Application of integrated method of HAZOP-AHP and fuzzy comprehensive evaluation in coal mine gas explosion accident

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Abstract. Hazard and Operability analysis (HAZOP), Analytic Hierarchy Process (AHP) and fuzzy comprehensive evaluation methods are all important safety evaluation methods. For HAZOP analysis, the subjectivity is strong, the analysis process is complex, and accurate quantitative analysis cannot be performed. Proposed a safety evaluation method that combines HAZOP, AHP and fuzzy comprehensive evaluation, and integrated the three methods to make the HAZOP analysis method from qualitative analysis to qualitative and quantitative analysis, and improve the accuracy of risk identification. Finally, taking the gas explosion accident as an example, the above method is used to briefly analyze the gas explosion accident to verify the scientificity and feasibility of the method.

Keywords: coal mine, gas explosion, HAZOP, AHP, fuzzy comprehensive evaluation

1. Integrated method of HAZOP-AHP and fuzzy comprehensive evaluation

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1.1. HAZOP evaluation method

HAZOP, also known as operability research, is a risk assessment method based on systems engineering that can be used for qualitative analysis or quantitative evaluation. It is mainly used to discover potential hazards and operational difficulties in the design and qualitative stages of chemical systems. In order to consider control and preventive measures. By analyzing the changes in the process state parameters during the production operation, the possible deviations in the operation control, and the impact of these changes and deviations on the system and the possible consequences, we can find out the reasons for the changes and deviations, and clarify the device or system and The main hazards and hazards in the
production process, and the measures that should be taken according to the consequences of changes and deviations. Later, the scope gradually expanded and was applied in many fields.

HAZOP is a comprehensive investigation of the object analysis, asking questions for every detail. For example, in the production and operation of the process, it is necessary to understand where the process parameters (temperature, pressure, flow, concentration, etc.) are inconsistent with the design requirements (that is, deviations), and then further analyze the causes of deviation and its results, and propose corresponding countermeasures.

1) Ask questions. In order to get straight to the problem of analysis, so when asking questions, only use None (No), More (More), Less (Less), As well as (and, and), Part of, Reverse), Other than (other) to cover all deviations.

2) Divide the unit and clarify the function. The analysis object is divided into several units. In the continuous process, the unit is mainly pipeline, and in the intermittent process, the unit is mainly equipment. Clarify the function of each unit, explain its operating status and process.

3) Define the keyword table. Analyze the possible deviations of each unit one by one according to the keywords. Generally, the possible deviations are analyzed step by step from the beginning of the process, pipelines, equipment, etc., until the end of the process.

4) Analyze the causes and consequences. Taking the chemical plant as an example, the process conditions (temperature, pressure, flow, concentration, impurities, catalyst, leakage, explosion, static electricity, etc.) should be analyzed; the startup and shutdown conditions (experiment, driving, maintenance, equipment and pipelines such as signs, reaction conditions, etc.) Mixed conditions, positioning conditions, process conditions, etc.); emergency treatment (gas, steam, water, electricity, materials, lighting, alarms, contact and other unplanned parking situations); even natural conditions (wind, thunder, rain, frost, snow, Fog, geology, building installation, etc.). Analyze the causes and consequences of deviations.

5) Formulate countermeasures.

6) Fill in the summary table. In order to summarize and fill in the analysis table of hazard and operability research and ensure that the analysis is detailed without omission, the analysis should be carried out one by one according to the keyword table. The keyword table can be determined according to the research object and environment.

The traditional HAZOP analysis divides the unit and determines the node according to the cause of the accident, analyzes the process flow through the guiding lexical method, analyzes the deviation, impact and consequence, and identifies the hazard source. This method can effectively identify risks, but due to its strong subjectivity, analysis takes a long time, there are certain shortcomings, and there are certain errors in the risk identification process.

