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The Application of Grey Clustering Decision in Determining the Rational Open-pit Limit of Mining

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Abstract—**The basic theory of grey decision-making and grey clustering decision is discussed in this paper. A kind of grey cluster assessment method for determining the rational open-pit limit of mining based on grey fixed weight clustering and white-ionization weight function is proposed. Grey clustering decision is used in determing the rational open-pit limit of mining, and it succeeds in obtaining the better and the optimal open-pit-stages limit design, which is obtained from the counting result of parameter-function method. The Application shows the method is practical for determining the rational open-pit limit of mining. A new method is provided in determining the rational open-pit limit of mining in this paper.**

I. INTRODUCTION

ALONG with the rapid development of computer technology and the application in various realms of sciences, the basic industry also has experienced fierce technological changes. In recent years, the computer and the automated technology already seeped in the mining industry [1]. However, we find that many problems of the mining engineering usually involve a lot of experience and analysis for uncertainties. Until now, the mining computation could not propose the persuasive quantitative relations for decision-making. This is because the mining geological conditions are complex, and production process and techniques are changeable. The existing mathematics and mechanics methods in solving mining problems are also imperfect [2]. So far, the understandings of mining rules and solutions for production problems mainly rely on project analogism without any direction of scientific theories. This is the fundamental reason leading to the lag in mining technology and hindering the development of mining industry.

As a new front-line science, the research on gray system has made progress in many aspects. Regardless of the fact that grey system is complex, fuzzy and nonstandard, the method applied is the Week Method. Whining using this method, the request for given information is weak; such information could be incomplete, qualitative and fuzzy. The more alternatives are considered when making a decision, the more prominent is grey system theory[3]. Research on the grey system theory and its application in mining industry, especially the application of grey decision-making in proposing mine, has shown great academic and practical significance.

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II. THE KEY PROBLEM

Since long ago, the design of reasonable open-pit limits mainly depends on manual work. By analogy or borrowing ideas from the existing information and experience, the actual alternatives are limited. It's very hard to define applicable standards for the appropriate open-pit limits. Under this circumstance, designers' experiences play decisive role. So such a traditional method based on experience to define the mining limit is inaccurate; furthermore, since in the designing stage, designers only conduct some qualitative investigation and superficial quantitative computation, they can not prove whether the proposals are reasonable, without mentioning which proposal is optimal.

Regarding mining in installments, in order to ensure the sustainable mining, based on the present technical and economical conditions, the most important work is to determine the reasonable open-pit limits. Usually, we apply parametric function method to obtain many alternatives. However, when considering the effective factors, such as quantity of underground ore, grade of the underground ore, quantity of rock, the ratio of rock's and high grade ore's quantity and the total benefit, it's hard to determine the reasonable open-pit limits by applying the existing decision-making techniques. By now, finding a reasonable and feasible decision-making technique becomes the key factor in determining the open-pit limits.

III. THE BASIC PRINCIPAL OF GREY CLUSTERING DECISION-MAKING

Decision-making is a process that bases on actual situation and predetermined goal and determines which action should be taken. Grey decision is the decision-making model including grey element or decision-making model with the combination of common decision-making model and grey decision-making model. Grey system mainly studies on selection of important method [3].

The grey clustering decision-making is applied to evaluate the decision-making objects by using many different indicators comprehensively, so as to determine whether the decision making objects meet the given accepting and rejecting standards. Its mathematical model [4] is:

Suppose that there are n decision objectives and s grey classes. $x_{ij}(i=1,2,\cdots,n; j=1,2,\cdots,m)$ is the decision objective i's quantitative evaluation concerning decision indicator j; $f_j^k(x_{ij})(j=1,2,\cdots,m;\ k=1,2,\cdots,s;)$ is the k-subclass white-ionization weight function of indicator j[6]; $\eta_j(j=1,2,\cdots,m)$ is the comprehensive decision weight of decision indicator j, here $\sum_{j=1}^{m}\eta_j=1$, then

$$\sigma_i^k=\sum_{j=1}^{m} f_j^k(x_{ij})\times\eta_j \tag{1}$$

is called the decision coefficient when the decision objective i belongs to k-grey class.

$$\sigma_i=(\sigma_i^1,\sigma_i^2,\cdots,\sigma_i^s);\ i=1,2,\cdots,\ \text{n} \tag{2}$$

is called the decision coefficient vector of decision objective i.

