.76 | 0.76 | 0.49 | 0.50 |
| colliery 2 | 1.73 | 1.94 | 1.94 | 1.94 | 1.71 | 1.40 |
| colliery 3 | 2.29 | 2.29 | 2.29 | 2.29 | 2.13 | 1.70 |
| colliery 4 | 0.95 | 0.79 | 1.08 | 1.08 | 0.60 | 0.70 |
| \(Y^t_i\) (10^6 tonnes) |    |    |    |    |    |    |
| colliery 1 | 0.70 | 0.60 | 0.50 | 1.24 | 0.49 | 0.50 |
| colliery 2 | 1.70 | 1.50 | 1.20 | 3.15 | 1.71 | 1.40 |
| colliery 3 | 2.00 | 1.80 | 1.50 | 3.87 | 2.13 | 1.70 |
| colliery 4 | 0.95 | 0.70 | 0.60 | 1.65 | 0.60 | 0.70 |
| \(S^t_i\) (10^6 tonnes) |    |    |    |    |    |    |
| colliery 1 | 0.21 | 0.37 | 0.63 | 0.15 | 0.15 | 0.15 |
| colliery 2 | 0.18 | 0.62 | 1.36 | 0.15 | 0.15 | 0.15 |
| colliery 3 | 0.44 | 0.93 | 1.73 | 0.15 | 0.15 | 0.15 |
| colliery 4 | 0.15 | 0.24 | 0.72 | 0.15 | 0.15 | 0.15 |

Table 5. The total benefit and total drainage of coal group.

| \(\alpha\) | 1   | 0.95 | 0.9 | 0.85 |
|------------|-----|------|-----|------|
| Total benefit (10^9 RMB) | 7.51 | 7.17 | 6.78 | 6.38 |
| Total drainage (10^7 m^3) | 35.04 | 33.29 | 31.54 | 29.79 |

Based on the above table 4, we can see the number of mining, sales and ending stocks, and can calculate the total income, on this basis, the total drainage can be calculated, these result are shown in table 5.

According to the above result, we conclude that dynamic strategies can coordinate economic and environmental conflicts. From the table 4 and table 5, it is not difficult to find that the group decision prefer to the small drainage coefficient, high coal prices of coal mines when the parameter \(\alpha\) changes from 1 to 0.85, that is to say more and more stringent environmental protection strategy. In other words, coal group will still exploit more in the environment-friendly, high-yield mining area when the coal group is under more stringent environmental policy.

For coal groups, they have a number of subordinate coal mines to meet demand of the market and their own development. They may consider closing high-drainage, low-yield coal mines to make the local sustainable development Contribution when faced with decline in coal demand, that is to say, to maximize their own benefits under the constraints of total drainage regulated by the local government.

6. Conclusion

This paper presents a dynamic multi-objective programming model to deal with the conflict between coal and water in large scale coalfields of coal group. This method gives a comprehensive consideration to economy and environment from a long-term perspective. By using the proposed model, coal group will make decision to maximize their own benefits under the environmental constraints limited by the local policy. In addition, coal group need to balance the subordinate mining production to ensure maximum benefit in the case of total drainage restrictions. According to the results of the model calculation and discussion, coal enterprises should arrange low-drainage, high-yield mining production in order to ensure the long-term prosperity of enterprises and local sustainable development.
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