

The assessment of emergency capability of coal mines based on AHP-fuzzy comprehensive method

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ABSTRACT

In order to improve emergency management capabilities and the prevention and control of major accidents, it is important to study various methods for the assessment of the emergency capabilities of coal mines. This paper aims to bring about an analytic hierarchy process (AHP) and fuzzy comprehensive method to assess the emergency capabilities of coal mines. Firstly, the key elements of the emergency management for coal mines are analyzed based on the theories of the emergency management. From the precaution, response, and recovery aspects, the assessment index system of the emergency management capabilities for coal mines is built and the basic indexes of each element are confirmed and discussed. Furthermore, a multi-level fuzzy comprehensive evaluation model for mine emergency management capability is built based on the AHP (Analytic Hierarchy Process) and fuzzy mathematics. The assessment index system and mathematical model are applied to a selected mining enterprise whose assessing result was "high". Some shortcomings of the emergency system of the coal mine were analyzed and some suggestions were proposed to improve the emergency capabilities for the coal mine. The study is helpful for emergency management and the prevention of major accidents in coal mines.

KEYWORDS: coal mine; emergency capability; AHP; fuzzy comprehensive assessment

1. INTRODUCTION

It is well known that coal resources are an important foundation for energy and raw materials. China's coal industry has made remarkable achievements after nearly a decade of rapid development and production safety in mining has greatly improved. However, safety management in coal mines is still not good enough and lots of accidents have happened in the last decades. According to the statistics, the mortality rate of coal mines in China is 2.81 in 2005, 2.04 in 2006, 1.49 in 2007, 1.18 in 2008, 0.89 in 2009, 0.75 in 2010, and 0.56 in 2011. Meanwhile, the mortality rate of coal mines is about 0.05 to 0.03 in the United States, Australia, and other developed countries in recent years. The mortality rate for one million tons of coal mines in China is almost 30 to 50 times that of the United States and other advanced countries. The most important reasons for the coal mine accidents in China are the imperfect emergency system and poor emergency management.

Effective emergency and rescue can lessen the casualties and wealth losses of mining accidents. Emergency management capability assessment is an important part of safety management in coal mines. At present, the relevant research on the safety of coal mines mainly concentrates on risk assessment and safety management methods, and it is limited in the

study of emergency management, especially in the quantitative calculations. Most studies focus on theoretical discussion and qualitative analysis. Therefore, in order to improve the emergency management capabilities to prevent or control major accidents, it is important for the safety of coal mines to study the methods of assessment of emergency management capabilities.

In this paper, the key elements of the emergency management for coal mine were analyzed based on the theories of emergency management. The assessment index system of the emergency management capability for coal mines was built and a multi-level fuzzy comprehensive evaluation model for mine emergency management capability was built based on AHP and fuzzy mathematics. The assessment index system and mathematical model were applied to a selected mining enterprise to find out the shortcomings of the existing emergency system. Finally, some conclusions and suggestions were proposed to improve the emergency capabilities of coal mines. The study results will be helpful in advancing safety and emergency management scientifically to prevent and control major accidents in coal mines. At the same time, the results provide a theoretical basis and management guidance for government departments to manage coal mines.

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2. KEY ELEMENTS OF EMERGENCY MANAGEMENT FOR COAL MINES

Emergency refers to how to answer the emergent conditions. Usually it means the treatment measures adopted when the emergent conditions happen, and it includes a series of safety techniques and measures adopted to avoid accidents or lessen casualties and wealth loss in production. Therefore, it is often called accident emergency. Emergency management includes rapid and early warning, effective control, and active treatment to minimize losses during the concurrent and feedback of the unexpected accidents. Emergency management capability is the capability to deal with and avoid risk, and it involves the former preparation, disaster response, and support and rebuilding after the natural or manmade disaster.

The objects of emergency management are the unexpected incidents that could induce large casualties, wealth loss, and environment pollution. The capability of emergency management is the capability to control the unexpected incidents. The capability of emergency management for coal mines means the capability to control major unexpected accidents. The assessment of emergency management can be useful in realizing the precaution and control of major accidents.

