Research Article

A Multicriteria Decision Model Based on Analytic Hierarchy Process for Managing Safety in Coal Mines

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This paper presents a comprehensive quantitative approach for managing safety in coal mines with a multicriteria decision-making model by using fuzzy mathematics. We develop a set of factors that affect the management of safety in coal mines, including ventilation, the mine roof, and mine temperature. The factors also include mine dust, mining gas, and mining water. Other factors are equipment reliability, explosive risk of equipment, maintenance of equipment, staff operations and staff training, staff attendance, index to evaluate and manage workload, and project quality, monitoring systems, and safety information. The approach is then applied to evaluate a case study on the safety management of the Fushan Coal Industry Co., Ltd. Coal Mine in Henan Province of China. The matrix that evaluates each factor is obtained through a membership function and scored by experts, and the weight of each attribute is obtained through an analytic hierarchy process. The evaluation results show that the Fushan Coal Industry Co., Ltd. Coal Mine overall has a good safety track record. However, the mine needs to further enhance how they manage safety, optimize the mine ventilation system, and further strengthen safety management practices to ensure the safety of production processes in the mine.

1. Introduction

Issues around safety have been challenging coal mining companies, which are exacerbated by factors such as the production process environment, technical equipment, and management level [1, 2]. As part of managing a company, the process of safety management can be a complex endeavor. In summary, safety management is a comprehensive system that identifies, documents, manages, assesses, and minimizes hazards and risks, which includes functions for ensuring safety procedures, implementing related policies, and making decisions and conducting planning, organizing, and coordinating tasks related to safety within a reasonable budget. Managing safety also requires the effective and efficient use of people, financial, material resources, and time [3, 4]. Therefore, a safety management system involves planning, organizing, coordinating, and controlling safe production processes so that risks can be reduced or even mitigated. The principles of safety management were a science that combines practicality and experience. Some management components mainly focus on the negative aspects, that is, elements that are threats and failures, as opposed to opportunities and successes. The aim of managing risk is to put mitigation measures in place to develop a process that is preventive and avoid long-term damage. Imperative to safety management includes a risk management plan, that is, the potential issues, problems, or catastrophes are identified. Then, the impacts of these problems are evaluated, and each risk is addressed by planning for its impacts. As such, safety procedures are established, followed by training of staff around these procedures, which not only enhance management efficiency and reduce the risk impacts but also allow for safe production processes [5–8]. Ultimately, the goal is to realize that “all accidents can be avoided” and “all risks can be controlled.” Therefore, safety management should be the basis of all corporate cultures and one of their core values in their efforts towards a
comprehensive system for the management of safety, health, and the environment [9].

The elements of managing safety in coal mines are based on a comprehensive risk identification process. Any factor that affects the management of safety, health, and the environment and related to people, machines, and the environment should be taken into consideration to establish a management framework that emphasizes the identification of hazards. A list should be created of the targeted requirements [10]. The basis of risk assessment is to identify hazards or the trends in hazards which ultimately determine the real impact of the hazards. Hazard identification is finding potentially or existing problematic areas that can cause harm to a work unit or system in a coal mine and identifies the work activities and tasks that need to be assessed. These can be formal or informal assessments, with the former being documented and the latter as ongoing tasks and undocumented. Then, the appropriate controls are determined and carried out to address the hazards with emphasis on the hazards that pose the greatest risk. Then, the hazards are reviewed again and follow-up work is done to ensure that the controls have been carried out as intended. The follow-up also ensures that the controls have been effective and there are no new hazards created in the process [11]. Risk assessment can be quantitative or qualitative in determining the likelihood of specific risks occurring and their scope and the degree of losses. The results are usually ranked in severity [12, 13]. Therefore, the purpose of a risk assessment is to ensure that the risks of the production process and operations can be effectively identified and understood and minimize them so that they meet industry standards. The methods that are most often used to identify sources of hazards and assess risk include preliminary and quantitative risk assessments; hazard and operability, failure mode and effect, job safety and checklist, and fault tree analyses. However, workers need to be informed about hazards and trained to identify and assess them and use control measures to ensure work safety. Therefore, they should have a comprehensive orientation and their full participation has to be ensured in hazard identification and control strategies. Their input should also be solicited throughout the entire process from the feasibility study to operation phase so as to ensure their participation and enhance their risk awareness [14–17].