1.2. AHP

The characteristic of Analytic Hierarchy Process is based on in-depth analysis of the nature, influencing factors and internal relations of complex decision-making problems, and using less quantitative information to mathematicize the thinking process of decision-making, thereby providing multiple goals and multiple criteria or complex decision-making problems without structural characteristics provide simple decision-making methods. It is especially suitable for occasions where it is difficult to directly and accurately measure the decision result.

The analytic hierarchy process is to decompose the decision-making problem into different hierarchical structures in the order of the general goal, the sub-goals of each level, the evaluation criteria, and the specific investment plan, and then the method of solving the eigen vector of the judgment matrix is used to obtain each level. The priority of each element to an element of the previous level, and finally the method of weighting and summing iteratively and the final weight of each alternative plan to the total goal, the one with the largest final weight is the optimal plan. The so-called "priority weight" here is a relative measure, which indicates the evaluation criteria or sub-objectives of a certain characteristic of each alternative plan, the relative measure of the superiority of the subscripts, and the importance of each sub-objective to the goals of the upper level. Relative measure of degree. The analytic hierarchy process
is more suitable for decision-making problems with hierarchical and interlaced evaluation indicators, and the target value is difficult to describe quantitatively. Its usage is to construct a judgment matrix to find its maximum eigenvalue and its corresponding eigen vector W. After normalization, it is the relative importance weight of a certain level of index to a certain related index of the previous level.

The analytic hierarchy process is a practical multi-scheme or multi-objective decision-making method. The research object is analyzed as a whole. The decision-making method is simple and practical, the calculation is simple, and the results are clear at a glance; it requires less quantitative information to perform simple weight calculations. A systematic analysis method, combining qualitative and quantitative, is easy to understand and master. The steps are:

1. Scale determination and construction of judgment matrix
   This step is the source of the original data (judgment matrix), such as using the 1-5 point scale method (minimum 1 point, maximum 5 points); combined with expert scores, the final judgment matrix table is obtained.

2. Feature vector, feature root calculation and weight calculation
   The purpose of this step is to calculate the weight value. If you need to calculate the weight, you need to calculate the eigen vector value first, so SPSSAU will provide the eigen vector index. At the same time, the maximum eigenvalue (CI) is obtained, which is used in the next consistency check.

3. Consistency inspection and analysis
   When constructing the judgment matrix, there may be logical errors. For example, A is more important than B, B is more important than C, but C is more important than A. Therefore, it is necessary to use the consistency test to check whether there is a problem. The consistency test uses the CR value for analysis. If the CR value is less than 0.1, it means that the consistency test is passed. Otherwise, it means that the consistency test is not passed.

   If the data does not pass the consistency check, you need to check whether there are logic problems, etc., and re-enter the judgment matrix for analysis.

1.3. Fuzzy comprehensive evaluation method

The fuzzy algorithm language is simple, does not require precise mathematical models, and is suitable for solving problems such as nonlinearity and strong coupling time-varying in process control. Combining fuzzy algorithm with analytic hierarchy process can remove deviations caused by subjective factors and deal with fuzzy and difficult to quantify problems. The most notable features of the fuzzy comprehensive evaluation method are:

1. Compare with each other. Taking the best evaluation factor as the benchmark, its evaluation value is 1; the remaining poor evaluation factors get the response evaluation value based on the degree of the poor quality.

2. The functional relationship between the evaluation value and the evaluation factor value can be determined based on the characteristics of various evaluation factors. There are many ways to determine this functional relationship. For example: statistical methods, various types of F distributions, etc., or expert ratings, etc. The steps are:

   1. Construction of fuzzy comprehensive evaluation index
      The fuzzy comprehensive evaluation index system is the basis for comprehensive evaluation. Whether the selection of evaluation index is appropriate will directly affect the accuracy of comprehensive evaluation. The construction of the evaluation index should be extensively involved in the industry data of the evaluation index system or related laws and regulations.

   2. Construct a weight vector
      Construct the weight vector through expert experience method or AHP analytic hierarchy process.

