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Fuzzy comprehensive evaluation of mining geological condition in the No.9 coal seam, Linhuan coal mine, Huaibei Coalfield, China

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Abstract

Many factors influence coal mining, such as coal seams, structure condition, lithologic characteristics of roof and floor, and so on. The mining technology and developing methods are not the same for different geological conditions. Based on mining geological conditions and the actual situation of the coal production in Linhuan coal mine, Huaibei Coalfield, combining the fuzzy comprehensive evaluation theory and method, this paper puts forward a kind of practical and reasonable structure system-evaluation prediction index system for fully-mechanized coal mining block. This system is applied to study mining geological condition in the No.9 coal seam Linhuan coal mine, Huaibei Coalfield, China, and make comprehensive evaluation and prediction for mining geological conditions of different blocks.

*Keywords:*Coal seam; mining geological condition; fuzzy comprehensive evaluation; structure

1. Introduction

Fully-mechanized coal mining has become the development direction of coal industry, for a series of advantages, such as high yield, high efficiency and low cost, ect. In recent years, fully-mechanized coal mining unit is applied by more and more bureau and mining, the production efficiency is improved greatly. However, efficiency of fully-mechanized coal mining is not fully brought into play according to the actual situation of many bureaus and mines. Some mines even play the role of opposite effect. Besides other control factors, the quality of geological condition in mine is an important aspect. In order to fully exert more effectively, geological factors influencing fully-mechanized coal mining, especially medium-small-

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sized structures and coal seam' changes, on which the systematic study and comprehensive evaluation is needed. Evaluation on mining geological condition in block is with a series of fuzzy feature, Which provides the possibility for applying the fuzzy mathematics method for evaluation prediction and research. As a kind of non-linear evaluation method, fuzzy comprehensive evaluation method has been widely used in theoretical analysis and engineering application [1-6]. Based on fuzzy comprehensive evaluation theory, mining geological factors which affect high yield and high efficiency is organically combined, and several indexes are integrated, accordingly complex degree of mining geological condition for high yield and high efficiency is generally established. The basic model of fuzzy comprehensive evaluation is used, the quantitative evaluation index of mine geological condition is determined by the system, the mine is divided into many units according to certain specifications, corresponding value of each index in different units is counted, consequently types of complicated degree about mining geological condition in different units is given by comprehensive evaluation by means of the electronic computer, which is its essence. On this basis, combining the geological rules and other methods, fuzzy comprehensive evaluation method make with forecasting on complexity of mining geological conditions of different blocks by analogy, so as to reasonably disposal excavate face and choose corresponding mining.

2. Fuzzy comprehensive evaluation principle

The essence of fuzzy comprehensive evaluation is a fuzzy transform. Let the set of n factors considered in evaluation be $U = \{u_1, u_2, \cdots, u_n\}$. Let the set of m comments be $V = \{v_1, v_2, \cdots, v_m\}$. Let the set of i factor be $R = \{r_{i1}, r_{i2}, \cdots, r_{im}\}$,which is regarded as a fuzzy subset on U.With riK presenting the grade of membership of factor ui aiming at comment vK ,The fuzzy relation between factor full sets and comment full sets can be described by the evaluation matrix R:

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ r_{n1} & r_{n2} & r_{n3} & r_{nm} \end{bmatrix}_{n\times m} \tag{1}$$

when an object is evaluated roundly, role of each factor for evaluating the level must be considered. The evaluation function can be viewed as the fuzzy subset of factor full sets U. It is $A = \{a_1, a_2, \cdots, a_n\}$, where $\sum_{i=1}^{n} a_i = 1, ai \geq 0$,with a_i presenting degree of membership of v_i aiming at A. It is measurement of function the single factor u_i act for judging the level .It represents ability of evaluation level on the basis of single factor,and its numerical value can be given according to experience.

Let B as synthesized by A and R be the final evaluation of an object with many factors considered by the valuators.This process is called as fuzzy comprehensive evaluation, whose computing formula is: $B = A \circ R$. Namely,

$$B = \begin{bmatrix} \underline{B_1} \\ \underline{B_2} \\ \vdots \\ \vdots \\ \underline{B_n} \end{bmatrix} = \begin{bmatrix} \underline{A_1} & \circ & \underline{R_1} \\ \underline{A_2} & \circ & \underline{R_2} \\ \vdots & & \vdots \\ \vdots & & \vdots \\ \underline{A_n} & \circ & \underline{R_n} \end{bmatrix} \quad (2)$$

Similarly, multi-grade fuzzy comprehensive evaluation model can be derived, because comments of its elements and administrative levels are consistent with comments. In the fuzzy synthetic process, different evaluation results are educed as a result of synthetic types. In this model, add- multiply operation by real number is adopted, which is finer than “∨， ∧” [7].