The elements for managing safety in coal mine systems are mutually influential yet distinct. There can be numerous positive and negative relationships. For example, when there is a high level of safety at work, production will increase, the benefits of enhancing safety are promoted which results in an increase in safety inputs, which in turn will increase commitment to safety and further improve the safety levels at work. Another example is that an increase in safety inputs will not only reduce the probability of accidents but also increase production, which in turn will increase the inputs. Of course, when the benefits of safety are relatively high, the investment in safety can be appropriately reduced, so as to control the production costs when the risk rate is not clearly increased. Based on the feedback, a system dynamics model of safety management in coal mines can be established [18, 19].

The degree of working safely in coal mining companies is affected and limited by three factors: people, resources, and the environment, and the status quo of these three factors is closely related to investment in safety by the companies. The various combinations of these factors affect the level of safety in coal mine production processes [20]. The investment of coal mining companies in the safety of its people, resources, and the environment can be considered to be investment in management and technology. The proportion of investment made in management and technology and allocated and the direction and amount of investment allocated to safety all depend on actual needs which not only reduce the likelihood of errors that affect people, resources, and the environment but also the likelihood of accidents. The benefits of ensuring safety are determined by the ratio of inputs and outputs [21–24]. Using the benefits of safety in the workplace as a measurement index quantifies intuitive expectations of safety standards [25]. Chinese coal mining companies strive to sustain safe production processes for the long term based on experience and implement safety policies based on the motto of “safety first, prevention is a priority and comprehensive intervention.” The management system for safe production processes should be specifically designed in consideration of the actual company environment, which may require a diversity of safety measures such as meetings; inspections; approval processes; targets, managing and handling incidents; dealing with unforeseen circumstances; investigating accidents and tracking their statistics; training, appraising, and rewarding or disciplining employees; and 100-day plan for safety.

After a management system is in place, the system should be evaluated on its effectiveness. There are many methods presented in the literature. For instance, Peng et al. [26] developed a multicriteria decision-making method to assess safety in coal mines, which uses a novel approach of linguistic intuitionistic fuzzy numbers (LIFNs) to describe the evaluation information, and propose the use of distance, a method of ranking and Frank operations. They demonstrate the effectiveness of the approach with a case study and validate its feasibility and effectiveness through a sensitivity analysis and a comparison with existing methods. Lee [27] established a quantitative model for assessing risk factors in aviation safety by evaluating all relevant estimation factors in accordance with their importance, degree of risk, detectability, likelihood of occurrence, urgency, and frequency. The model was validated through a case study. Hee et al. [28] established a screening system that incorporates a computer program for self-assessment in marine systems, which selects and trains operators to compare and evaluate incidents caused by human and organization factors. Wang et al. [29] used a nonlinear method to find the primary risk factors that lead to mining accidents and created a concept map of the risk factors with information from current related studies, which include criteria at the managerial, environmental, operational, and personal levels. They were evaluated and ranked by using a fuzzy analytic hierarchy process (AHP) to develop a management model which would give guidance to safety managers in the mining process. Wang et al. [30] proposed an early warning
indexing system based on the four factors of “personnel, environment, equipment, and management” and optimized a back-propagation neural network model by using measures for improvement such as an additional momentum, adaptive learning rate, a particle swarm optimization algorithm, weight variables, and an asynchronous factor for learning. Then, the model was applied to a comparative study of a sample of coal mines for early warning of safety issues. Liu et al. [31] proposed an indexing system for evaluating safety based on factors specific to coal mining and combined an AHP and gray clustering to establish a comprehensive model to ensure that the weight coefficients are accurate and objective. Li et al. [32] proposed an indexing system that assesses the results of risk evaluations for safety in coal mining and provided methods for advance warning of risks and methods to control risk. The resultant standards and measures can be used to mitigate unforeseen issues. Li et al. [33] used a multicriteria decision analysis method called the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) to create an indexing system that evaluates the safety of four coal mines in China. They then compared their method with other evaluation methods and demonstrate its robustness. Shen et al. [34] proposed an online fuzzy evaluation method that is a multicriteria evaluation for comprehensively assessing coal mines. They established a multilevel indexing system with both subjective and objective indicators. They applied their method to a case study that involves five coal mines under the jurisdiction of a coal mine company and demonstrated its effectiveness.

