

Article

Coal Mine Fire Emergency Rescue Capability Assessment and Emergency Disposal Research

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Abstract: Nowadays, underground coal mine accidents occur frequently, causing huge casualties and economic losses, most of which are gas explosion accidents caused by fires. In order to improve the emergency rescue capability of coal mine fires and reduce the losses caused by coal mine fires, this article is dedicated to the assessment of coal mine fire rescue capability. Taking the fire emergency rescue system of Lugou mine as an example, based on the introduction of gray system theory and gray evaluation method, an evaluation model was established to assess the risk of the fire emergency rescue index system of Lugou mine. Four primary and 19 secondary indicators were delineated, and a hierarchical structure model of the fire emergency rescue capability of the Lugou mine was established by combining expert opinions, and the weights of indicators at all levels were calculated by using hierarchical analysis. We then used the gray system evaluation method and expert scoring to judge the safety level of various indicator factors in the index system. The evaluation results show that the risk level of the emergency rescue system of the Lugou mine fire is higher than the fourth level. The main risk indicator factors are firefighting equipment, decision-making command, emergency education and training, and fire accident alarm. In response to this evaluation result, corresponding control measures were formulated in four aspects: rescue organization guarantee, personnel guarantee, material guarantee, and information guarantee, which optimally improved the emergency rescue capability of the Lugou mine fire and reduced the loss caused by fire.

Keywords: coal mine fire; emergency rescue; grey evaluation method; hierarchical analysis; risk assessment



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1. Introduction

China is very rich in coal resources, and as an important source of energy for the country, it occupies a crucial position in the sustainable development of the national economy [1,2]. According to statistics, about 70% of mega-accidents and 50% of major accidents occur in the coal industry [3]. Nowadays, underground accidents in coal mines are frequent, causing huge casualties and economic losses. The majority of these accidents are caused by fire-induced gas explosions, with the severity of death reaching more than nine people per fire accident, and the severity of death in all other accidents is less than that of fire accidents, so coal mines need to pay sufficient attention to fire [4–6]. In recent years, China's coal enterprises also generally pay attention to the prevention of coal mine fire accidents, and the construction of a major disaster prevention and protection system for China's coal enterprises has gone through five stages: passive prevention, traditional empirical prevention pre-prevention post-prevention, systematic prevention and protection, and systematic scientific management [7–9]. At present, most of China's coal enterprises are still in the fourth stage, and the emergency rescue construction of China's coal enterprises still has problems in all aspects.

An objective evaluation of the emergency rescue system of coal enterprises can make the emergency management of coal enterprises more scientific and reasonable, continuously improve the emergency management of coal enterprises, and make the emergency

rescue work relevant. Yan Liang et al. [10,11] proposed a step-by-step evaluation method of emergency rescue collaborative capability based on AHP-fuzzy comprehensive evaluation in order to study the evaluation of emergency rescue collaborative capability in coal mines with the participation of multiple subjects. Han et al. [12] applied wireless sensor technology to a mine emergency rescue system to meet the needs of mine safety production and designed an intelligent sensor node for underground disaster emergency rescue to accomplish emergency rescue and hazard prediction of underground coal mine disaster accidents. Liu et al. [13] combined virtual reality (VR) technology, used Unity3D as the development platform and established a coal mine fire emergency rescue VR training system based on the common fire handling process in coal mines to improve the efficiency of comprehensive emergency disposal on site. Wu et al. [14] analyzed the construction of China's coal mine emergency system and the current situation of fire emergency rescue and put forward some suggestions for the development of China's coal mine fire emergency rescue. Zhang et al. [15] analyzed the current situation of coal mine fire accident rescue technology, discussed the problems of fire rescue technology and equipment in emergency rescue, and proposed a technical solution for fire accident rescue equipment. Gao et al. [16] improved the coal mine emergency rescue command information system designed by improving the whole process of coal mine accident emergency command and comprehensively improved the emergency organization ability, rescue guarantee ability, and command coordination ability of coal mine enterprises. Wang et al. [17] discussed the emergency avoidance and emergency rescue techniques in underground coal mines, strengthened the supervision and analysis of emergency avoidance and emergency rescue measures within each enterprise, and paid great attention to the possible fire and explosion problems in the coal mining process. Cheng et al. [18] proposed a maturity evaluation model of coal mine emergency rescue capability to quantitatively evaluate the emergency rescue capability of coal mines and clarify the shortcomings of coal mines in the process of emergency rescue capability construction. Bhattacharjee et al. [19] present the response time of a proposed system for detecting fire hazards in a bord-and-pillar coal mine panel. It uses wireless sensor networks (WSNs) and can be used to detect the exact fire location and spreading direction; and also provide a fire prevention system to stop the spread of fire to save the natural resources and the mining personnel from fire. Barros-Daza et al. [20] proposed a data-driven approach that can provide mine firefighters with the most appropriate decisions in real time during an ongoing underground coal mine fire. The method used a feed-forward artificial neural network (ANN) to classify fires in order to provide the best decision considering only measurable parameters in underground coal mines. Onifade et al. [21] outlined the identification of safety practices, mine rescue teams and their tasks, and safety management and showed that preparation for self-rescue is one of the most important factors in an organized and timely emergency response to mines. The control of fires and gas leaks by Özmen et al. [22] provided an immediate method for rescue efforts for fatalities or injuries and for detecting personnel who need to be resuscitated outside the mine that evacuation and recovery operations should be guided by continuous monitoring of the mine environment due to fire and explosion risks. The above-mentioned scholars have conducted certain research on domestic and international coal mine emergency response capabilities, but there is little research on the assessment of emergency rescue capabilities related to coal mine fires.

Conducting research on the evaluation of emergency rescue security for coal mine fires can make emergency rescue work relevant. This can make the fire emergency rescue work carried out in the process of scientific and procedural. Thus, emergency rescue work can play an effective role in the event of a fire. Based on this, the evaluation method built on the basis of gray system theory in this paper can not only make a comprehensive evaluation of the overall emergency rescue capacity of coal mine fires but can also give the corresponding risk weighting results for the evaluation indexes, which makes the evaluation results more reasonable and scientific.

2. Theoretical Basis

2.1. Brief Description of Grey System Theory

Grey System Theory (GST) was first proposed by Professor Deng Julong of the Huazhong University of Technology in the 1980s in his published book *Control Problems of Grey Systems* [23]. This theory takes the system's discipline perspective as the entry point and successfully achieves the study of uncertainty problems through the use of applied mathematics. The main target of this theory is the case where the underlying data is small, and some information is not clear. The theory considers that information systems are not only composed of white systems with completely transparent information and black systems with completely opaque information but also gray systems with partially clear and partially unclear information that often exist [24–26]. Since some of the information is known, gray theory can be explored to understand the operation of the whole system by exploring the known information; plus, it has no special requirements on the system data distribution and changes, so it has a very wide range of applications.