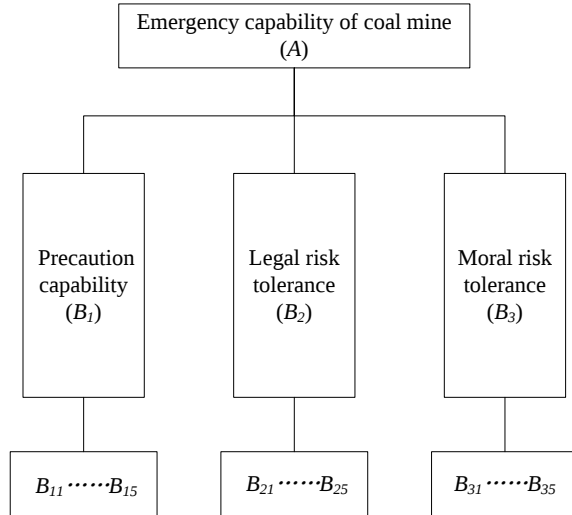


Figure 1: Structure of emergency capability of coal mine.

Emergency management is a lasting and persistent process. The key elements of emergency management include four phases: precaution, preparation, responds and recovery (Fan, 2011). The precaution and preparation phases share many common elements, so they are always combined in practice. The structure of emergency capabilities of coal mines is shown in Figure 1.

From the Figure 1, it can be seen that the precaution capability, response capability, and recovery capability constitute the emergency capability of coal mines. The precaution capability B_1 includes six indexes such as regulations and standards B_{11} , safety management B_{12} , emergency organization and plans B_{13} , emergency resources B_{14} , and training and education B_{15} . The response capability B_2 includes six indexes such as emergency communication B_{21} , rescue actions B_{22} , medical aid B_{23} , resources allocation B_{24} , and refuge and evacuation B_{25} . The recovery capability B_3 includes five indexes such as scene cleaning B_{31} , damage evaluation and insurance B_{32} , emergency plan update and improvement B_{33} , rebuilding B_{34} , plan improvement, and perfection B_{35} .

In order to assess the emergency capability of coal mine, it is necessary to build the scientific and reasonable index system and apply the operable assessment methods to the emergency management system, and make comprehensive assessment to get a conclusion periodically. All the jobs will find out the merit and shortcoming of the emergency management, and the actual capability of emergency management of coal mine will be enhanced step by step.

3. ASSESSMENT INDEX SYSTEM OF EMERGENCY CAPABILITIES FOR COAL MINES BASED ON AHP

3.1 Analytic Hierarchy Process

AHP (Analytic Hierarchy Process) (Chen et al., 2009; Zheng et al., 2010) is a kind of decision-making method that is applied widely to solve relatively obscure or complicated decision problems by qualitative and quantitative analysis methods. Because the emergency capability of coal mines is a complex decision problem, the assessment model of the emergency capability of coal mines can be established based on the AHP (Analytic Hierarchy Process) method.

AHP quantifies the judgement made by the experience of the decision maker. Furthermore, it can layer our thought process and compare related items and check the rationality of the compared result step wisely to supply the convictive criterion. Many decisions can be solved by the analytic hierarchy process.

The steps of AHP include:

- (1) Building hierarchy structure model;
- (2) Establishing judgment matrix;
- (3) Consistency checking for judgment matrix;
- (4) Calculating weight vector;
- (5) Calculating combinatorial weight vector;
- (6) Overall consistency checking;

(7) Fuzzy comprehensive judgment.

3.2 Assessment indexes

According to research on the emergency capability evaluation of coal mines and the AHP method, combined with the advices of emergency, safety, management, and fire experts, a comprehensive index system of emergency capability for coal mines is built from the perspective of the whole process of the emergency management of coal mines. The assessment indexes system of the emergency capability of coal mines is built in Table 1.

Table 1: Assessment indexes system for coal mines.

Top layer	Second layer	Third layer (index layer)
Emergency capability of coal mine A	Precaution capability B ₁	Regulations and standards B ₁₁
		Safety management B ₁₂
		Emergency organization and plan B ₁₃
		Emergency resources B ₁₄
		Training and education B ₁₅
	Response capability B ₂	Emergency communication B ₂₁
		Rescue actions B ₂₂
		Medical aid B ₂₃
		Resources allocation B ₂₄
		Refuge and evacuation B ₂₅
	Recovery capability B ₃	Scene cleaning B ₃₁
		Damage evaluation and insurance B ₃₂
		Emergency plan update and improvement B ₃₃
		Rebuilding B ₃₄
		Plan improvement and perfection B ₃₅

It is obvious that the assessment index system includes multilevel indices. There are three emergency elements in the second-level and seventeen elements in the third-level. Each second-level index includes many third-level indices. There are six items in the precaution capability, six items in the response capability, and five items in the recovery phase. All the seventeen items reflect the capability of the emergency management for major accidents of coal mines.