   3. Build an evaluation matrix
      Establish a suitable membership function to construct a good evaluation matrix.

   4. The synthesis of evaluation matrix and weight
      Synthesize it with a suitable synthesis factor and interpret the result vector.
1.4. Integrated method of HAZOP-AHP and fuzzy comprehensive evaluation

The specific steps of the method are: Analyze the process with Analytic Hierarchy Process, determine the scale and construct the judgment matrix, calculate the eigen vector, eigen root and weight, and check the consistency; perform HAZOP analysis on the equipment and nodes, understand the design intent, and select the process Parameter, assumption deviation, study the consequence of deviation, study the reason of deviation, divide the index into 1-level index and 2-level index, take the second-level index as HAZOP node, analyze the deviation, analyze the cause and consequence of the deviation. Analyze using guiding words, deviation = guiding words + process parameters. Select guiding words, use possible meaningful deviations as guiding words, and select Less (less), No (blank), Reverse, etc. as guiding words to analyze each node; then perform analytic hierarchy process analysis to evaluate safety. The index system is divided into the highest level, the middle level and the lowest level. From top to bottom, it is represented by A, B, and C, and the same level is represented by 1, 2, and 3. Next, the weights of the analyzed indicators are determined according to the analytic hierarchy process. Construct a judgment matrix, use MATLAB to calculate the maximum eigenvalue $\lambda_{max}$ and eigen vector W of the judgment matrix; establish a fuzzy evaluation matrix to determine the factor set, which can be expressed as $U=\{u_1,u_2,\ldots,u_m\}$, which is generally fuzzy. Establish a comprehensive judgment set. The judgment set is composed of the possible judgment structure of the judged object. It is represented by $V=\{v_1,v_2,\ldots,v_n\}$, and the judgment set can be divided into 3~7 levels. Calculate the degree of membership, select the large fuzzy distribution as the membership function, ask multiple experts to score the element layer, calculate the membership degree through the membership function $A(x)$, find the evaluation grade, and find the evaluation grade based on the relationship between the membership degree and the evaluation index. Find the element layer evaluation vector. Determine the weight vector of factors. Since the importance of each factor is different, that is, the weight is different, set the weight of each factor $u_i$ as $a$, then the fuzzy set of the weight set of each factor can be expressed as: $W = \{a_1, a_2,\ldots, a_m\}$. The single-factor fuzzy evaluation results in the evaluation matrix. The single-factor fuzzy evaluation starts from one factor to determine the degree of membership of the evaluation object to the evaluation set $V$. Level I index $B_i$ ($i=1, 2, 3$), there are $j$ level II indicators, the establishment of a level I evaluation index fuzzy matrix set $R_i$, $R$ matrix data is composed of expert scores, $\circ$ is a fuzzy operator. Obtain the first-level fuzzy evaluation matrix, perform fuzzy comprehensive evaluation according to the first-level evaluation index to get the final evaluation result $F$. Determine the affiliation level, in order to improve the credibility and accuracy of this evaluation, establish a mathematical model of the coal mine gas explosion safety system, obtain the evaluation score, and compare the score with $A_i$ to determine the affiliation level; conduct risk evaluation; practical application. Its mentality analysis diagram is shown in Figure 1.

![Figure 1. Integrated method of HAZOP-AHP and fuzzy comprehensive evaluation](image-url)
The evaluation method that combines HAZOP-AHP and fuzzy comprehensive evaluation has the following advantages: it can simplify the analysis process, make the analysis results clear at a glance, require less quantitative information, and perform simple weight calculations; it does not require precise mathematical models and is suitable for solving Non-linearity, strong coupling and time-varying problems in process control. It can remove deviations caused by subjective factors, and deal with fuzzy and difficult to quantify problems. Combining AHP and fuzzy comprehensive evaluation with HAZOP will improve the accuracy of analysis; all three evaluation methods can be analyzed more comprehensively and accurately; the three methods can be combined organically to give full play to their respective characteristics, which can be effective Improve the accuracy of the evaluation results; these three evaluation methods have complementary advantages, not only can find out the unsafe factors that may cause accidents more comprehensively and clearly, but also provide a new way for system safety analysis to make the system dangerous sexual analysis is more scientific, reasonable and feasible, providing theoretical support and new ideas for effective prevention and reduction of accidents; establishing effective connections between equipment and equipment, equipment and nodes, and nodes and nodes, so as to make the analysis more systematic, complete, and effective.  