If $\max\limits_{1\le k\le s}\{\sigma_i^k\}=\sigma_i^{k^*}$,then i, the decision objective belongs to grey class k^*.

Suppose $\max\limits_{1\le k\le s}\{\sigma_{i_1}^k\}=\sigma_{i_1}^{k^*}$, $\max\limits_{1\le k\le s}\{\sigma_{i_2}^k\}=\sigma_{i_2}^{k^*}$, $\sigma_{i_1}^k>\sigma_{i_2}^k$,then among grey classes k^*,the decision-making objective i_1 is better than objective i_2.

Suppose that $\max\limits_{1\le k\le s}\{\sigma_{i_1}^k\}=\sigma_{i_1}^{k^*}$, $\max\limits_{1\le k\le s}\{\sigma_{i_2}^k\}=\sigma_{i_2}^{k^*}$, $\cdots$, $\max\limits_{1\le k\le s}\{\sigma_{i_l}^k\}=\sigma_{i_l}^{k^*}$,in addition,

$$\sigma_{i_1}^k>\sigma_{i_2}^k>\sigma_{i_3}^k>\cdots>\sigma_{i_l}^k\ ,$$

If the number that decision-making grey classes k^* contain is l_1, we call that l_1 $i_1,i_2,i_3,\cdots,i_{l_1}$ are grey classes k^*'s input objectives and $i_{l_1+1}, i_{l_1+2}, i_{l_1+3},\cdots,i_l$ are grey classes k^*'s alternative objectives.

IV. AN EXAMPLE OF APPLYING GREY CLUSTERING DECISION-MAKING TO DETERMINE THE OPEN-PIT LIMITS

When we design Jin Duicheng molybdenum ore open-pit limit, based on the six proposals which are searched though the parametric function, suppose that there are five decision-making indicators; they are the quantity of milling in ore (high grade ore), grade of milling in ore, quantity of rock (including quantity of not milling in ore (low grade ore) and rock), the ratio of rock's and milling in ore's quantity , the total benefit (see Exhibit 1). Then we make clustering decisions according to the three grey classes --- basic proposal, feasible proposal and optimal proposal.

Statistics for evaluation indicator
Exhibit 1

proposal	Quantity of milling in ore	Grade of milling in ore	Quantity of rock	The ratio of rock's and milling in ore's quantity	Total benefit
a1	11.9	97.6	7.1	60.8	24.2
a2	47.6	95.2	24.5	52.7	97.8
a3	64.7	90.8	40.2	63.6	92.2
a4	78.8	91.1	57.9	75.2	91.1
a5	89.6	91.0	77.0	88.0	73.2
a6	98.1	91.5	95.7	99.9	54.2

In Exhibit 1, since the effect values of decision-making indicators are converse, namely, the greater the three decision-making indicators --- quantity of underground ore, grade of underground ore and total benefit are, the better; however, the less effect values of quantity of rock and the ratio of rock's and high grade ore's quantity indicators, the better. So the two indicators, quantity of rock and the ratio of rock's and high grade ore's quantity, need to be transformed equivalently and this paper applies the following transformation formula:

$$x_{ij}^*=\max_{1\le i\le 5}\{x_{ij}\}+\min_{1\le i\le 5}\{x_{ij}\}-x_{ij}$$
$$(i=1,2,3,4,5;\quad j=3,4;) \tag{3}$$

here:

i ——scheme i;

j ——scheme j.

