The Application of Fuzzy Analytic Hierarchy Process for Thick Coal Seam Mining Methods in China

Wang Lei, Yang Yang, Cheng Huimin

Faculty of Resource & Safety Engineering, China University of Mining and Technology (Beijing), Beijing, 100083, China

Abstract

In China's energy reserves and production, the thick coal seams account for almost 45 per cent of national coal resources. It is in dominant position for coal mining. At present, mining methods of thick coal seam include slicing, top coal caving and large cutting height. Although these methods have achieved great development and applied in many mining area, there are subjectivity and one-sideness in the process of mining methods selection, various factors are not considered, therefore, mining method that is final determined can not be fully convinced, it will bring some dangers to mining, and cause hazardous accidents. In order to solve these problems, four factors that affect selection of mining methods are presented in this paper, the evaluation model of thick coal seam mining methods are constructed based on Fuzzy Analytic Hierarchy Process. This model is more scientitic and reasonable than traditonal choice in coal mining. It can not only enhance recovery rate of coal resource, decrease accident of coal mining, but also ensure steady growth of social economy. In this paper, FAHP model is applied in shendong mining area to evaluate 7~9m thick coal seam mining methods, and achieving satisfactory results.

Key words: optimization model, FAHP, thick coal seam, mining methods

1.Introduction

Coal resources are the material basis of human survival, while it is the main energy resource in China, which is the security of society and economic development and accounted for 70% of

primary energy consumption. The middle and thick coal seam account for 45% of China's proved reserves, which is considered the primary mineable coal bed. Therefore, it's necessary to make further research of selecting the rational mining method[1]. Because this is not only related to the steady economic growth, but also related to mine safety and environmental protection. The principles of scientific mining, green mining, and sustainable development need to be followed in the mining process. The paper uses fuzzy comprehensive evaluation method to compare the thick seam mining methods and constructs of the preferred model for thick seam mining methods in geological conditions, technical level, economic indicators and safety factors. The model is applied to Shendong mining area 7~9m seams and further illustrates the objective reasonableness of the model.

2.The selection problem based on fuzzy multi-objective mining method

Currently, there are three mining method for thick seams: mining with large mining height, top coal caving mining and slice mining. In the coal mining process, there are many factors that influence the choice of mining method and choosing the relatively important factors to build the model will benefit the assessment and the decision of preferred mining method. The selected factors can be divided into two categories: quantitative index and qualitative index. Quantitative index means that factors affecting mining method selection can be represented in digital form and calculated. Qualitative index means that influencing factors can be only described by the language in the evaluation process, and such index need to be translated into quantifiable index to be calculated. Therefore, the selecting of mining method should be based on an integrated decision-making process of multi-level and multi-objective factors, which combines qualitative and quantitative of the various impact factors for the mining method and transforms the different dimension evaluation index into dimensionless values for comparative analysis. This paper summarizes and defined 31 factors affecting the choice of thick seam mining methods, using the principle of AHP and fuzzy comprehensive evaluation to calculate the weight and membership of the model,

which makes thick mining method more scientific and rational[2,3].

2.1 The theory of AHP

The theory of AHP is raised by American operations researcher T.L.Saaty in 1970s, which is grouping and transforming the complex hierarchical relationships to hierarchical structure. Therefore, the model is more simple and easy to be calculated[4,5].

(1) Build hierarchical model

Group the factors depending on the different attributes and divide factors of the same or similar attribute into a group. The first layer is the target layer, which is the problem to be solved. The second layer is the rule hierarchy, which is the concrete manifestation of the decision objectives. The third layer is the subsidiary level, which is a further explanation of the rule hierarchy. The bottom layer is the scheme, which is an alternative solution. Diagram is as follows:

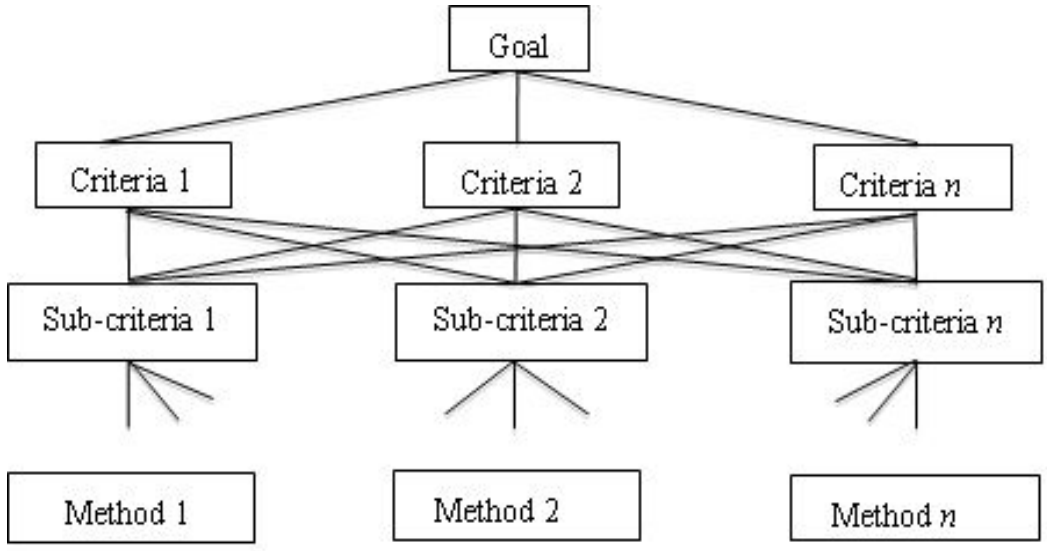


Fig. 1 Hierarchical model for assessing mining methods.

(2)Build the comparison matrix

Comparison matrix is constructed based on the importance of the lower layer to the upper factors. The constructed judgment matrix is: $A=(a_{ij})_{n*n}$, and the value judgment of a_{ij} is as follows:

Tab 1 Pair-wise comparison scale

Score	Definition
1	Equal importance
3	Slightly importance
5	Strongly importance
7	Very strongly importance
9	Extremely importance
2，4，6，8	Intermediate values between the two adjacent judgment

(3) The calculate of the weight

According to the judgment matrix and using the method of characteristic root calculate the weight of underlying factors to upper factors. The formula is: $AW = \lambda_{\max W}$. Make the weights normalize after obtaining.

(4)Consistency test

In the progress of constructing the judgment matrix based on the criteria scale, the judgment of result is susceptible to subjective factors, which cause the bias of eigenvalue. Therefore, The results need to be tested for consistency. The formula is: $\mathbf{C.R.} = \frac{C.I.}{R.I.}$, it's acceptable when the value of C.R. is less than 0.1, otherwise , reject. Where I can get a different value determined according to the order through table.

(5) Sort

The step is only a single level of calculation, but the end result needs to be synthesized weights to obtain preferred solution.

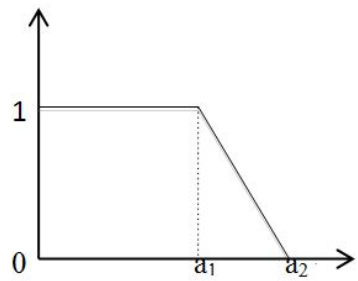
2.2 Fuzzy comprehensive evaluation

The method of fuzzy comprehensive evaluation can be divided into single -level and multi -level evaluation. There are more factors influencing the mining method selection in coal mining, so the paper uses multi-level evaluation method to evaluate. The evaluation procedure is as follows[6]:

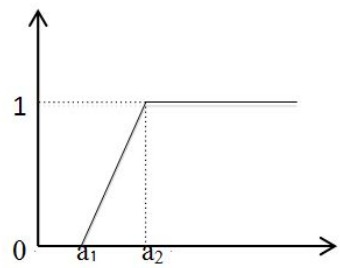
(1) Determine the membership function

The grade judgment of qualitative index is divided into four and assigned 0.4, 0.3, 0.2, 0.1, which represent " excellent, good, fair, poor." Quantitative index is determined by the distribution function.

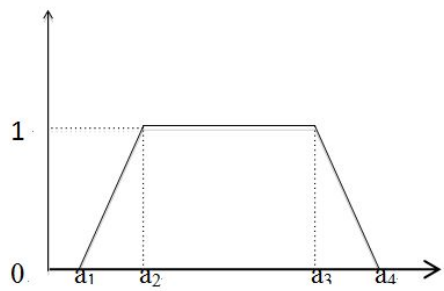
This paper selected trapezoidal and semi-trapezoidal distribution function to calculate, Diagram is as follows:



(a)low type



(b)lager type



(c)middle type

Fig.2 Trapezoid and semi-trapezoid distribution function.

3. Engineering example

Shendong coal mining area is located in Daliuta community, Shenmu town, Yulin district, Shanxi province, which is a major coal-producing regions and the first annual amount of 100 million tons or more of coal mining of China. Shendong coal mining area has simple

(2) Classification factors and establish the evaluation stage

Factors divided by attributes into $U_i=\{u_{i1}, u_{i2}, u_{i3}\ldots\ldots u_{im}\}$, where i=1,2,3……m. Evaluation sets generally have the only one , which is expressed as: $V=\{v_1,v_2,v_3\ldots\ldots v_p\}$.

(3)Constructed the fuzzy weight vector

The weight index of factor u_{ij} in the j^{-th} of class I is w_{ij}, the factors set of weights is: $W=(W_1,W_2,W_3\ldots W_m)$.