A level fuzzy subset obtained through comprehensive evaluation is $B = b_1/u_1 + b_2/u_2 + \cdots + b_n/u_n$, (where j=1,2,…,m), with b_j presenting degree of membership of b_j aiming at B.

Generally, a correction method where maximum membership degree criterion is adopted and other membership’s contribution is considered is adopted.

Fuzzy comprehensive evaluation based on the theory and method of fuzzy mathematics is a new method to solve a problem, which affects comprehensive evaluation on geological factors of fully-mechanized coal mining. The evaluation procedures can be summarized briefly as follows:

(1) Determine the evaluation index, establish the set of factors $U = \{u_1, u_2, \cdots, u_n\}$. The set of factors is a common set ,which is comprised of various factors that influence the geological condition of fully-mechanized coal mining. That is to say, the factor itself can be fuzzy, but also not fuzzy. However, subordinate relationship they aiming at the set of factors is clear.

(2) Calculate corresponding weight coefficient of each index in the evaluating process, weight vector is formed in the set of factors U is $A = \{a_1, a_2, \cdots, a_m\}$, where a_i presents weight of factor i in the evaluation.

A weight set of A can be determined by various methods for mutual validation and complement, such as Expert evaluation method, Correlation coefficient method and Grey correlation method. Determinate weight coefficient is operated by means of it, to be validated by index of actual fully-mechanized coal mining condition after the evaluation result is obtained. If verification is not satisfactory, each index weight coefficient is selected again .Weight coefficient of different regions or different coal seams in the same region needs to be adjusted timely.

（3）Choose evaluation objects and determine the set of comments. According to partition ahead of the geological block, evaluation units are determined. That is evaluation about the object set of $u_1, u_2, \cdots, u_n$ aiming at comments level, which constitutes the fuzzy relation matrix of $R = (r_{ij})_{m \times n}$.

(4) Select proper fuzzy synthetic operator, establish a mathematical model of comprehensive evaluation, and solve for basic results of the evaluation. According to the maximum membership degree and adjusting principles, the final evaluation results can be obtained, and accordingly fully-mechanized coal mining conditions of each assessment unit or block are determined.

3. Partition of evaluation objects and evaluation grade

According to qualitative evaluation of the mine geological rules and the mining geological conditions, the comments sets of {V} in quantitative evaluation of fully-mechanized coal mining geological conditions all adopt various factors, whether total comment sets or factor comments subsets. According to whether or not complexity levels of the mining geological conditions adapt to comprehensive mechanized mining method, comments are plotted into four types. Namely:

$$V = \{V_1, V_2, V_3, V_4\} \tag{3}$$

where,
V1——Suitable for fully-mechanized conditions;
V2——Rather suitable for fully-mechanized conditions;
V3——Not rather suitable for mining conditions;
V4——Not suitable for mining conditions.

That is to say, $V = \{v_1, v_2, \cdots, v_m\}$ equal to {Suitable for fully-mechanized conditions，Rather suitable for fully-mechanized conditions，Not rather suitable for mining conditions，Not suitable for mining conditions}，where $m = 4$. v_1、v_2、v_3 and v_4 are marked off according to each membership degree of u_i. They are marked as follows: $u_i < 0.25$, $0.25 \le u_i < 0.5$, $0.5 \le u_i < 0.75$, $u_i \ge 0.75$, when the point respectively vests in v_1, v_2, v_3, and v_4. According to fuzzy evaluation result of single factor, comprehensive evaluation matrix is formed, the evaluation results are educed through choosing appropriate fuzzy synthetic operator. On this basis, according to each evaluation unit of b_j value, based on the maximum membership degree principle ,and synthetically considering other membership contribution, specific partition method are as follows:

when $b_j = \max\{b_1, b_2, b_3, b_4\} \ge 0.5$, the maximum membership degree principal is adopted. Now the evaluation unit is the region of v_j .

when $b_j = \max\{b_1, b_2, b_3, b_4\} < 0.5$,the weighted average method is adopted. Namely,

$$Q = \frac{\sum_{j=1}^{m} (j \bullet b_j^k)}{\sum_{j=1}^{m} b_j^k} \tag{4}$$

4. Establishment of the evaluation index

The geological factors in fluencing coal mining are variety,such as structure condition, coal seam condition, roof and floor condition and each factor of other mining geological conditions.Therefore, some principles should be followed when evaluation indexes are selected. Geological factors choosed should have characteristics as follows:

- Feasibility. The data needed by the factors can be determined by drilling and exploration data
- Representative. This factor has obvious characteristic, which has obvious effect on the system.
- Independence. Various factors will not be impacted repeatedly.
- Use a zero before decimal points: “0.25”, not “.25”.