3.3 Calculating index weight

Based on the AHP, the assessment model of the emergency capability of coal mines has been built to analyze the actual emergency management capability of the enterprise in this paper. Firstly, the weight that each index affects the object was assured by analyzing all the scores confirmed by experts, then the qualitative indexes were quantified, and the emergency capability of coal mines was confirmed at

last. Thus, we can estimate the actual emergency management capability of coal mine enterprises.

The judgment matrix can be established by inviting the experts to mark all of the indices. The indices judgment of A is illustrated in Table 2.

Table 2: Judgment Matrix for A

A	A ₁	A ₂	A ₃
A ₁	1	1/3	4
A ₂	3	1	6
A ₃	1/4	1/6	1

According to the above judgment matrix, the weight of each index can be calculated by mathematical tools such as MATLAB, and also the weight vector and the consistency test. All the results are shown in Table 3.

Table 3: Consistency checking of the judgment matrix.

Judgment matrix	n	λ_{max}	CI	RI	CR	consistency
A	3	3.03	0.01	0.58	0.03	Pass
B ₁	5	5.23	0.05	1.12	0.05	Pass
B ₂	5	5.33	0.08	1.12	0.07	Pass
B ₃	5	5.08	0.04	0.90	0.03	Pass

Where, n is the number of indexes; λ_{max} is the maximum eigenvalue of judgment matrix; CI is the consistency index, When CI is more than 0 slightly, the matrix A will be in relatively good agreement, otherwise, the consistency of A is poor.

Based on the above table, the consistency ratio CR of each judgment matrix is less than 0.1, which indicates the consistency checking is ok. The weight of each index is shown in Table 4.

Table 4: Weight vector of each layer of index system.

Judgment matrix	Weight vector(w)
A	0.2706 0.6442 0.0852
B ₁	0.2615 0.0634 0.5128 0.1290 0.0333
B ₂	0.4047 0.1769 0.0590 0.2551 0.1043
B ₃	0.4620 0.1739 0.1778 0.0862 0.1002

4. FUZZY COMPREHENSIVE ASSESSMENT MODEL

The fuzzy comprehensive evaluation is performed by using the single factor evaluation results and evaluation object related. The corresponding evaluation matrix is constructed and the decision

weighting factor importance degree of each factor is used for the fuzzy transformation. Finally the evaluation results are found. Through the fuzzy comprehensive evaluation, risk management decisions can be quantitatively calculated for each oil and gas pipeline construction project. In order for the final evaluation results to have practical reference significance, the vector and the fraction vector are used to calculate a total score, and then the control method of rating scores to determine the result of the evaluation belongs to the grade.

4.1 Building indices

According to the indices system built in Table 1, establish collection U:

$$U=\{B_1, B_2, B_3\}$$

$$U_1=\{B_{11}, B_{12}, B_{13}, B_{14}, B_{15}\}$$

$$U_2=\{B_{21}, B_{22}, B_{23}, B_{24}, B_{25}\}$$

$$U_3=\{B_{31}, B_{32}, B_{33}, B_{34}, B_{35}\}$$

4.2 Establishing judgement collection

The capability of emergency management for coal mines can be divided into five levels from high to low.

$$\text{Judgement collection}=\{V_1, V_2, V_3, V_4, V_5\}$$

V_1 =higher, V_2 =high, V_3 =middle, V_4 =lower, V_5 =low.

In the calculation of the total system scores, risk management and decision-making can refer to Table 5 to determine the pipeline risk tolerance decision value. Then, the level of risk factor can be confirmed according to the decision value and also risk decision can be determined.

Table 5: Value and level of emergency management capability.

Risk level	Assessment Values	Level of	measurement
1	>90	Higher	maintain
2	90 ~ 76	High	Advanced
3	75 ~ 60	Middle	need Advanced
4	59 ~ 50	Lower	Must Advanced
5	< 49	Low	rectify

4.3 Fuzzy comprehensive assessment

There is a fuzzy mapping from U to V, where $u_i \rightarrow f(u_i) = (r_{i1}, r_{i2}, \dots, r_{im}) \in F(V)$. The fuzzy mapping f can identify a fuzzy relationship between U and V $R_f(u_i, v_i) = f(u_i)(v_i) = r_{ij}$; therefore, R_f can be expressed as a fuzzy matrix.

$$R = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1m} \\ r_{21} & r_{22} & \dots & r_{2m} \\ \dots & \dots & \dots & \dots \\ r_{n1} & r_{n2} & \dots & r_{nm} \end{bmatrix}$$

Thus, a comprehensive evaluation can be performed.