2.2. Grey System Evaluation Method

Usually, there are three research methods involving information uncertainty, namely, the fuzzy comprehensive evaluation method, the probability statistics method, and the gray system evaluation method. Among them, the fuzzy comprehensive evaluation method is a comprehensive evaluation method based on fuzzy mathematics, and the theory is very widely used. It mainly transforms the qualitative evaluation of the evaluation subject into quantitative evaluation through the determination of the affiliation degree and determines the weight vector of the evaluation index through the AHP hierarchical risk method. It can be well applied to research problems with unknown data sources and difficult to quantify, and the evaluation conclusions are relatively accurate and more in line with the actual situation, with the disadvantage that the conclusions are somewhat subjective [27–29]. The probability distribution method is an evaluation method based on mathematical statistics created to study relatively scattered data. The method has high requirements for the underlying data, but the conclusions tend to be relatively reliable [30,31]. The gray system evaluation method is used in the study of uncertain information systems to make a scientific prediction and evaluation analysis of the system by studying the laws embedded in the system. This method requires less basic data, and its conclusions are more researchable compared to the fuzzy synthesis evaluation method. This is because the gray system evaluation method is able to make an objective assessment not only of the project as a whole but also of the subdivided secondary and tertiary indicators of the project [32,33]. Although all three research methods are able to study systems with uncertain information, gray system theory is more feasible in practice compared to the other two research methods.

2.3. Operation Process of Gray System Evaluation Method

2.3.1. Establishing Factors Affecting the Evaluation Index System

By identifying the construction factors of the Lugou coal mine fire emergency rescue system through hierarchical analysis, the influencing factors were divided into three levels, which belong to the three-level gray comprehensive evaluation.

2.3.2. Determination of Assessment Index Weights

Based on the results of the questionnaire of the expert group, the discriminant matrix of the importance of the risk of the assessment indexes was constructed by a two-by-two comparison. Then, based on the expert discriminant matrix, the weight values of the risk indicators of the assessment were obtained by applying the hierarchical analysis method. Next, the results obtained above were corrected using a gray correlation, and the weight results of each assessment index were obtained.

(1) Each factor in the criterion layer is compared separately in each element (scheme) in the scheme layer. Their importance is scored using the numbers in the interval (1, 9) to form a judgment matrix. After the consistency ratio test $C \times R = \frac{\lambda_{max} - n}{(n-1)R \times I} < 0.1$ is met, the weight direction $w_i' = (w_1, w_2, \dots, w_5)$ is obtained. Normalization is performed to obtain w_i , which satisfies $0 \leq w_i \leq 1, i \leq 1$ and $\sum_{i=1}^k w_i = 1$.

The values of the consistency check table RI can be referred to in Table 1.

Table 1. The values of the consistency check table RI.

Matrix Order	3	4	5	6	7	8	9	10	11	12
$R \times I$	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49	1.52	1.54

Several power species vectors are combined to obtain a matrix X with k rows and n columns.

$$X = \begin{bmatrix} X_{11} & X_{12} & \dots & X_{1n} \\ X_{21} & X_{22} & \dots & X_{2n} \\ \vdots & \ddots & \ddots & \vdots \\ X_{k1} & X_{k2} & \dots & X_{kn} \end{bmatrix} \quad (1)$$

(2) Select a maximum weight value from matrix W as the maximum reference value and reassign this value to the other weight values in matrix A to obtain the reference data column $X_0 = (X_0(1), X_0(2), \dots, X_0(N))$. Next, each indicator series $X_1, X_2, \dots, X_n$ and the distance between the reference data column W_0 .

$$D_{0i} = \sum_{k=1}^m (X_0(k) - A_i(k))^2, i = 1, 2, 3, 4 \dots n \quad (2)$$

Then, the weight value of each evaluation index:

$$W_i = \frac{1}{1 + D_{0i}} \quad (3)$$

Calculate the indicator weights using the normalization method:

$$W_i^* = \frac{w}{\sum_{i=1}^n W_i} \quad (4)$$

Finally, the combination weights in the secondary indicator layer are calculated.

(3) Determine the weight of each risk factor of the gray category and whitening weight function of the risk assessment index as $W = \{W_1, W_2, W_3, \dots, W_n\}$ and the evaluation matrix as $B_{ij} (B_{ij} = W_i \times R_{ij})$, where: $W_1 + W_2 + \dots + W_n = 1$.

The comprehensive gray evaluation value W is obtained by single valorization, and the specific operation is to assign values according to each gray class level. Since there are k evaluation gray classes, the comprehensive gray evaluation value of the evaluated item can be expressed as:

$$W = B \times (\lambda_1, \lambda_2, \dots, \lambda_k)^T \quad (5)$$

W is the gray number and the comprehensive gray evaluation value of the evaluated item. Finally, W can be substituted into the whitening weight function of each evaluated gray class, and the gray class rank to which W belongs can be determined by comparing the magnitude of the result of each of its whitening weight functions.

3. Project Case

3.1. Overview of Lugou Coal Mine and Fire Analysis

3.1.1. Basic Overview of Lugou Mine

Lugou Mine is located northeast of Fengfeng Mining District, 26 km from Handan City in the east, 13 km and 25 km from Fengfeng Mining District and Magnetic County in the south, and 20 km from Wu'an City in the north. The mine's railroad line is connected to the Beijing–Guangzhou Line at Matou Station. The mine is conveniently connected to S211 provincial highway to the west, the Qinglan highway to the north, the Handan ring city to the east, and roads to Handan, Wu'an, Fengfeng, and Matou cities, counties, and towns. The administrative area belongs to Lugou Town of Wu'an City; geographical coordinates: 114°20'25" E, 36°45'35" N. The west and south of the well field are adjacent to Dashe Mine and Xintun Mine, respectively, and the F1 and F14 positive faults form the natural boundary of the well field in the north and south, respectively, while the southwest is adjacent to Dashe Mine and the southeast is adjacent to Xintun Mine, and the east and west are bounded by man-made boundaries respectively.

The coal seams mined in the Lugou Mine are mainly the Carboniferous Benxi Group, Taiyuan Group, and Permian Shanxi Group, of which Taiyuan Group and Shanxi Group are the main coal-bearing seams in the area. The No.2 (big) coal of the Shanxi Group and No.4 (wild green) coal of the Taiyuan Group are the main coal seams mined in the mine. The No.2 (big) coal seam is located in the lower part of the Shanxi Group of the Permian System, and the upper part is about 45 m away from the Camel Neck Sandstone at the bottom of the Lower Stone Box Group. The lower part is 23~40 m from the No.4 coal seam, averaging 35 m. The coal thickness is 1.95~7.15 m, averaging 4.84 m, which is one of the main mineable coal seams. The mineable area is 8.05 km², with an assigned elevation of −250~−800 m and a burial depth of 473.26~963.71 m. The No.4 (Wild Green Coal) coal seam is located in the upper part of the Taiyuan Group, with a coal thickness of 0.45~1.94 m, averaging 1.22 m, a coal thickness variation coefficient of 31%, and a recoverability index of 0.89. The coal seam has an assigned elevation of −300~−850 m and a burial depth of 510~1000 m. At 1000 m, the coal-bearing area is 6.85 km², which is a relatively stable and mostly recoverable coal seam.