The success of using multicriteria decision-making models and fuzzy logic to manage safety in coal mines has been evident in the literature. Based on multicriteria decision-making models and fuzzy logic, an indexing system for evaluating factors that affect the management of safety in coal mines is proposed in this study, and an evaluation method that uses fuzzy mathematics is applied to examine a case study on safety management of the Fushan Coal Industry Co., Ltd. Coal Mine in Henan Province, China. The matrix that evaluates each factor is obtained through a membership function and scored by experts, and the weight of each attribute is obtained through an AHP. As a result, a safety rating for the Fushan Coal Industry Co., Ltd. Coal Mine is obtained which can be used to rate other similar mines in China.

2. Methodology

2.1. Influential Factors for Managing Safety in Coal Mines

As one of the imperative factors of the advanced modern management of safe production processes, safety evaluation plays an important role in improving the degree of intrinsic safety and managing the safety levels of coal mines, reducing the risks of coal mine production processes, preventing accidents, and ensuring safe production processes. It is therefore important to choose the most appropriate safety evaluation factors [35–39]. In the mining industry, these factors should address the main existing problems around safety in coal mines, which are then taken into consideration with existing laws, regulations, and procedures such as current safety regulations and on-site evaluations of experts. In this paper, the following influential factors are used to examine the management of safety in coal mines: the management of ventilation in mines, mine roof, and mine temperature. The factors also include mine dust, mining gas, and mining water hazards. Other factors are equipment reliability, explosive risk of equipment, daily and regular maintenance of equipment, staff operations and staff training, staff attendance, index to evaluate and manage workload, project quality, monitoring system, and safety information. All 17 factors are shown in Figure 1.

2.2. Construction of Comprehensive Evaluation Model to Manage Safety in Coal Mines

The fuzzy set theory was first proposed by computer scientist Lofti Zadeh (1965) to describe situations with vague data or data that are not precise, that is, to model phenomena in the real world. Zadeh (1965) proposed the use of a “membership function” which assigns a membership grade that ranges between zero and one to each object. This function transcends the limitations of the classical set theory, where the membership in a set is described in binary terms; the elements either belong or do not belong to the set. Fuzzy set and fuzzy logic theories are therefore the formal means of mathematically representing imprecise information and processing this information [40].

A comprehensive evaluation method based on multicriteria decision-making models that uses fuzzy mathematics is proposed in this study. This comprehensive evaluation method quantifies the fuzzy indexes that reflect the evaluated factors (i.e., the method determines the degree of membership) by constructing hierarchical fuzzy subsets and then studying the evaluation of each index by using fuzzy transformation. This method can deal with all kinds of complex system problems that are difficult to describe with mathematics. The method can be used to carry out quantitative evaluations of complex systems for managing safety in coal mines [41].

To formulate a quantitative mathematical model, it is necessary to define two finite domains as

\[
\begin{align*}
U &= \{u_1, u_2, \ldots, u_m\} \\
V &= \{v_1, v_2, \ldots, v_n\}
\end{align*}
\]

where \( U \) represents the set composed of all evaluation factors \( u_i \) and \( V \) represents all of the collected levels of ratings, \( v_i \).

Let \( i (i = 1, 2, \ldots, m) \) be the evaluation factor in \( U \), its single factor evaluation result is \( R_1 = [R_{11}, R_{12}, \ldots, R_{1n}] \). Then, the decision matrix with \( m \) evaluation factors is given in Equation (2), which provides the fuzzy relationship from \( U \) to \( V \). It is assumed that the weight vector of each evaluation factor is \( A = [a_1, a_2, \ldots, a_m] \), and \( \sum_{i=1}^{p} a_i = 1, a_i \geq 0, i = 1, 2, L L, n \).

\[
R = \begin{bmatrix}
R(u_1) \\
R(u_2) \\
R(u_p)
\end{bmatrix} = \begin{bmatrix}
\begin{bmatrix}
R_{11} & R_{12} & L & R_{1m} \\
R_{21} & R_{22} & L & R_{2m} \\
r_{p1} & r_{p2} & L & r_{pm}
\end{bmatrix} \\
L \\
L
\end{bmatrix}
\]
Then, the vector of the fuzzy evaluated result of each evaluated object is obtained through synthesis with each evaluated object by using an appropriate operator, namely,

\[ A \circ R = (a_1, a_2, L, L, a_p) \]

where \( A \) is the fuzzy vector of the evaluated object, \( R \) is the fuzzy vector of the operator, \( a_1, a_2, \ldots, a_p \) are the fuzzy values of the evaluated object, \( r_{11}, r_{12}, L, r_{1m} \) are the fuzzy values of the operator for the first evaluated object, and so on. The result of the operation is a new vector \( B \) with fuzzy values \( b_1, b_2, L, L, b_m \).