5. A CASE STUDY

In this paper, a coal mine was taken as a case to study risk tolerance and decision making. Using the established emergency capability model of fuzzy comprehensive assessment, the emergency capability value of the coal mine is carried out to determine the level of the emergency of the coal mine.

Before evaluation, relevant experts to judge, must be recruited and the importance of each index of emergency capability on the effect of each index of the coal mine must be compared. By inviting 10 relevant experts including coal mine, safety, technology, emergency, and fire experts, the importance of each index of the coal mine can be confirmed. The arbitrarily corresponding matrix of risk factors can be determined to find the score of the fuzzy comprehensive evaluation. Finally, the level of emergency capability of the coal mine can be determined.

In order to explain the calculation, we can take the precaution capability B_1 as an example. The experts' judgments on the precaution capability are listed in Table 6.

Table 6: Judgments of experts to the precaution capability B_1 .

	Higher	High	Middle	Lower	Low
B_{11}	0.3	0.5	0.2	0	0
B_{12}	0.8	0.2	0	0	0
B_{13}	0.7	0.3	0	0	0
B_{14}	0.2	0.3	0.5	0	0
B_{15}	0	0	0	0	1

So the R_f can be expressed as a fuzzy matrix as follows.

$$R(B_1) = \begin{bmatrix} 0.3 & 0.5 & 0.2 & 0 & 0 \\ 0.8 & 0.2 & 0 & 0 & 0 \\ 0.7 & 0.3 & 0 & 0 & 0 \\ 0.2 & 0.3 & 0.5 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

Then,

$$R_{B1} = w_{B1} \bullet R(B_1)$$

$$= \begin{pmatrix} 0.2615 \\ 0.0634 \\ 0.5128 \\ 0.1290 \\ 0.0333 \end{pmatrix}^T \bullet \begin{pmatrix} 0.3 & 0.5 & 0.2 & 0 & 0 \\ 0.8 & 0.2 & 0 & 0 & 0 \\ 0.7 & 0.3 & 0 & 0 & 0 \\ 0.2 & 0.3 & 0.5 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

$$= (0.5139 \quad 0.3360 \quad 0.1168 \quad 0 \quad 0.0333)$$

Also,

$$R_{B2} = (0.3490 \quad 0.2326 \quad 0 \quad 0 \quad 0.4184)$$

$$R_{B3} = (0.7393 \quad 0.1472 \quad 0.0274 \quad 0 \quad 0.0862)$$

So,

$$R(A) = \begin{pmatrix} 0.5139 & 0.3360 & 0.1168 & 0 & 0.0333 \\ 0.3490 & 0.2326 & 0 & 0 & 0.4184 \\ 0.7393 & 0.1472 & 0.0274 & 0 & 0.0862 \end{pmatrix}$$

$$R_A = w_A \bullet R(A)$$

$$= \begin{pmatrix} 0.2706 \\ 0.6442 \\ 0.2856 \end{pmatrix}^T \bullet \begin{pmatrix} 0.5139 & 0.3360 & 0.1168 & 0 & 0.0333 \\ 0.3490 & 0.2326 & 0 & 0 & 0.4184 \\ 0.7393 & 0.1472 & 0.0274 & 0 & 0.0862 \end{pmatrix}$$

$$= (0.4949 \quad 0.2895 \quad 0.0773 \quad 0 \quad 0.1383)$$

Then, the emergency capability of the coal mine can be got by $R_A \cdot (93, 80, 70, 55, 45)^T$, and the result is 82.16. Therefore, according to the decision standard values listed in Table 5, the level of the coal mine is high but the emergency regulations and standards, emergency training, and education still need to be strengthened.

6. CONCLUSIONS

(1) The capability of emergency management for coal mine means the capability to control major unexpected accidents. Emergency management is a lasting and persistent process which includes precaution, response, and recovery.

(2) The assessment index system includes multilevel indices. The three phases of emergency management constitute the second-level indices. Each second-level index includes many third-level indices, which sum to fifteen items. There are five items in the precaution phase, five items in the preparedness phase, five items in the response phase, and four items in the recovery phase. All the fifteen items directly reflect the capability of the emergency management for major accidents.

(3) The capability of the emergency management for coal mines can be assessed by establishing the analytic hierarchy process model, and the assessment result can reflect the actual emergency management degree. All the studies are helpful in improving the

emergency management level and preventing major accidents.

(4) The practical application shows that the emergency capability of the coal mine is "high". However, the emergency regulations and standards, emergency training, and education still need to be strengthened.

7. ACKNOWLEDGEMENT

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