3.1.2. Analysis of Coal Mine Fire Accidents

As coal mines increase in depth, so do the disasters in the mines, among which the chances of coal mine fires increase. When a fire occurs, the first thing to know is the conditions under which it occurred and where it is likely to occur, develop certain measures for the likely location, and understand the emergency response organization and its responsibilities in the event of a fire.

Fires must occur under certain conditions: combustibles, oxygen, and heat sources. According to the different combustibles, the occurrence of fire can be divided into spontaneous combustion fire and external fire. Among them, combustible materials, oxygen, and heat sources are the conditions necessary for the occurrence of external fires. External fires occur because of prevention, and control must be based on the conditions of their occurrence to start. The necessary conditions for the occurrence of internal fires are oxygen, combustible materials, and combustible materials in the slow oxidation process of accumulating energy. Oxygen in the air is consumed in the combustion process. Mining areas and high-riser areas of the roadway are prone to accumulate gas, and when mine fires occur, they can cause gas explosions to a large extent, posing a serious threat to the lives of underground miners.

3.2. Coal Mine Fire Emergency Rescue Capability Evaluation Index

(1) Rescue Organization Guarantee

Fire accidents in coal mines are generally more significant. In order to prevent them from happening, coal mines with better organizational management capabilities are a must. Therefore, the organizational management capabilities of the coal mine should mainly include the reasonableness of the organizational set-up of the fire emergency rescue, the

decision-making and command capabilities of the fire emergency response agency, the ability to resume the accident investigation and learn from the accident, the soundness and reasonableness of the rules and regulations documents of the fire emergency rescue, the thoroughness and flexibility of the emergency plan, and another five aspects.

(2) Personnel Guarantee

The construction of personnel security is the basis of emergency work in coal mines, such as the level of experts in emergency rescue in coal mines. The ability of on-site rescue, medical, security, and other personnel; the basic quality of employees; the effectiveness of emergency education and training for the quality of employees; reasonable scope and frequency of exercises; evaluation of the effectiveness of exercises; and continuous improvement of the rescue system. Personnel security is mainly evaluated from five aspects: rescue experts, rescue team, staff quality, emergency education and training, and rehearsal and improvement of the plan.

(3) Information Guarantee

The information security construction of coal mining enterprises is the focus of emergency work in coal mine fires, such as the swiftness of communication, the swiftness of accident alarms, and the completeness of information resources such as hazard source databases. Therefore, the level of information security in coal mines is mainly assessed in five aspects, such as communication and liaison, on-site monitoring, accident alarm, information resources, and personnel positioning.

(4) Material Guarantee

Material security is the basis of emergency work in coal mines, and it is also particularly important because adequate material security is a prerequisite for emergency rescue. Material security is mainly assessed from four aspects: the equipment of the enterprise, the reserve of materials and the deployment of transportation, and the supply of materials.

3.3. Establishing a Risk Assessment Index System

Because of the complexity of the emergency management system for coal mine fires, it is important to conduct a comprehensive and objective evaluation. From the identification of the main index factors in Section 3.2, it can be concluded that the evaluation index system consists of three parts: one is the target, the second is the primary index, and the third is the secondary index, and the corresponding set of factors is:

$$A = \{C_1, C_2, \dots, C_{19}\} \quad (6)$$

Target coal mine emergency rescue capacity indicators, the first-level indicators are divided into the following four areas: organizational security, personnel security, information security, and material security. The secondary indicators consist of 19 evaluation indicators, as shown in Figure 1. Among them, 1~5 of the secondary indicators belong to the first-level indicators of organizational security, 6~10 of the secondary indicators belong to the first-level indicators of personnel security, 11~15 of the secondary indicators belong to the first-level indicators of information security, and 16~19 of the secondary indicators belong to the first-level indicators of material security.

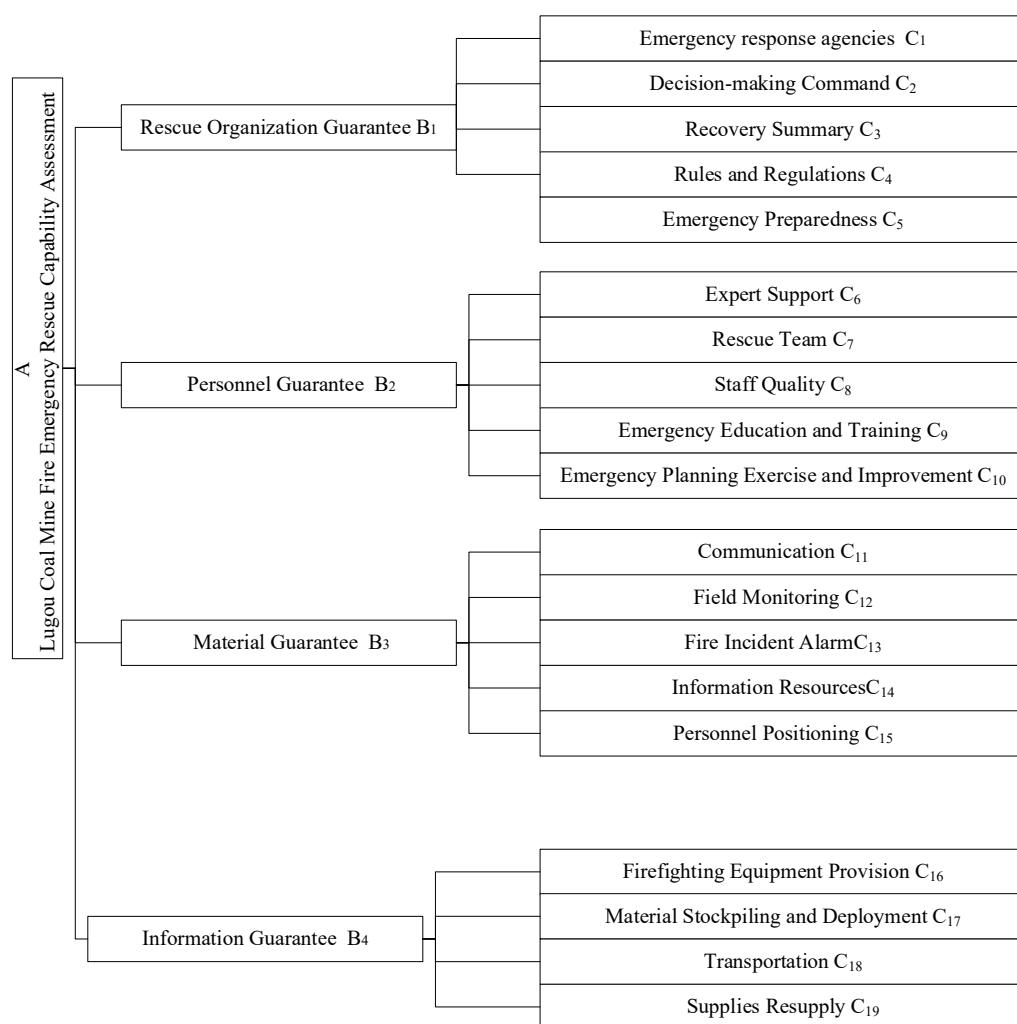


Figure 1. Hierarchy of emergency response capabilities for the Lugou Mine fire.