2. HAZOP-AHP and fuzzy comprehensive evaluation integrated method to evaluate coal mine gas explosion

The causes of coal mine gas explosion accidents are very complicated. A detailed analysis of coal mine gas explosion accidents is carried out to analyze the causes of the accident. It mainly includes factors such as human, machine, environment, pipe and various defects. Various factors interact to cause coal mine gas accidents. Happened. Through detailed analysis of the cause of the accident, the occurrence of accidents can be effectively prevented. Using HAZOP analysis, the coal mine gas explosion accident is divided into the following key indicators, as shown in Table 1.  

| Level I index | Level II index |
|--------------|----------------|
| Gas concentration (B1) | The local ventilator stops (C1) |
| | Gas accumulation in coal mining face (C2) |
| | Air duct leakage (C3) |
| Detonate the fire source (B2) | Flame (C4) |
| | Impact and friction sparks (C5) |
| | Electrical short circuit (C6) |
| Gas management (B3) | Electric fire (C7) |
| | Gas leak detection (C8) |
| | Failure to detect on time (C9) |
| | Alarm power failure device (C10) |
| | Gas handling error (C11) |
| | Negligence (C12) |
| | Failure to deal with the accumulated gas in time (C13) |

Take the level II index as the HAZOP node, analyze its deviation, analyze the cause and consequence of the deviation. Analyze using guiding words, deviation = guiding words + process parameters. Select guiding words, use possible meaningful deviations as guiding words, select Less (less), No (blank), Reverse, etc. as guiding words, and analyze each node, as shown in Table 2, Table 3, and Table 4. Show.
### Table 2. HAZOP analysis table of gas concentration indexes and Affiliations

| Level II Index       | Guiding Words | Causes                                      | Consequences                                      | Measures                                         |
|----------------------|---------------|---------------------------------------------|---------------------------------------------------|-------------------------------------------------|
| Local ventilator     | Other than    | Power outages, malfunctions                 | Poor ventilation in the mine, which could easily  | Immediately perform circuit overhaul or ventilator |
| stopped              |               |                                             | lead to increased gas concentration               | maintenance                                     |
|                      |               |                                             |                                                   |                                                 |
| Gas accumulation in  | More          | Accumulation in the upper corner,           | Easy to cause a gas explosion accident             | Change the ventilation system; change the       |
| coal mining face     |               | insufficient air volume                     |                                                   | direction of the air flow; dilute the upper     |
|                      |               |                                             |                                                   | corner gas concentration                        |
|                      |               |                                             |                                                   |                                                 |
| Air duct leakage     | Other than    | The type of air duct, the number, method    | The maintenance and management of the air duct    | Reduce the effective air volume of the local     |
|                      |               | and quality of joints, diameter, wind       | are closely related.                               | ventilator and bring serious hidden dangers to  |
|                      |               | pressure, etc.                              |                                                   | the safety of the tunneling face.               |
|                      |               |                                             |                                                   | Reduce the man-made damage of the air duct;     |
|                      |               |                                             |                                                   | use the joint method of small air leakage to    |
|                      |               |                                             |                                                   | connect the air duct; reduce the number of      |
|                      |               |                                             |                                                   | air duct joints                                 |