(4) Single fuzzy evaluation

Make u fuzzy transformation to V after getting the fuzzy matrix, synthesize the fuzzy matrix and multiplicity of weight, the formula is: $B_i=W_i \circ R_i=(b_{i1},b_{i2},b_{i3}\ldots b_{ip})$.

(5) Determine the results

Determine the final result is repeating the fourth step, that step is calculated as the previous level from the bottom until you come to the final result, and total sorts the final result, choose the best solution.

coal mining structure: the coal seam pitch is 3°, the average thickness of seam is 6.3m, the protodrakonov coefficient F=3~4, which belong to hard coal. The geologic structure in the mining area is simple: the roof and floor is stable. The normal water inflow reaches 204.31m^3/h. The mining area is in low gas burst.

3.1 Determine the impact of factors and calculate the weight

This paper draws and sums up 31 factors, and divides into four categories, the table is as follow table 2：

Table 2 factors in underground coal mine

Factors of thick coal seam mining method							
Geological factors		Technological factors		Economical factors		Safety factors	
hydrogeology	coal seams	roadway excavation maintenance	mining equipment	economic	social benefits	production safety	disaster prevention
geological structure	dip angle	speed of roadway excavation	shearer	recovery rate of working face	surface subsidence	work environment	gas prevention
roof stability	thickness	size of roadway section	conveyor	yield of per face	water pollution	labor intensity	coal dust prevention
floor stability	hardness	roadway maintain	support	unit coal cost	air pollution		spontaneous combustion
gas geological condition	degree of joints and fracture				gangue dispose		roof control
hydrogeology condition	gangue						water control
faults							

According to the experts scoring method, the judgment matrix is constructed after determining factors. Using the YET ANOTHER AHP（YAAHP）software can import the average of exports scoring scores and obtain the weight of each factors[7]. As shown in Fig2. The

technical factors are the main impact for the method selecting of Shendong thick seam mining from the weight value, and the safety factors are followed.

Fig3

3.2 Fuzzy Comprehensive Evaluation

（1）the calculation of fuzzy matrix

Using the fuzzy membership function calculate the factors value of fuzzy matrix. In this paper, the example is using the three factors in the method of mining with large mining height.

According to relevant policies and regulations, the mining rate of thick coal seam mining area should not be less than 75%, and the mining rate of coal face should not less than 93%. The average mining rate of Shendong mining area is 95.3%. By using the membership function,

$$A=\begin{cases} 0 & <93 \\ \dfrac{95.3-93}{98-93} & 93\le x<98 \\ 1 & \ge 98 \end{cases},$$

the value assigned of A is 0.46.

The Shendong mining area is the advanced level of exploitation mining area, whose actual capacity is 5000t/h far beyond the average daily production of coal face. It is assigned 1 based on the partial large membership function.

According to the analysis of the actual cost of each ton of coal in Shendong mining area, the investing cost range of each ton of coal is determined 40~70 Yuan(RMB)/t and the investing cost of

each ton of coal is 58.63 Yuan(RMB)/t by mining with large height method. Based on the membership function,

$$A=\begin{cases} 1 & <40 \\ \dfrac{70-58.63}{70-40} & 40\le x<70 \\ 0 & \ge 70 \end{cases}$$

, the value assigned of A is 0.379.

After obtained the fuzzy matrix of all factors, the weight of factors is synthesized with membership in order to get the final result by using the formulae $B_i=W_i \circ R_i=(b_{i1},b_{i2},b_{i3}\ldots b_{ip})$.

For example with economic factors, the synthesis results are as follows:

$$B_5=W_5\circ R_5=\begin{bmatrix} 0.1095 & 0.3090 & 0.5816 \end{bmatrix}\circ\begin{bmatrix} 0.46 & 0.4 & 0.6 \\ 1.0 & 1.0 & 1.0 \\ 0.379 & 0.9 & 0.3 \end{bmatrix}=\begin{bmatrix} 0.58 \end{bmatrix}$$

Obtain the membership of all factors and normalize it. The membership of mining with large height method is 37%, the membership of top coal caving mining is 34%, and the membership of slice mining is 29%. Obviously, the method of thick seam mining in Shendong mining area should be selected mining with large height.

4. Conclusion

The problem of thick seam mining method selection is a complex decision-making process, which involves the relevant knowledge of mining, operations research, economics and management science. Therefore, it will lead people to make mistakes when people just rely on the subjective choices. The less-severe result is causing economic losses and the severe one is casualties. By studying the mining method of thick seam in Shendong coal mining area, the applicability FAHP is proved and the Correctness of selection model of thick seam mining method is validated. Simultaneously, it solves the problem that the qualitative index is difficult to quantify in multi-objective decision-making process, which makes the complex relationships hierarchical and principled. Therefore, the results using the model calculated are more objective and reasonable. The rational mining method will increase coal production and economic benefit, which also ensure the safety of personnel.

5.References

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