3.4. Determination of Weights

3.4.1. Calculating the Weight of First-Level Indicators

(1) Determination of weights is the primary link in the use of the gray evaluation model. The general gray correlation to determine the index weights often leads to changes in the final correlation results due to the fluctuation of the correlation coefficient in the formula. In order to avoid this, this paper adds the normalization method to the gray correlation coefficient to determine the evaluation index weights.

Forty experts were invited to conduct a questionnaire survey, and then the results of each ten experts were divided into one group. After obtaining the results of four expert groups, the average results of each group were obtained separately. First, the correlation of the weights of the four evaluation indicators of the first level indicator layer of rescue organization security, personnel security, material security, and information security was judged, and the corresponding weight empirical values were obtained by two-by-two comparison according to the risk hierarchy analysis chart. Finally, the risk judgment matrices of the five expert groups were constructed separately, as shown in Tables 2–5.

$$A_1 = \begin{bmatrix} 1 & 1/3 & 1/2 & 2 \\ 3 & 1 & 2 & 1/6 \\ 2 & 1/2 & 1 & 4 \\ 1/2 & 6 & 1/4 & 1 \end{bmatrix} \quad (7)$$

$$A_2 = \begin{bmatrix} 1 & 1/2 & 1/2 & 1 \\ 2 & 1 & 1 & 2 \\ 2 & 1 & 1 & 2 \\ 1 & 1/2 & 1/2 & 1 \end{bmatrix} \quad (8)$$

$$A_3 = \begin{bmatrix} 1 & 1/2 & 1/3 & 1 \\ 2 & 1 & 1/2 & 2 \\ 3 & 2 & 1 & 3 \\ 1 & 1/2 & 1/3 & 1 \end{bmatrix} \quad (9)$$

$$A_4 = \begin{bmatrix} 1 & 1 & 1/3 & 1/2 \\ 1 & 1 & 1/3 & 1/2 \\ 3 & 3 & 1 & 3 \\ 2 & 2 & 1/3 & 1 \end{bmatrix} \quad (10)$$

Table 2. A₁-B Judgment Matrix.

Target Layer A ₁	B ₁	B ₂	B ₃	B ₄
B ₁	1	1/3	1/2	2
B ₂	3	1	2	1/6
B ₃	2	1/2	1	4
B ₄	1/2	6	1/4	1

Table 3. A₂-B Judgment Matrix.

Target Layer A ₂	B ₁	B ₂	B ₃	B ₄
B ₁	1	1/2	1/2	1
B ₂	2	1	1	2
B ₃	2	1	1	2
B ₄	1	1/2	1/2	1

Table 4. A₃-B Judgment Matrix.

Target Layer A ₃	B ₁	B ₂	B ₃	B ₄
B ₁	1	1/2	1/3	1
B ₂	2	1	1/2	2
B ₃	3	2	1	3
B ₄	1	1/2	1/3	1

Table 5. A₄-B Judgment Matrix.

Target Layer A ₄	B ₁	B ₂	B ₃	B ₄
B ₁	1	1	1/3	1/2
B ₂	1	1	1/3	1/2
B ₃	3	3	1	3
B ₄	2	2	1/3	1

Using the feature vector method to find out the weight of the five expert groups on the first level indicator layer using Python, respectively, the judgment result is:

$$X_1 = (0.1852, 0.2463, 0.3445, 0.2267) \quad (11)$$

The maximum eigenvalue $\lambda_{max} = 6.1314$ and checking Table 1 gives $R * I = 0.89$. Substituting into the formula gives $C \times R = \frac{\lambda_{max} - n}{(n-1)R \times I} = \frac{6.1314 - 4}{(4-1) \times 0.89} = 0.7983 < 0.1$,

indicating that the discriminant matrix satisfies the consistency requirement, which means that the obtained eigenvectors are valid.

Using the feature vector method to find out the weight of the five expert groups on the first level indicator layer using Python, respectively, the judgment result is:

$$X_2 = (0.1667, 0.3333, 0.3333, 0.1667) \quad (12)$$

The maximum eigenvalue $\lambda_{max} = 4.0000$ and checking Table 1 gives $R \times I = 0.89$. Substituting into the formula gives $C \times R = \frac{\lambda_{max}-n}{(n-1)R \times I} = \frac{4-4}{(4-1) \times 0.89} = 0 < 0.1$, indicating that the discriminant matrix satisfies the consistency requirement, which means that the obtained eigenvectors are valid.

Using the feature vector method to find out the weight of the five expert groups on the first level indicator layer using Python, respectively, the judgment result is:

$$X_3 = (0.1412, 0.2627, 0.4450, 0.1411) \quad (13)$$

The maximum eigenvalue $\lambda_{max} = 4.0104$ and checking Table 1 gives $R \times I = 0.89$. Substituting into the formula gives $C \times R = \frac{\lambda_{max}-n}{(n-1)R \times I} = \frac{4.0104-4}{(4-1) \times 0.89} = 0.0039 < 0.1$, indicating that the discriminant matrix satisfies the consistency requirement, which means that the obtained eigenvectors are valid.

Using the feature vector method to find out the weight of the five expert groups on the first level indicator layer using Python, respectively, the judgment result is:

$$X_4 = (0.2136, 0.2136, 0.2136, 0.3592) \quad (14)$$

The maximum eigenvalue $\lambda_{max} = 4.0606$ and checking Table 1 gives $R \times I = 0.89$. Substituting into the formula gives $C \times R = \frac{\lambda_{max}-n}{(n-1)R \times I} = \frac{4.0606-4}{(4-1) \times 0.89} = 0.0227 < 0.1$, indicating that the discriminant matrix satisfies the consistency requirement, which means that the obtained eigenvectors are valid.