### Table 3. HAZOP analysis table of detonating fire source index

| Level II Index       | Guiding Words | Causes                                      | Consequences                                      | Measures                                         |
|----------------------|---------------|---------------------------------------------|---------------------------------------------------|-------------------------------------------------|
| Open flames          | More          | Fire from blasting, smoking, electric       | Gas explosions                                     | Frighten the use of open flames                  |
|                      |               | welding, large light bulbs                 |                                                   |                                                 |
| Impact, friction     | More, as well | Some devices and metal friction will cause   | Gas explosion                                      | Install overheating protection devices and       |
| spark                | as           | the temperature to rise and produce sparks. |                                                   | temperature detection alarm power-off devices   |
|                      |              |                                             |                                                   | on friction heating devices; on the metal       |
|                      |              |                                             |                                                   | surface of friction parts, attach low-activity  |
| Electrical short     | Part Of       | Short circuit in transformer, motor, switch;| Electric shock; grid leakage; short circuit       | The installation of electrical equipment must    |
| circuit              |               | poor cable connection method, insulation    | overload                                          | be strictly constructed; check the insulation   |
|                      |               | breakdown short circuit;                   |                                                   | of the equipment regularly                      |
| Electrical fire      | Part Of, Other| Live maintenance; equipment failure to      | Causing mine fire or even explosion               | Adhere to the principle of protection for all    |
|                      | than          | explode                                     |                                                   | types of electrical appliances; regular         |
|                      |               |                                             |                                                   | maintenance;                                    |
Table 4. HAZOP analysis table of gas management indicators

| Level II Index | Guiding Words | Causes | Consequences | Measures |
|----------------|---------------|--------|--------------|----------|
| Missed gas detection | Other than | Lack of rules and regulations; the operator is irresponsible | The gas concentration is easy to exceed the limit, causing an accident | Train the operators in accordance with relevant regulations, and only after passing the safety training. |
| Failure to test on time | Part Of | Safety education is not in place, operating procedures are not perfect | It is easy to cause accidents | Regular safety education is conducted so that all operators are fully aware of the hazards of gas |
| Alarm power failure instrument failure | Other than, Less | Position is improper, alarm power failure instrument failure. | When the gas concentration rises, the alarm and response cannot be made in time, which is easy to cause accidents. | Find problems in time, eliminate faults in time, and overhaul circuits and equipment |
| Gas handling error | More, Other than | Third-level education, and type of work education do not meet the requirements | A large amount of gas accumulates in the roadway, causing people to suffocate, poison, and explode in case of open fire. | Safety education is strictly prohibited. Psychologically, perform gas treatment at will |
| Negligence | More, Other than | Safety education is not in place, site operations are perfunctory | Easy to cause accidents, turning potential safety hazards into safety accidents | Operators must not save trouble and cut corners in underground operations |
| Failed to deal with the accumulated gas in time. | Other than | Illegal operation and illegal command | Increased gas concentration, causing suffocation, poisoning or death, or even fire and explosion. | Discover problems in time, report in time, draw up a safety responsibility implementation system, and stop violations in time |

2.1. Coal mine gas explosion safety evaluation index system
Combining AHP analytic hierarchy process with HAZOP analysis, the coal mine gas explosion safety evaluation index system is divided into the highest level, the middle level and the lowest level. It is represented by A, B, C from top to bottom, and 1, 2, 3 for the same level. To represent (as shown in Table 1).

2.2. Evaluation index weight calculation
AHP is based on the coal mine gas explosion safety evaluation index system, constructs the judgment matrix according to the analytic hierarchy process, uses MATLAB to calculate the maximum eigenvalue $\lambda_{max}$ and eigen vector $W$ of the judgment matrix, and conducts the consistency test. The evaluation random consistency index is shown in Table 5. The judgment matrix is shown in Table 6. If the test coefficient CR<0.1, then the test is passed, and then the index weight is quantified. The index weight of level I unit = (1,1,1), $\lambda_{max}$=3, CR=0, the index weight of level II, see table 9 shown.