After the two indicators, quantity of rock and the ratio of rock's and milling in ore's quantity in Exhibit 1, have been transformed equivalently, we get the quantitative evaluation matrix C* of the five decision-making indicators:

$$C^* = \begin{bmatrix} x_{11} & x_{12} & x_{13} & x_{14} & x_{15} \\ x_{21} & x_{22} & x_{23} & x_{24} & x_{25} \\ x_{31} & x_{32} & x_{33} & x_{34} & x_{35} \\ x_{41} & x_{42} & x_{43} & x_{44} & x_{45} \\ x_{51} & x_{52} & x_{53} & x_{53} & x_{55} \\ x_{61} & x_{62} & x_{63} & x_{64} & x_{65} \end{bmatrix}$$

$$= \begin{bmatrix} 11.9 & 97.6 & 95.7 & 91.8 & 24.2 \\ 47.6 & 95.2 & 78.3 & 99.9 & 97.8 \\ 64.7 & 90.8 & 62.6 & 89.0 & 92.2 \\ 78.8 & 91.1 & 44.9 & 77.4 & 91.1 \\ 89.6 & 91.0 & 25.8 & 64.5 & 73.2 \\ 98.1 & 91.5 & 7.1 & 52.7 & 54.2 \end{bmatrix}$$

Suppose that f_j^k as white-ionization weight functions of the j decision-making indicators concerning the k grey classes, $f_j^k \in (0,1)$,there are three forms of white-ionization weight function[7], shows as Fig.1. Fig.2 as the white-ionization weight function of each grey class.

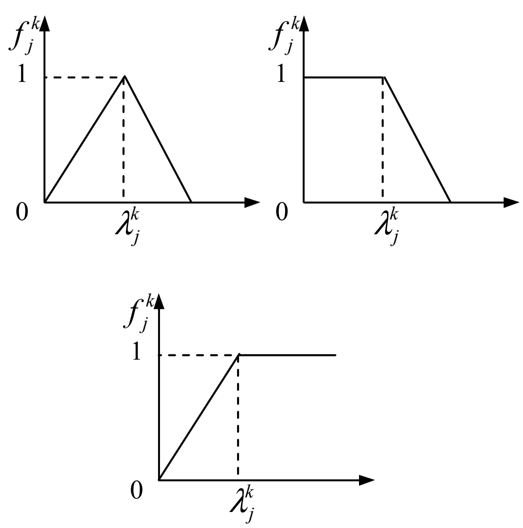

Fig.1 The forms of white-ionization weight function

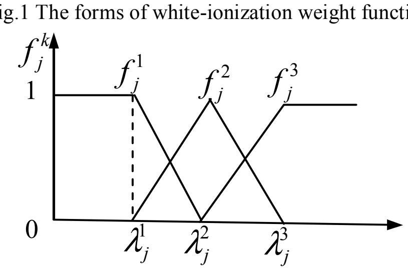

Fig.2 The white-ionization weight function of each grey class

Suppose that white-ionization weight functions of the five decision-making indicators concerning the three grey classes are, respectively

$$f_j^1[90,95,-,-],\ f_j^2[75,85,-,95],\ f_j^3[-,-,65,80]$$

$$f_j^1(x) = \begin{cases} 0 & , \quad x < 90 \\ \dfrac{x-90}{5} & , \quad 90 \le x \le 95 \\ 1 & , \quad x > 95 \end{cases}$$

$$f_j^2(x) = \begin{cases} 0 & , \quad x < 75 \\ \dfrac{x-75}{10} & , \quad 75 \le x \le 85 \\ \dfrac{95-x}{10} & , \quad 85 < x \le 95 \\ 0 & , \quad x > 95 \end{cases}$$

$$f_j^3(x) = \begin{cases} 0 & , \quad x < 0 \\ 1 & , \quad 0 \le x \le 65 \\ \dfrac{80-x}{15} & , \quad 65 < x \le 80 \\ 0 & , \quad x > 80 \end{cases}$$

Here j=1,2,3,4,5; Furthermore, the white-ionization weight functions with different terms are identical.