(2) Using the improved gray correlation to determine the weight of the judgment indicators, five expert groups have given the corresponding weight empirical values for the five first-level judgment indicators in the criterion layer, which we can form into a new risk judgment matrix.

$$X = (X_1, X_2, X_3, X_4)^T = \begin{bmatrix} 0.1852 & 0.1667 & 0.1412 & 0.2136 \\ 0.2436 & 0.3333 & 0.2627 & 0.2136 \\ 0.3445 & 0.3333 & 0.4550 & 0.2136 \\ 0.2267 & 0.1667 & 0.1411 & 0.3592 \end{bmatrix} \quad (15)$$

① Composition of the reference judgment matrix. From the matrix, we select a maximum weight value as the common reference weight value and then reassign this weight value to the reference weight values of each of the five expert groups to form a new reference sequence X_0 , and then add X_0 to the discriminant matrix x to form a new matrix.

$$X = \begin{bmatrix} X_0 \\ X_1 \\ X_2 \\ X_3 \\ X_4 \end{bmatrix} = \begin{bmatrix} 0.4550 & 0.4550 & 0.4550 & 0.4550 \\ 0.1852 & 0.1667 & 0.1412 & 0.2136 \\ 0.2436 & 0.3333 & 0.2627 & 0.2136 \\ 0.3445 & 0.3333 & 0.4550 & 0.2136 \\ 0.2267 & 0.1667 & 0.1411 & 0.3592 \end{bmatrix} \quad (16)$$

② Calculate the distance between each indicator sequence X_1, X_2, X_3, X_4, X_5 and the reference sequence X_0 .

$$D_{oi} = \sum_{k=1}^4 (X_{ok} - X_{ik})^2 \quad (17)$$

$$D_{o1} = \sum_{k=1}^4 (X_{ok} - X_{1k})^2 = 0.3127 \quad (18)$$

$$D_{o2} = \sum_{k=1}^4 (X_{ok} - X_{2k})^2 = 0.1548 \quad (19)$$

$$D_{o3} = \sum_{k=1}^4 (X_{ok} - X_{3k})^2 = 0.0853 \quad (20)$$

$$D_{o4} = \sum_{k=1}^4 (X_{ok} - X_{4k})^2 = 0.2429 \quad (21)$$

③ Find the weights of each indicator.

Calculate the distance between each indicator sequence X_1, X_2, X_3, X_4, X_5 and the reference sequence X_0 .

$$D_{oi} = \sum_{k=1}^4 (X_{ok} - X_{ik})^2 \quad (22)$$

④ Calculate the normalized weights of each indicator.

$$W_i^* = \frac{W_i}{\sum_{i=1}^4 W_i} \quad (23)$$

Finally, the normalized weights of each criterion are combined to obtain the risk of the risk criterion obtained by improving the gray correlation.

$$W^* = (W_1^*, W_2^*, W_3^*, W_4^*) = (0.2272, 0.2583, 0.2748, 0.2397) \quad (24)$$

Similarly, the normalized weights of each evaluation index layer can be obtained by the above method, and the normalized weight results of each evaluation index are directly shown in Table 6 in this paper due to the limitation of research space.

Table 6. Weight set of indicators for the evaluation of emergency rescue capacity of Lugou Mine fire.

Target Layer	First-Level Indicator Layer	Secondary Indicator Layer
Lugou Coal Mine Fire Emergency Rescue Capability Assessment	Rescue Organization Guarantee B_1 (0.2272)	Emergency response agencies C_1 (0.1991) Decision-making Command C_2 (0.2022) Recovery Summary C_3 (0.2013) Rules and Regulations C_4 (0.1981) Emergency Preparedness C_5 (0.1993)
	Personnel Guarantee B_2 (0.2583)	Expert Support C_6 (0.1013) Rescue Team C_7 (0.1979) Staff Quality C_8 (0.2008) Emergency Education and Training C_9 (0.2025) Emergency Planning Exercise and Improvement C_{10} (0.1976)
	Material Guarantee B_3 (0.2748)	Communication C_{11} (0.2006) Field Monitoring C_{12} (0.1992) Fire Incident Alarm C_{13} (0.2033) Information Resources C_{14} (0.2007) Personnel Positioning C_{15} (0.1962)
	Information Guarantee B_4 (0.2397)	Firefighting Equipment Provision C_{16} (0.2521) Material Stockpiling and Deployment C_{17} (0.2493) Transportation C_{18} (0.2493) Supplies Resupply C_{19} (0.2493)

3.4.2. Determine the Risk Evaluation Level

The determination of the risk evaluation level is the premise of the gray evaluation weight vector. The risk level of a certain risk evaluation index is substituted into the corresponding whitening weight function to obtain the gray correlation coefficient, and then the gray evaluation weight vector can be derived. In this paper, based on the examination of the emergency rescue capability of the Lugou coal mine fire, the risk evaluation level is divided into five levels, namely low, low, average, high, and high, corresponding to the numbers 1, 2, 3, 4, and 5. If the experts think that the risk level of this evaluation index is between the two can be expressed as 0.5, 1.5, 2.5, 3.5 and 4.5. Questionnaires were distributed to the members of the four expert groups to classify the risk level of each evaluation index, and the final statistical results are shown in Table 7.

Table 7. Expert questionnaire.

First-Level Indicator Layer	Secondary Indicator Layer	Expert Group One	Expert Group Two	Expert Group Three	Expert Group Four
Rescue Organization Guarantee B_1	Emergency response agencies C_1	3	4	3.5	4
	Decision-making Command C_2	4	3.5	4	3
	Recovery Summary C_3	3	4	3	2.5
	Rules and Regulations C_4	4	4	3.5	2
	Emergency Preparedness C_5	3.5	3.5	3	3.5
Personnel Guarantee B_2	Expert Support C_6	2	3	2	3.5
	Rescue Team C_7	3	3.5	4	3
	Staff Quality C_8	3	3	4	3
	Emergency Education and Training C_9	3.5	3	3	3
	Emergency Planning Exercise and Improvement C_{10}	4	4	3	3
Material Guarantee B_3	Communication C_{11}	3	2.5	3	3.5
	Field Monitoring C_{12}	2.5	3	3	3
	Fire Incident Alarm C_{13}	3	3.5	3.5	4
	Information Resources C_{14}	4	4	3	4
	Personnel Positioning C_{15}	2.5	4	2	3
Information Guarantee B_4	Firefighting Equipment Provision C_{16}	3	3	3	4
	Material Stockpiling and Deployment C_{17}	2.5	3	3	3.5
	Transportation C_{18}	3	2	2.5	3.5
	Supplies Resupply C_{19}	3	3	3	4

3.4.3. Evaluation of the Determination of the Gray Category

Each assessment gray class corresponds to a risk level, and the classification of the gray class level is determined according to the corresponding whitening weight function. Each whitening power function corresponds to a risk level, and the gray class level of the assessment index can be obtained by substituting the expert's scoring results of the assessment index into the corresponding whitening power function. Since the risk level was divided into five categories when the experts scored the indexes, five whitening weight functions were constructed according to the index levels, as follows.