Table 5. Average random consistency index RI

| n  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|----|---|---|---|---|---|---|---|---|---|----|----|----|----|
| RI | 0 | 0 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 | 1.51 | 1.54 | 1.56 |
Table 6. Judgment matrix of gas concentration

| C   | C1  | C2  | C3  |
|-----|-----|-----|-----|
| C1  | 1   | 1/2 | 3   |
| C2  | 2   | 1   | 3   |
| C3  | 1/3 | 1/3 | 1   |

Table 7. Judgment matrix for detonating fire source

| C   | C4  | C5  | C6  | C7  |
|-----|-----|-----|-----|-----|
| C4  | 1   | 1/3 | 1   | 1   |
| C5  | 1/3 | 1   | 1   | 2   |
| C6  | 1/3 | 1   | 1   | 1   |
| C7  | 1/3 | 1/3 | 1/3 | 1   |

Table 8. Gas management judgment matrix

| C   | C8  | C9  | C10 | C11 | C12 | C13 |
|-----|-----|-----|-----|-----|-----|-----|
| C8  | 1   | 1/3 | 1   | 1/7 | 1/3 | 1/7 |
| C9  | 3   | 1   | 1   | 1/5 | 1/5 | 1/3 |
| C10 | 1   | 1   | 1   | 1/3 | 1/7 | 1/5 |
| C11 | 7   | 5   | 3   | 1   | 1/3 | 1/3 |
| C12 | 3   | 5   | 7   | 3   | 1   | 1/3 |
| C13 | 7   | 3   | 5   | 3   | 3   | 1   |

Table 9. Evaluation index weight

| Level II index | Weight value WB | Characteristic value $\lambda_{max}$ | Test coefficient CR |
|----------------|-----------------|-------------------------------------|---------------------|
| C1             | 0.3328          | 3.0468                              | 0.0450              |
| C2             | 0.5283          |                                     |                     |
| C3             | 0.1388          | 4.1514                              | 0.0567              |
| C4             | 0.2570          |                                     |                     |
| C5             | 0.3383          |                                     |                     |
| C6             | 0.2570          |                                     |                     |
| C7             | 0.1477          |                                     |                     |
| C8             | 0.83            |                                     |                     |
| C9             | 0.89            |                                     |                     |
| C10            | 0.79            |                                     |                     |
| C11            | 0.89            |                                     |                     |
| C12            | 0.93            |                                     |                     |
| C13            | 0.80            |                                     |                     |

2.3. Fuzzy comprehensive evaluation

The fuzzy comprehensive evaluation method is divided into the following five steps:

1) Determine the set of factors

   The factor set can be expressed as $U=\{u_1,u_2,\ldots,u_m\}$, $m$ — the number of judging factors; $u_i$ — the $i$-th judging factor. The hierarchy of rating factors can be divided into the first, second, and third judging factor sets, which are generally vague.

2) Establish a comprehensive judgment set
The judging set is composed of the possible judging structures of the judging object, represented by \( V = \{v_1, v_2, ..., v_n\} \), \( n \) — the number of judging structures, \( V_j \) — the \( j \)-th type of evaluation result, the judging set can be divided into 3~Level 7.

(3) Calculate the degree of membership

Select the large fuzzy distribution as the membership function, ask multiple experts to score the element layer, and calculate the membership through the membership function \( A(x) \), as shown in equation (1).

\[
A(x) = \begin{cases} 
0, & x < 60 \\
\frac{x - 60}{90 - 60}, & 60 \leq x \leq 90 \\
1, & x > 90 
\end{cases}
\]  
(1)

(4) Seeking evaluation grade

According to the relationship between the degree of membership and the evaluation index, the evaluation level is calculated, and the evaluation vector of the element layer is calculated, as shown in Table 10.