And then adopt evaluation and experience from mining experts; the panel of experts evaluates each indicator synthetically and marks for each indicator based on productive practice and theories; and finally, the indicators' weights of decision-making are as follows:

$$\eta_1 = 0.15,$$
$$\eta_2 = 0.10,$$
$$\eta_3 = 0.15,$$
$$\eta_4 = 0.30,$$
$$\eta_5 = 0.30;$$

$$\begin{aligned} \sigma_1^1 &= \sum_{j=1}^{5} f_j^1(x_{1j}) \times \eta_j = f_1^1(x_{11}) \times \eta_1 + f_2^1(x_{12}) \times \eta_2 \\ &+ f_3^1(x_{13}) \times \eta_3 + f_4^1(x_{14}) \times \eta_4 + f_5^1(x_{15}) \times \eta_5 \\ &= f_1^1(11.9) \times 0.15 + f_2^1(97.6) \times 0.10 + f_3^1(95.7) \\ &\times 0.15 + f_4^1(91.8) \times 0.30 + f_5^1(24.4) \times 0.30 \\ &= 0 \times 0.15 + 1 \times 0.10 + 1 \times 0.15 + \frac{91.8-90}{5} \\ &\times 0.30 + 0 \times 0.30 \\ &= 0.358 \end{aligned}$$

Likewise, we will get:

$$\sigma_1^2 = \sum_{j=1}^{5} f_j^2(x_{1j}) \times \eta_j = 0.096$$

$$\sigma_1^3 = \sum_{j=1}^{5} f_j^3(x_{1j}) \times \eta_j = 0.450$$

So

$$\sigma_1 = (\sigma_1^1, \sigma_1^2, \sigma_1^3) = (0.385, 0.096, 0.450)$$

Similarly, we can get:

$$\sigma_2 = (\sigma_2^1, \sigma_2^2, \sigma_2^3) = (0.700, 0.049, 0.167)$$

$$\sigma_3 = (\sigma_3^1, \sigma_3^2, \sigma_3^3) = (0.148, 0.306, 0.300)$$

$$\sigma_4 = (\sigma_1^1, \sigma_1^2, \sigma_1^3) = (0.088, 0.285, 0.214)$$

$$\sigma_5 = (\sigma_5^1, \sigma_5^2, \sigma_5^3) = (0.030, 0.121, 0.586)$$

$$\sigma_6 = (\sigma_6^1, \sigma_6^2, \sigma_6^3) = (0.180, 0.035, 0.700)$$

From the following equations,

$$\max_{1 \le k \le 3}\{\sigma_1^k\} = 0.450 = \sigma_1^3$$

$$\max_{1 \le k \le 3}\{\sigma_2^k\} = 0.700 = \sigma_2^1$$

$$\max_{1 \le k \le 3}\{\sigma_3^k\} = 0.306 = \sigma_3^2$$

$$\max_{1 \le k \le 3}\{\sigma_4^k\} = 0.285 = \sigma_4^2$$

$$\max_{1 \le k \le 3}\{\sigma_5^k\} = 0.586 = \sigma_5^3$$

$$\max_{1 \le k \le 3}\{\sigma_6^k\} = 0.700 = \sigma_6^3$$

We know, proposal 2 of open-pit limits is the best one; and number 3 and 4 are feasible proposals; number 1, 5 and 6 are basic proposals. Although proposal 3 and four are feasible proposals, they have difference and proposal 3 is better than 4. If there is only one proposal which will be put in practice, we should chose proposal number 2 as the most reasonable open-pit limit proposal.

V. CONCLUSION

This paper applies the basic principles of grey decision-making theory and grey clustering decision-making theory, makes grey clustering decisions for the open-pit limits obtained through parametric function and gets the optimal and feasible proposals for mining in installments. In order to make sure that the open-pit limits are reasonable, this paper applies multi mining limit proposals, discusses the influencing factors --- quantity of milling in ore, grade of milling in ore, quantity of rock (including quantity of not milling in ore (low grade ore) and rock), the ratio of rock's and milling in ore's quantity, the total benefit, and provides new decision-making train of thought and methods when determining the reasonable open-pit limits.

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