Risk level—low: first gray category: $k = 1, x \in (0, 1, 2)$

$$f_1(d_{ijk}) = \begin{cases} d_{ijk}, & x \in [0, 1] \\ 2 - d_{ijk}, & x \in [1, 2] \\ 0, & x \notin [0, 2] \end{cases} \quad (25)$$

Risk level—lower: second gray class: $k = 2, x \in (0,2,4)$

$$f_2(d_{ijk}) = \begin{cases} \frac{d_{ijk}}{2}, x \in [0, 2] \\ \frac{4-d_{ijk}}{2}, x \in [2, 4] \\ 0, x \notin [0, 4] \end{cases} \quad (26)$$

Risk level—general: third gray class: $k = 3, x \in (0,3,6)$

$$f_3(d_{ijk}) = \begin{cases} \frac{d_{ijk}}{3}, x \in [0, 3] \\ \frac{6-d_{ijk}}{3}, x \in [3, 6] \\ 0, x \notin [0, 6] \end{cases} \quad (27)$$

Risk level—higher: fourth gray class: $k = 4, x \in (0,4,8)$

$$f_4(d_{ijk}) = \begin{cases} \frac{d_{ijk}}{4}, x \in [0, 4] \\ \frac{8-d_{ijk}}{4}, x \in [4, 8] \\ 0, x \notin [0, 8] \end{cases} \quad (28)$$

Risk level—higher: fifth gray class: $k = 5, x \in (0,5,+\infty)$

$$f_5(d_{ijk}) = \begin{cases} \frac{d_{ijk}}{5}, x \in [0, 5] \\ 1, x \in [5, +\infty] \end{cases} \quad (29)$$

3.4.4. Grey Evaluation Weight Vector of Secondary Indicators

Taking the gray comprehensive evaluation weight vector of assessment index C_1 as an example, the scoring results of five expert groups on assessment index C_1 are substituted into five whitening weight functions.

$$k = 1, X_{111} = \sum_{p=1}^4 f_1(C_{11p}) = f_1(C_{111}) + f_1(C_{112}) + f_1(C_{113}) + f_1(C_{114}) = f_1(3) + f_1(4) + f_1(3.5) + f_1(4) = 0 \quad (30)$$

$$k = 2, X_{112} = \sum_{p=1}^4 f_2(C_{11p}) = f_2(C_{111}) + f_2(C_{112}) + f_2(C_{113}) + f_2(C_{114}) = f_2(3) + f_2(4) + f_2(3.5) + f_2(4) = 0.5 + 0.25 = 0.75 \quad (31)$$

$$k = 3, X_{113} = \sum_{p=1}^4 f_3(C_{11p}) = f_3(C_{111}) + f_3(C_{112}) + f_3(C_{113}) + f_3(C_{114}) = f_3(3) + f_3(4) + f_3(3.5) + f_3(4) = 1 + \frac{2}{3} + \frac{2.5}{3} + 1 = 3.17 \quad (32)$$

$$k = 4, X_{114} = \sum_{p=1}^4 f_4(C_{11p}) = f_4(C_{111}) + f_4(C_{112}) + f_4(C_{113}) + f_4(C_{114}) = f_4(3) + f_4(4) + f_4(3.5) + f_4(4) = \frac{3}{4} + 1 + \frac{4.5}{4} + 1 = 3.875 \quad (33)$$

$$k = 5, X_{115} = \sum_{p=1}^4 f_5(C_{11p}) = f_5(C_{111}) + f_5(C_{112}) + f_5(C_{113}) + f_5(C_{114}) = f_5(3) + f_5(4) + f_5(3.5) + f_5(4) = \frac{3}{5} + \frac{4}{5} + \frac{3.5}{5} + \frac{4}{5} = 2.9 \quad (34)$$

So, the total gray evaluation coefficient of the evaluation index is C_1 .

$$X_1 = \sum_{k=1}^5 X_{11k} = X_{111} + X_{112} + X_{113} + X_{114} = 10.695 \quad (35)$$

Then, the gray evaluation weight vector of evaluation index C_1 can be calculated, and the k th gray evaluation weight is:

$$k = 1, r_{111} = \frac{X_{111}}{X_1} = 0 \quad (36)$$

$$k = 2, \quad r_{112} = \frac{X_{112}}{X_1} = 0.0701 \quad (37)$$

$$k = 3, \quad r_{113} = \frac{X_{113}}{X_1} = 0.2964 \quad (38)$$

$$k = 4, \quad r_{114} = \frac{X_{114}}{X_1} = 0.3623 \quad (39)$$

$$k = 5, \quad r_{115} = \frac{X_{115}}{X_1} = 0.2712 \quad (40)$$

The gray evaluation weight vector of C_1 can be derived.

$$r_1 = (r_{111} + r_{112} + r_{113} + r_{114} + r_{115}) = (0, 0.0701, 0.2964, 0.3623, 0.2712) \quad (41)$$

Similarly, the expert classification levels of the remaining evaluation indexes are substituted into each whitening weight function separately to obtain their corresponding gray evaluation weight vectors. Due to the limitation of research space, the calculation process of the gray evaluation weight vectors of other evaluation indicators is omitted from the text and written directly.

$$r_2 = (0, 0.0718, 0.3035, 0.3471, 0.2776) \quad (42)$$

$$r_3 = (0, 0.1609, 0.3218, 0.2874, 0.2299) \quad (43)$$

$$r_4 = (0, 0.1231, 0.2787, 0.3323, 0.2659) \quad (44)$$

$$r_5 = (0, 0.1155, 0.3233, 0.3118, 0.2494) \quad (45)$$

$$r_6 = (0, 0.2583, 0.2978, 0.2466, 0.1973) \quad (46)$$

$$r_7 = (0, 0.1155, 0.3233, 0.3118, 0.2494) \quad (47)$$

$$r_8 = (0, 0.1361, 0.333, 0.2949, 0.2359) \quad (48)$$

$$r_9 = (0, 0.1562, 0.3418, 0.2789, 0.2231) \quad (49)$$

$$r_{10} = (0, 0.0941, 0.3133, 0.3293, 0.2634) \quad (50)$$

$$r_{11} = (0, 0.1807, 0.3315, 0.271, 0.2168) \quad (51)$$

$$r_{12} = (0, 0.2017, 0.3433, 0.2577, 0.1972) \quad (52)$$

$$r_{13} = (0, 0.0943, 0.3113, 0.3302, 0.2642) \quad (53)$$

$$r_{14} = (0, 0.0488, 0.2927, 0.3659, 0.2927) \quad (54)$$

$$r_{15} = (0, 0.2124, 0.2992, 0.2714, 0.2171) \quad (55)$$

$$r_{16} = (0, 0.1361, 0.333, 0.2949, 0.2359) \quad (56)$$

$$r_{17} = (0, 0.1807, 0.3315, 0.271, 0.2168) \quad (57)$$

$$r_{18} = (0, 0.2319, 0.3089, 0.2551, 0.2041) \quad (58)$$

$$r_{19} = (0, 0.1361, 0.333, 0.2949, 0.2359) \quad (59)$$

So, the gray evaluation matrix of the first level indicators B_1 , B_2 , B_3 , and B_4 is:

$$R_1 = \begin{bmatrix} r_1 \\ r_2 \\ r_3 \\ r_4 \\ r_5 \end{bmatrix} = \begin{bmatrix} 0 & 0.0701 & 0.2964 & 0.3623 & 0.2712 \\ 0 & 0.0718 & 0.3035 & 0.3471 & 0.2776 \\ 0 & 0.1609 & 0.3218 & 0.2874 & 0.2299 \\ 0 & 0.1231 & 0.2787 & 0.3323 & 0.2659 \\ 0 & 0.1155 & 0.3233 & 0.3118 & 0.2494 \end{bmatrix} \quad (60)$$

$$R_2 = \begin{bmatrix} r_6 \\ r_7 \\ r_8 \\ r_9 \\ r_{10} \end{bmatrix} = \begin{bmatrix} 0 & 0.2583 & 0.2978 & 0.2466 & 0.1973 \\ 0 & 0.1155 & 0.3233 & 0.3118 & 0.2494 \\ 0 & 0.1361 & 0.3330 & 0.2949 & 0.2359 \\ 0 & 0.1562 & 0.3418 & 0.2789 & 0.2231 \\ 0 & 0.0941 & 0.3133 & 0.3293 & 0.2634 \end{bmatrix} \quad (61)$$

$$R_3 = \begin{bmatrix} r_{11} \\ r_{12} \\ r_{13} \\ r_{14} \\ r_{15} \end{bmatrix} = \begin{bmatrix} 0 & 0.1807 & 0.3315 & 0.2710 & 0.2168 \\ 0 & 0.2017 & 0.3433 & 0.2577 & 0.1972 \\ 0 & 0.0943 & 0.3113 & 0.3302 & 0.2642 \\ 0 & 0.0488 & 0.2927 & 0.3659 & 0.2927 \\ 0 & 0.2124 & 0.2992 & 0.2714 & 0.2171 \end{bmatrix} \quad (62)$$

$$R_4 = \begin{bmatrix} r_{16} \\ r_{17} \\ r_{18} \\ r_{19} \end{bmatrix} = \begin{bmatrix} 0 & 0.1361 & 0.3330 & 0.2949 & 0.2359 \\ 0 & 0.1807 & 0.3315 & 0.271 & 0.2168 \\ 0 & 0.2319 & 0.3089 & 0.2551 & 0.2041 \\ 0 & 0.1361 & 0.333 & 0.2949 & 0.2359 \end{bmatrix} \quad (63)$$

3.5. Comprehensive Evaluation of First-Level Indicators

To do a comprehensive evaluation of the first-level indicators B_1 , B_2 , B_3 , and B_4 , the weight vectors of B_1 , B_2 , B_3 , and B_4 have been previously derived as follows.

$$A_1 = (0.1991, 0.2022, 0.2013, 0.1981, 0.1993) \quad (64)$$

$$A_2 = (0.1013, 0.1979, 0.2008, 0.2025, 0.1976) \quad (65)$$

$$A_3 = (0.2006, 0.1992, 0.2033, 0.2007, 0.1962) \quad (66)$$

$$A_4 = (0.2521, 0.2493, 0.2493, 0.2493) \quad (67)$$

The weight vectors A_1 , A_2 , A_3 , and A_4 of each first-level indicator B_1 , B_2 , B_3 , and B_4 are multiplied with the corresponding gray evaluation matrices R_1 , R_2 , R_3 , and R_4 . The comprehensive evaluation weight vectors B_1 , B_2 , B_3 , and B_4 of each first-level indicator can be obtained as follows.

$$B_1 = A_1 \times B_1 = (0, 0.1083, 0.3048, 0.3280, 0.2588) \quad (68)$$

$$B_2 = A_2 \times B_2 = (0, 0.1266, 0.2921, 0.2674, 0.2139) \quad (69)$$

$$B_3 = A_3 \times B_3 = (0, 0.1471, 0.3156, 0.2995, 0.2378) \quad (70)$$

$$B_4 = A_4 \times B_4 = (0, 0.1711, 0.3266, 0.2790, 0.2232) \quad (71)$$

3.6. Comprehensive Evaluation of Objectives

Combining the data in Section 3.5, we can obtain the gray evaluation weight matrix R of the emergency rescue capability of the Lugou coal mine fire.

$$R = \begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \end{bmatrix} = \begin{bmatrix} 0 & 0.1083 & 0.3048 & 0.3280 & 0.2588 \\ 0 & 0.1266 & 0.2921 & 0.2674 & 0.2139 \\ 0 & 0.1471 & 0.3156 & 0.2995 & 0.2378 \\ 0 & 0.1711 & 0.3266 & 0.2790 & 0.2232 \end{bmatrix} \quad (72)$$

The weight vector A has been derived above:

$$A = W^* = (0.2272, 0.2583, 0.2748, 0.2397) \quad (73)$$

The gray comprehensive evaluation weight vector B of the emergency rescue capability of the Lugou coal mine fire can be derived.

$$B = A \times R = (0, 0.1387, 0.3097, 0.2928, 0.2329) \quad (74)$$

In order to make the evaluation results more effective and avoid losing too much information, we mono-value the gray comprehensive evaluation weight vector B . Since four evaluation gray classes are constructed in the gray model at this time, the C^T vector is constructed to assign values to the gray comprehensive evaluation weight vector B by gray level.

$$C^T = (\lambda_1, \lambda_2, \lambda_3, \lambda_4) = (1, 2, 3, 4, 5)^T \quad (75)$$

$$W = B \times C^T = (0, 0.1387, 0.3097, 0.2928, 0.2329) \times (1, 2, 3, 4, 5)^T = 3.5422 \quad (76)$$

By singularizing the gray comprehensive evaluation weight vector B , the gray comprehensive evaluation value W of the emergency rescue capability of the Lugou Mine fire was obtained as 3.5422. Finally, the gray comprehensive evaluation value was substituted into the five whitening weight functions, and the whitening weight function values of the five classes of gray were compared separately.

$$f_1(W) = 0 \quad (77)$$

$$f_2(W) = 0.229 \quad (78)$$

$$f_3(W) = 0.819 \quad (79)$$

$$f_4(W) = 0.886 \quad (80)$$

$$f_5(W) = 0.708 \quad (81)$$

By calculating the values of various whitening weight functions for the assessment of the fire emergency rescue capability of the Lugou mine, it can be seen that the gray comprehensive evaluation weight vector W obtains the largest function value when substituted

into the fourth self-whitening weight function, and the maximum function value is 0.91. According to the meaning of the risk level represented by the fourth whitening weight function, it can be concluded that the overall risk level of the assessment of the fire emergency rescue capability of the Lugou Mine is “higher”, which should be taken seriously.