**Table 10. The relationship between membership degree and evaluation grade**

| Membership function | Evaluation grade  |
|---------------------|-------------------|
| \( S(x) = 1 \)      | excellent         |
| \( 2/3 \leq S(x) < 1 \) | good             |
| \( 1/3 \leq S(x) < 2/3 \) | in               |
| \( 0 < S(x) < 1/3 \)  | difference        |
| \( S(x) = 0 \)      | inferior          |

(5) Determine the factor weight vector

Since the importance of each factor is different, that is, the weight is different, let the weight of each factor \( u_i \) be \( a \), then the fuzzy set of the weight set of each factor can be expressed as: \( W = \{a_1, a_2, ..., a_m\} \).

(6) Single-factor fuzzy evaluation, get the evaluation matrix

Single-factor fuzzy evaluation starts from one factor to determine the degree of membership of the evaluation object to the evaluation set \( V \). Level I index \( B_i \) (\( i = 1, 2, 3 \)), there are \( j \) level II indicators, the establishment of a level I evaluation index fuzzy matrix set \( R_i \). \( R \) matrix data is composed of expert scores, as shown in equation (2), combined The weight set \( W \) of the class II system is calculated according to formula (3), and \( \circ \) is a fuzzy operator. The first-level fuzzy evaluation matrix \( N = [N_1, N_2, N_3]^T \) is obtained, and the final evaluation result \( F \) is obtained by fuzzy comprehensive evaluation according to the first-level evaluation index, as shown in equation (4).

\[
R_i = \begin{bmatrix} r_{i11} & r_{i12} & \cdots & r_{i1j} \\
r_{i21} & r_{i22} & \cdots & r_{i2j} \\
\end{bmatrix}
\]  
(2)

\[
N = W_c \circ R_i = (N_1, N_2, N_3)
\]  
(3)

\[
F = W_b \circ N
\]  
(4)

Choice of fuzzy operator:

The characteristics of fuzzy operators are shown in Table 11. According to the actual situation, choose the \( M(\cdot, \oplus) \) operator that can take all factors into consideration.
Table 11. Comparison of characteristics of fuzzy operators

| Operator | type | Comprehensive degree | Utilization of information | system weight |
|----------|------|----------------------|----------------------------|--------------|
| $M(\land, \oplus)$ | weighted average type | strong | not obvious | not obvious |
| $M(\lor, \oplus)$ | weighted average type | strong | enough | obvious |
| $M(\land, \lor)$ | The main factor is prominent, | weak | insufficient | not obvious |
| $M(\lor, \lor)$ | The main factor is prominent, | weak | insufficient | obvious |

(7) Determine the level of membership

In order to improve the credibility and accuracy of this evaluation, let $A_i=(55, 65, 75, 85, 95)$, establish a mathematical model of the coal mine gas explosion safety system, obtain the evaluation score, and compare the score with $A_i$ to determine the affiliation level. As shown in equation (5).

$$u_i = \sum_{j=1}^{s} N_i \cdot S_j \quad (5)$$

3. Example application

Xinhua Coal Mine in Jinsha County, Guizhou Province, is a private enterprise and is a resource integration mine. The mine adopts inclined shaft development, three shafts (main inclined shaft, auxiliary inclined shaft and return air inclined shaft), and the central parallel extraction ventilation. There are 2 mineable coal seams, with an average thickness of 2.1m, 1.3m, and a coal seam inclination angle of 4-6°. The gas level identification result is a high gas mine, the relative gas emission is 73.91m³/t, and the absolute gas emission is 24.03m³/min. Taking this coal mine as the research object, establish a coal mine gas safety evaluation system. 15 experts and scholars will score the coal mine gas safety evaluation system, calculate the membership degree of each factor, conduct safety evaluation of the mine, and finally summarize the results and calculate $\mu$ the degree of membership of the level index is shown in Table 12.