Finally, the concentration of the fuzzy set is calculated by using

\[ S = B \ast C^T, \]  

where \( C^T \) is the corresponding score of the factor. The final score \( S \) can be used to quantitatively evaluate the management of safety in coal mines.

3. Case Study

The Fushan Coal Industry Co., Ltd. Coal Mine is located northwest of Yuzhou City in Henan Province, China. This area is located on the edges of the southern part of the North China craton and the shallow part of the western flank of the Baisha-Xuchang syncline. The stratum has a northeast trend and the inclination is in the southeast direction. The terrain
of the mining area has large undulations. Overall, the terrain is elevated in the east and north, and lower in the west and south. There are low mountains and hills. The No. 21 Coal Seam of the Fushan Coal Industry Co., Ltd. Coal Mine runs along the first mine—the Guanshan No. 1, and the Zhaozhuang, Weiyou, and Hougou No. 1 Coal Mines. With the exception of the main shaft and system of the Guanshan No. 1 coal mine being used as the auxiliary inclined shaft after technical modifications, the other mines have been abandoned and no longer in use. The coal bearing strata in this area are the upper Carboniferous Taiyuan, lower Permian Shanxi, and Lower and Upper Shihezi formations, which have a total thickness of 706.40 m. The mined area has a monoclinal structure which has a northeast trend and an inclination in the southeast direction. The overall stratigraphic strike is in the NE-SW direction, and the dip angle ranges from 18° to 30°.

3.1. Determining Membership of Each Evaluation Factor and Constructing Evaluation Matrix. As one of the elements of the advanced modern management of safe production processes, safety evaluations play an important role and whether the development of a related indexing system is necessary is the key for carrying out safety evaluations. Managing safety in coal mines requires a complex and comprehensive indexing system, which directly affects the accuracy of the evaluation results. The following four attributes are needed to develop a robust indexing system:

(1) Scientific: the evaluation index must be obtained after an objective analysis and theoretical knowledge applied to ensure the clarity of the concepts and expand its applications

\[
\begin{align*}
\{ & u_i = \frac{a - x}{a - b} & (R_i \leq x \leq \frac{R_i + R_{i+1}}{2}, i = 1, 2, a = \frac{R_i + R_{i+1}}{2}, b = R_i) \\
& u_{i+1} = \frac{x - b}{2(a - b)}
\end{align*}
\]

\[
\begin{align*}
& u_1 = 1 - \frac{X}{2R_1} \\
& u_2 = \frac{X}{2R_1} & (X \leq R_1), \\
& u_3 = 0 \\
& u_4 = 0 \\
& u_5 = 1 - \frac{X}{2R_1} & (X > R_3).
\end{align*}
\]

(2) Systematic: the system needs to systematically focus on managing safety in coal mines and follows a certain hierarchical structure

(3) Generalizable: the established and selected indicators can be generalized but also unique or have different relevancy

(4) Independent: the selected indicators can describe the characteristics of the evaluated object but without duplication

First, the evaluation factor set is determined, \( U = \{\text{ventilation}, \text{mine dust}, \text{mine gas}, \text{mining water hazard prevention}, \text{mine roof}, \text{mine temperature}, \text{equipment reliability}, \text{explosive risk of equipment}, \text{daily maintenance of equipment}, \text{regular maintenance of equipment}, \text{staff operations}, \text{staff training}, \text{staff attendance}, \text{workload}, \text{project quality}, \text{monitoring system}, \text{and safety information}\} \). Then, the membership of each evaluation factor is determined. First, the set of ratings is determined, which has five levels in this study based on real-life scenarios, that is, the set of ratings \( V = \{\text{excellent}, \text{good}, \text{fair}, \text{poor}, \text{and very poor}\} \). A linear analysis method is used, which adopts a uniform distribution as the membership function of each factor and determines the degree of membership of each evaluation factor. In this method, a series of values that form the demarcation of the boundaries are determined in a continuous interval, and then, the values of the actual factor are processed by using a linear interpolation to obtain the degree of membership that corresponds to a factor. For a given factor, the degree of membership is determined from Equation (5) for uniform distribution.
For the membership of the other qualitative factors, experts are used in the scoring process. In order to eliminate the adverse effects of the maximum, minimum, and abnormal scores and focus on the average score of the experts, the scores of some of the uncertain factors $C_i$ are treated as follows, so as to obtain the membership of the factors:

$$a_i = \frac{b_i + (N - 2)p + d_i}{100N},$$

(6)

where $a_i$ is the degree of membership of a nondeterministic factor $C_i$, the average value of $C_i$ scores by $N$ experts, $b_i$ is the score below the average score, and $d_i$ is the score above the average score.