By using the gray comprehensive evaluation model to assess the risk of the emergency rescue capability of the Lugou Mine fire, the results showed that the overall risk level was high. From the weight values of the risk assessment indicators, we can see that in the first level of risk assessment indicators, information security, and personnel security have higher risk weight values, followed by material security and rescue organization security. In the information security indicators, the weight value is higher for the fire incident alarm, fire information resources, and communication indicators. Among the personnel security indicators, those with higher weight values are emergency education and training, staff quality, and emergency plan rehearsal and improvement. The higher weighted indicators of rescue organization are decision-making and command, recovery summary, and emergency plan. The higher weight value in material security is for firefighting equipment and material reserve and deployment. Among the indicators, the one with the highest weight value is the firefighting equipment. This is because in the early stage of a fire accident, if there is enough firefighting equipment to extinguish the fire, meaning the possibility of a fire accident in a coal mine will be significantly reduced.

4. Suggestions for Preventive Countermeasures

(1) Rescue Organization Construction Optimization

Emergency rescue capacity is a dynamic process, including prevention, preparation, response, and recovery of four stages of coal mines, which should build a perfect rescue organization solid rescue organization foundation and establish a tight rescue organization structure. Staffing should be in place, and the division of labor should be clear. Continue to strengthen the “four teams a group” model, to solve the problem of a single function of the mine rescue team. Implement leadership accountability, play a central role in innovative activities to ensure that the organizational and personnel, technical and institutional security is significant, the relevant command operation is coordinated and orderly, and steadily improve the ideological awareness of safety production. Develop work objectives for managers at all levels, clarify safety responsibilities, and achieve over-prevention.

(2) Material Security Optimization

The material security aspect of the fire emergency rescue has also been improved, improving the existing monitoring and surveillance system, as well as firefighting equipment. At the same time, technical innovation, the basis of innovation, is material security; material security is the top priority. The mine has installed and used a meteorological chromatography analysis beam tube monitoring and surveillance system, which plays an important role in the prevention and early warning of fire accidents in the mine. However, in order to ensure its reliability and usable parts, they still need to be improved on the basis of the existing one. The main measures are as follows: strengthen management, enhance maintenance, improve accuracy, etc. The specific measures required by the mine for the beam pipe monitoring and surveillance system are applied on site as follows: (1) For the ventilation section of the beam pipe monitoring, mainly to establish a complete management system while strengthening the strength of the beam pipe group. (2) For the ventilation technology department to establish a safety meter metering and inspection system, the laboratory set up of a meter identification station responsible for calibration gas dispensing, metering and calibration, performance inspection of various safety monitoring equipment, and other major factors must be implemented. (3) The technical and management personnel of the beam tube monitoring system must be certified.

(3) Rescue Personnel Protection Optimization

Strengthen the emergency rescue personnel strength, and change the current rescue team’s multiple management status quo, to ensure that after an accident, they can meet the personnel requirements to quickly carry out the relevant emergency rescue work. Improve

the emergency rescue team guarantee system to ensure that everyone can enter the prevention guarantee system, one post, and two responsibilities; everyone has the responsibility. Strengthen the quality of emergency management personnel in coal mining enterprises, strengthen institutional constraints, strengthen emergency awareness, strengthen the significant impact of rescue training, unify rescue protection standards, and improve operability. Carry out drills for efficiency and improve the competence of emergency management. Material security needs to be improved in terms of equipment provision, reserve and deployment of materials, transportation, and replenishment of materials.

(4) Information Security Optimization

In the local rescue, there is also a serious lack of information, emergency rescue information security, including the way of communication contact, the receipt and notification of information, information reporting, etc. As one of the six security systems in coal mines, the communication and contact system plays a very important role in emergency management and can greatly improve the efficiency of emergency rescue. It should establish a perfect early warning and information reporting system, improve the emergency communication guarantee system, play the role of underground facilities, monitoring, and surveillance, and improve the emergency call function of the personnel positioning system. Ensure smooth communication in the emergency rescue process; once an emergency occurs at the scene, the site staff can report the disaster situation to the rescue command center immediately. When monitoring system alarms, the duty person in charge of the operation unit in the alarmed area needs to report the scene to the dispatching room immediately. Moreover, to solicit the dispatching room issued by the accident disposal advice, the duty officer of the alarmed area operation unit must immediately implement the disposal measures issued by the dispatching room. At the same time, they must also continue to report the warning information to the dispatching room according to the actual situation on site so that members of the command can respond quickly to develop a reasonable rescue plan and ensure the timeliness of emergency rescue.

5. Conclusions

This paper takes the assessment of the fire emergency rescue capability of Lugou Mine as the engineering background, uses the assessment model combining hierarchical analysis and gray system theory to make an accurate risk evaluation of the fire emergency rescue capability of Lugou Mine, and finally proposes corresponding countermeasures based on the evaluation conclusions subject to the shortcomings of the fire emergency rescue capability of Lugou mine. The conclusions are as follows:

(1) According to the characteristics of the coal seam of Lugou Mine combined with historical data and information, the entire coal mine fire emergency rescue capability was divided into four primary indicators after expert discussion: four aspects such as rescue organization guarantee, personnel guarantee, material guarantee, and information guarantee. Using hierarchical analysis to find out the weights of each index factor, we obtained the dominance of firefighting equipment, decision-making command, crowded education and training, and fire accident alarm indicators in the whole assessment system;

(2) After using the hierarchical analysis method to derive the weights of the risk factors, the risk level of the fire emergency rescue capability of the Lugou Mine was found to be “high” at the fourth level by combining the grey system theory analysis. In order to reduce the probability of fire accidents, improve the emergency response capability of coal mines, reduce casualties and property damage, and ensure the safe production of coal mines, we propose countermeasures for the indicators with higher weights and the shortcomings of the fire emergency response capability of Lugou Mine;

(3) In fire emergency rescue, material security optimization can improve the existing monitoring systems, as well as firefighting equipment. In terms of rescue personnel security optimization, the current multiple management rescue teams could be further improved through partners that strengthen the efficiency of emergency rescue personnel. Ensure that, after an accident, one can meet the personnel requirements to quickly carry out the relevant

emergency rescue work. In the rescue organization, construction optimization continues to strengthen the “four teams a group” model, to solve the problem of a single function of the mine rescue team. In the rescue information security optimization, establish a perfect early warning and information reporting system, and improve the emergency communication security system.

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