5. values of evaluation index and determination of membership

The values of evaluation index and determination of membership in comprehensive evaluation is the key and difficulty.Due to the complexity and diversity of the geological conditions, the selection of evaluation index and determination of membership must be close to the actual situation in research region. Therefore, based on systemic analysis of geological conditions and geological factors of fully-mechanized mining at home and abroad, fully utilizing the actual situation of the coal production in huaibei linhuan coal mine, evaluation indexes are summarized,which reflects reality Scientificly and quantitatively but also are popular and practical. When the membership function for evaluation indexes is determined, method of establishing linear function is adopted. Membership function curves are shown in Fig.1and Fig.2.

The positive membership function curve (The values of evaluation indexes are positively related with the set of comments.) is shown in Fig.1.

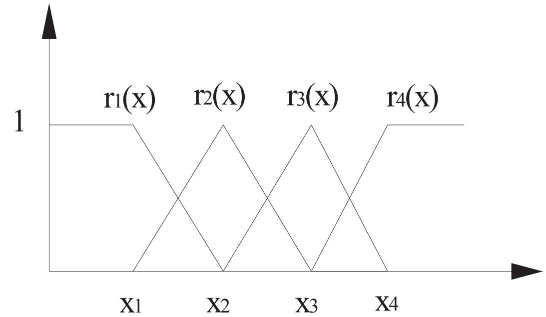

Fig.1. The positive membership function curve.

The converse membership function curve (The values of evaluation indexes are conversely related with the set of comments.) is shown in Fig.2.

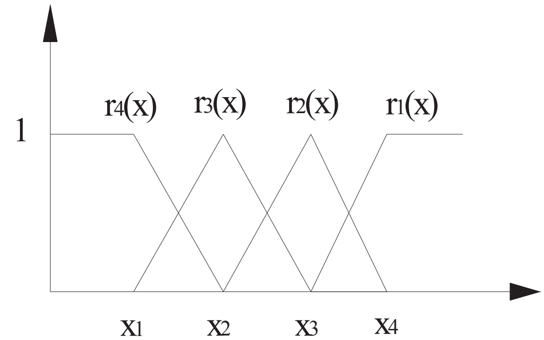

Fig.2. The converse membership function curve.

6. Weight distribution of evaluation index

What is called weight, which refers to importance degree of an evaluation factor in the whole system. According to mining geological conditions and production experience for many years in Linhuan coal mine, Huaibei Coalfield, weight of each factor is obtained by adopting hierarchical analysis method from expert evaluation. As shown in Tab.2:

7. Analysis of evaluation results

According to b_j value of each assessment unit, based on the maximum membership principle, and combining the weighted average method, comprehensive evaluation results of each assessment unit from the No-9 coal seam in Linhuan mine are shown in Table 3.

According to the calculation results in table 3, the ownership of fully-mechanized geological conditions of each evaluation block in No-9 coal seam can determined as follows:

Region type Ⅰ, which is Suitable for fully-mechanized :region D、region and region J;

Region type Ⅱ leaning Region type Ⅰ, which is rather suitable leaning suitable for fully-mechanized: region B、region E、region I、region K and region L;

Region type Ⅱ, which is rather suitable for fully-mechanized: region H;

Region type Ⅱ leaning Region typeⅢ, which is rather suitable leaning not rather suitable for fully-mechanized: region C、region F;

Region typeⅣ, which is not suitable for fully-mechanized: region A.

As seen from the above calculation results of comprehensive evaluation, mining geological complexity in different regions of the No.9 coal seam in Linhuan coalmine has the difference, with regions of good and not good fully-mechanized geological conditions (figure 3).Regions with good mining geological condition include: region D、region G、region J、region B、region E、region I、region K and region L; fully-mechanized geological conditions are common in region H、region C and region F; and region A with poor fully-mechanized geological conditions is not suitable for fully-mechanized.