Based on an actual scenario of the Fushan Coal Industry Co., Ltd. Coal Mine, each set of factors is determined by using Equation (5), and the evaluation matrix $R$ is obtained. In order to eliminate the influence of different physical dimensions on the decision results, the decision matrix $R'$ can be converted into a normalized matrix $R = (r_{ij})_{m \times n}$, where

$$y_{ij} = \left( \frac{\min_i x_{ij} - x_{ij}}{x_{ij} - \max_i x_{ij}}, \frac{\max_i x_{ij} - \min_i x_{ij}}{x_{ij} - \min_i x_{ij}} \right),$$

(3.2)

$$y_{ij} = \left( \frac{\max_i x_{ij} - x_{ij}}{x_{ij} - \min_i x_{ij}}, \frac{\max_i x_{ij} - \min_i x_{ij}}{x_{ij} - \min_i x_{ij}} \right),$$

(3.3)

$$R = \begin{bmatrix}
0.20 & 0.20 & 0.10 & 0.11 & 0.28 & 0.32 & 0.22 & 0.32 & 0.28 & 0.20 & 0.30 & 0.42 & 0.23 & 0.33 & 0.28 & 0.32 & 0.30 \\
0.20 & 0.30 & 0.20 & 0.29 & 0.22 & 0.38 & 0.28 & 0.38 & 0.30 & 0.30 & 0.38 & 0.17 & 0.27 & 0.32 & 0.34 & 0.30 \\
0.10 & 0.10 & 0.25 & 0.22 & 0.20 & 0.15 & 0.13 & 0.30 & 0.32 & 0.30 & 0.20 & 0.18 & 0.34 & 0.28 & 0.28 & 0.27 & 0.40 \\
0.30 & 0.20 & 0.20 & 0.18 & 0.15 & 0.10 & 0.17 & 0 & 0.02 & 0.10 & 0.12 & 0.02 & 0.16 & 0.12 & 0.12 & 0.07 & 0 \\
0.20 & 0.20 & 0.25 & 0.10 & 0.15 & 0.05 & 0.20 & 0 & 0 & 0.10 & 0.08 & 0 & 0.10 & 0.02 & 0 & 0 & 0
\end{bmatrix}^T.$$

(7)

### 3.2. Determining Weight Vector of Evaluation Factors

Saaty [42] first proposed the concept of AHP weighting, which is a pairwise comparison method for the decision-making of complex multiobjective problems. The AHP is used to systematically disaggregate decisions into different hierarchical levels. In the first level is the aim, followed by the main criteria of a problem which can be divided into lower levels of subcriteria, or levels of indicators or constraints. Pairwise comparisons at each level are subjectively described in terms of their importance by using an $n \times n$ judgement matrix; $C = [c_{kp}]_{n \times n}$, where $c_{kp}$ denotes the $k^{th}$ and $p^{th}$ attributes of the pairwise comparison, which is determined by the judgement and analysis of experts. The pairwise comparisons are evaluated based on a relative scale proposed in Saaty [31]. This scale ranges from 1 to 9, as shown in Table 1.

<table>
<thead>
<tr>
<th>Scale</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equal importance</td>
</tr>
<tr>
<td>3</td>
<td>Moderate importance</td>
</tr>
<tr>
<td>5</td>
<td>Strong importance</td>
</tr>
<tr>
<td>7</td>
<td>Very strong importance</td>
</tr>
<tr>
<td>9</td>
<td>Extreme importance</td>
</tr>
</tbody>
</table>

Matrix $C$ is a positive reciprocal matrix. All of the diagonal elements are equal to 1, that is, when $k = p$, $c_{kp} = 1$. Therefore, only the actual judgement of $n(n-1)/2$ pairs is required. After the judgement matrix is established, the weight vector $w = [W_1, W_2, \cdots, W_n]$ can be calculated. If $\lambda_{\text{max}}$ is the maximum eigenvalue of matrix $C$, then

$$Cw = \lambda_{\text{max}}w.$$

(8)

Although Saaty [31] proposed many methods to solve the weight vector, one of the more commonly used methods is the normalization method. First, matrix $C$ is normalized:

$$c'_{kp} = \frac{c_{kp}}{\sum_{k=1}^{n} c_{kp}}, k = 1, 2, \cdots, n.$$

(9)

Then, the weight is calculated by using Equations (10) and (11):

$$w_k = \frac{\sum_{p=1}^{n} c'_{kp}}{n}, k = 1, 2, \cdots, n.$$

(10)
From the evaluation result Industry Co., Ltd. Coal Mine.