Table 12. Statistics of membership

| Level II index | A1(bad) | A2(poor) | A3(medium) | A4(good) | A5(excellent) |
|----------------|---------|----------|-------------|----------|----------------|
| C1             | 0       | 0        | 1           | 0        | 0              |
| C2             | 0       | 0.6      | 0.4         | 0        | 0              |
| C3             | 0       | 0.47     | 0.47        | 0.07     | 0              |
| C4             | 0       | 0        | 0.53        | 0.47     | 0              |
| C5             | 0.6     | 0.4      | 0           | 0        | 0              |
| C6             | 0.27    | 0.73     | 0           | 0        | 0              |
| C7             | 0.33    | 0        | 0.67        | 0        | 0              |
| C8             | 0.47    | 0.53     | 0           | 0        | 0              |
| C9             | 0       | 0        | 0.33        | 0.6      | 0.07           |
| C10            | 0       | 0        | 0.8         | 0.2      | 0              |
| C11            | 0       | 0.73     | 0.27        | 0        | 0              |
| C12            | 0       | 0        | 0.87        | 0.13     | 0              |
| C13            | 0       | 0        | 0.67        | 0.93     | 0              |

From Table 9 the degree of membership obtains the second-level index evaluation matrix $R_i$.

$$R_i = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 \\ 0 & 0.6 & 0.4 & 0 & 0 \\ 0 & 0.47 & 0.47 & 0.07 & 0 \end{bmatrix}$$
According to the evaluation index weight table 6 and formula (3):

\[ N_1 = \overrightarrow{W_1} \circ R_1 = (0.01 0.382 0.607 0.01 0) \]

\[ N_2 = \overrightarrow{W_2} \circ R_2 = (0.316 0.323 0.261 0.121 0) \]

\[ N_3 = \overrightarrow{W_3} \circ R_3 = (0.39 0.146 0.082 0.576 0.064) \]

From the formula (4):

\[ F = \overrightarrow{W} \circ N = (0.009 0.21 0.043 0.31 0.36) \]

From the formula (5):

\[ u = \sum_{i=1}^{5} \mu(F) \cdot A_i = 77.92 \]

According to the weighted average method, the overall system score is 77.92. It can be seen that the safety level of the system is medium. Therefore, there is a danger of gas explosion during the operation of the coal mine. Using the HAZOP analysis method to analyze the coal mine, it can be seen that the coal mine has not inspected the gas situation at the operating point or discharged gas before the operation; the local fans have stopped running; the gas sensors and the local fan start-stop sensors have not been installed as required. You are to blame for the monitoring equipment; the on-site management is chaotic, the management personnel command in violation of regulations, and the operators do not work according to the regulations; the safety inspection is perfunctory; the portable gas alarm is not worn according to the regulations; the technical management is not in place; the reasonable safety technical measures are not formulated; Operators have weak safety awareness and fail to abide by safe operation procedures; inspections and supervisions for major safety hazards are not in place, and supervision is ineffective.

4. Conclusion

(1) This article analyzes coal mine gas explosion accidents, uses HAZOP-AHP and fuzzy comprehensive evaluation integrated methods to specifically divide coal mine gas explosion accidents into 3 level I indicators and 13 level II indicators, and analyzes possible coal mine gas explosion accidents. Risk factors, their causes, consequences and corresponding countermeasures are researched and analyzed.

(2) The integrated method of HAZOP-AHP and fuzzy comprehensive evaluation, the establishment of coal mine gas explosion safety evaluation index system, the use of analytic hierarchy process (AHP) to calculate the weight of each factor, the use of fuzzy comprehensive evaluation to analyze the safety level of coal mine gas, and the identification of potential hazards of equipment, Carry out hidden danger
investigation and risk assessment of accidents in order to take measures to eliminate hidden dangers that affect the normal operation of the system and personal safety.

3) Apply the integrated method of HAZOP-AHP and fuzzy comprehensive evaluation to actual coal mine operations. Through the establishment of a safety evaluation index system, combined with the fuzzy comprehensive evaluation method, the safety evaluation of coal mine gas is carried out, the safety level of coal mine gas is evaluated, and the hidden safety hazard is eliminated in time. The dangers and operational difficulties in actual operations are easy to consider and control preventive measures.

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