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TABLE I Weight distribution of evaluation index of the No.9 coal seam in Linhuan coalmine

Evaluation factor	symbol	factor weight
coal seam theckness	u_{11}	0.12
coal seam obliquity	u_{12}	0.18
coal seam theckness variation coefficient	u_{13}	0.18
coal seam theckness recoverable index	u_{14}	0.12
fault density	u_{21}	0.20
breaking strength	u_{22}	0.20

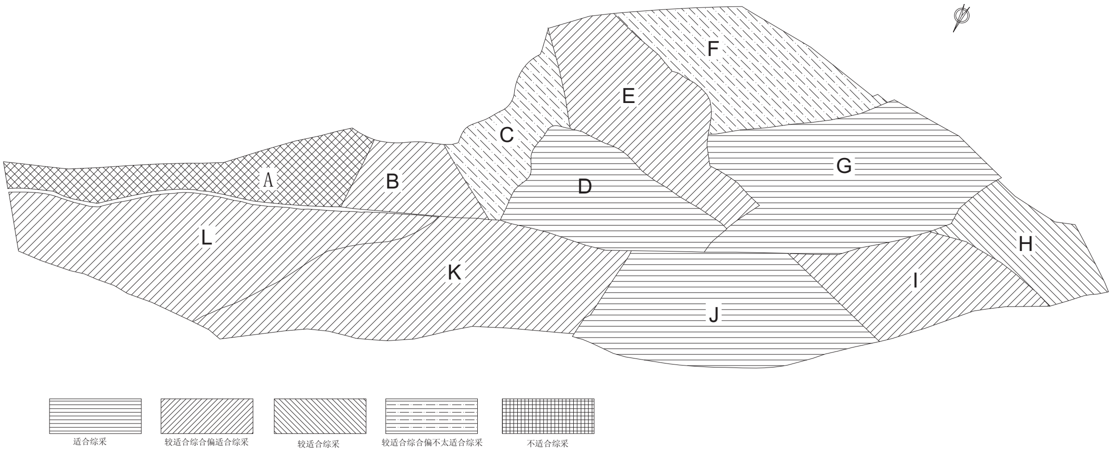

Fig. 3. Comprehensive evaluation figure fully-mechanized geological conditions in the No.9 coal seam in Linhuan mine

TABLE II . Evaluation index system

evaluation index of fully-mechanized mining geological conditions	***coal seam conditions（u1）***	***coal seam theckness (u11)***
		coal seam obliquity (u12)
		coal seam theckness recoverable index (u13)
		coal seam theckness variation coefficient (u14)
	Structure conditions (u2)	***fault density (u21)***
		breaking strength coefficient (u22)

TABLE III Fuzzy comprehensive evaluation results of each assessment unit in the No.9 coal seam in Linhuan coal mine

evaluation unit	evaluation results						
	b1	*b2*	*b3*	*b4*	*Q*	*region type*	*weighted average method*
A	*0.203*	*0.217*	*0.065*	*0.515*	*3.379*	*Ⅳ*	*not suitable for mining conditions*
B	*0.424*	*0.139*	*0.305*	*0.184*	*1.939*	*Ⅱleaning Ⅰ*	*rather suitable leaning suitable*
C	*0.440*	*0.060*	*0.117*	*0.383*	*2.318*	*ⅡleaningⅢ*	*rather suitable leaning not rather suitable*
D	*0.960*	*0.040*	*0.000*	*0.000*	*1.002*	*Ⅰ*	*suitable for mining conditions*
E	*0.425*	*0.281*	*0.174*	*0.180*	*1.734*	*Ⅱleaning Ⅰ*	*rather suitable leaning suitable*
F	*0.271*	*0.301*	*0.305*	*0.122*	*2.182*	*ⅡleaningⅢ*	*rather suitable leaning not rather suitable*
G	*0.528*	*0.272*	*0.000*	*0.200*	*1.493*	*Ⅰ*	*suitable*
H	*0.391*	*0.065*	*0.244*	*0.228*	*2.039*	*Ⅱ*	*rather suitable*
I	*0.382*	*0.366*	*0.238*	*0.014*	*1.735*	*Ⅱleaning Ⅰ*	*rather suitable leaning suitable*
J	*0.700*	*0.300*	*0.000*	*0.000*	*1.156*	*Ⅰ*	*suitable*
K	*0.330*	*0.480*	*0.010*	*0.180*	*1.881*	*Ⅱleaning Ⅰ*	*rather suitable leaning suitable*
L	*0.440*	*0.327*	*0.096*	*0.137*	*1.553*	*Ⅱleaning Ⅰ*	*rather suitable leaning suitable*