3.3. Fuzzy Comprehensive Evaluation of Fushan Coal

To ensure the accuracy of the judgement and analysis of experts, the matrix needs to be tested for consistency in order to ensure the accuracy of the weight vector. CI denotes the consistency index of the matrix, which is calculated as follows:

\[
CI = \frac{\lambda_{\text{max}} - n}{n - 1}.
\]

The consistency index is then compared with a random consistency index to see if \( CR < 0.1 \), see Table 2.

Then, the consistency ratio is calculated which compares the consistency and random consistency indexes:

\[
CR = \frac{CI}{RI},
\]

when \( CR < 0.1 \), the inconsistency of the judgement matrix is acceptable. When \( CR \geq 0.1 \), the inconsistency of the judgement matrix is not acceptable, and the judgement matrix \( C \) needs to be revised. The weight vector of each factor is obtained, \( A = [0.0835, 0.0985, 0.0762, 0.0645, 0.05584, 0.07586, 0.06582, 0.02354, 0.08569, 0.07895, 0.06895, 0.03852, 0.03585, 0.04582, 0.04565, 0.02588, 0.03093] \).

<table>
<thead>
<tr>
<th>Relative importance</th>
<th>Definition</th>
<th>( p ) is just as important as factor ( k ) when compared to each other</th>
<th>( p ) is slightly more important than factor ( k )</th>
<th>( p ) is more important than factor ( k )</th>
<th>( p ) is significantly more important than factor ( k )</th>
<th>( p ) is extremely more important than factor ( k )</th>
<th>Median value of factors ( p ) and ( k )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>Factor ( p )</td>
<td>Factor ( p )</td>
<td>Factor ( p )</td>
<td>Factor ( p )</td>
<td>Factor ( p )</td>
<td>Factor ( p )</td>
</tr>
<tr>
<td>2, 4, 6, 8</td>
<td></td>
<td>( c_{pk} ) = ( c_{kp} )</td>
<td>( c_{pk} )</td>
<td>( c_{kp} )</td>
<td>( c_{kp} )</td>
<td>( c_{kp} )</td>
<td>( c_{kp} )</td>
</tr>
</tbody>
</table>

\[
W = \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} = \begin{bmatrix} \frac{1}{n} \sum_{i=1}^{n} c_{1i}' \\ \frac{1}{n} \sum_{i=2}^{n} c_{2i}' \\ \vdots \\ \frac{1}{n} \sum_{i=n}^{n} c_{ni}' \end{bmatrix}.
\]

Since the judgement matrix is established based on the judgement and analysis of experts, the matrix needs to be consistent to ensure the accuracy of the weight vector. \( CR < 0 \) when \( CR < 0 \) when the consistency and random consistency indexes:

\[
\text{Consistency} = \frac{\sum_{i=1}^{n} c_{ii}'}{n},
\]

\[
\text{Random Consistency} = \frac{\sum_{i=1}^{n} c_{ii}'}{n}.
\]

\[
CR = \frac{\text{Consistency}}{\text{Random Consistency}}.
\]

\[
\text{Median} = \frac{\text{Consistency} + \text{Random Consistency}}{2}.
\]

4. Conclusion

A multicriteria decision-making model for managing safety in coal mines based on fuzzy set is constructed, which includes 17 factors for managing safety, including ventilation, mine dust, mine gas, mining water, mine roof, mine temperature, equipment reliability, explosive risk of equipment, daily maintenance of equipment, regular maintenance of equipment, staff operations, staff training, staff attendance, workload, project quality, monitoring system, and safety information.

Taking the safety management of the Fushan Coal Industry Co., Ltd. Coal Mine as an example, the evaluation matrix of each factor is obtained through membership function and expert scoring. After conducting an analytic hierarchy process, this coal mine receives a good rating. Nevertheless, there is room for improvement as this mine needs to optimize the mine ventilation system. This method can be used as to evaluate the management of safety in coal mines in China.

Data Availability

The datasets generated during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

No conflicts of interest exist in the submission of this manuscript, and all of the authors approve the manuscript for publication.

Acknowledgments

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