Risk Evaluation and Simulation Analysis of Occupational Diseases in Coal Mine Workers

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Abstract. In order to solve the problem of inaccuracy in the evaluation of occupational disease risk due to the characteristics of unknown and uncertainty, the coal mine occupational disease evaluation system was constructed, the weighting method of "AHP+entropy method" was introduced, and the Lagrangian function and European style were used. The distance function is used to obtain the combined weights of occupational disease evaluation indicators, and the unascertained measurement theory is used to construct the occupational disease risk evaluation model. After that, the Arena software is used for simulation analysis, and the continuous space iteration method is used to obtain the priority of coal mine occupational disease influencing factors. A case study on the occupational disease risk of Zhenchengdi Coal Mine is carried out with the method proposed in this paper. The simulation results and evaluation results are consistent with engineering examples, which shows that the evaluation model based on the "AHP+entropy weight method" unascertained measurement theory is practical and accurate. It is feasible and reliable, also can provide a basis for the risk assessment and prevention of coal mine occupational diseases.

Keywords: Coal mine, occupational disease, AHP+entropy method, evaluation system, unascertained measurement theory, simulation analysis.

1. Introduction
There are many occupational hazards such as dust, noise, poison, and high temperature in the production environment of coal mines [1]. Strengthening the research on the risk assessment of occupational diseases in coal mines is an important means to prevent and control the hazards. At present, the commonly used methods for evaluating occupational diseases in coal mines include fuzzy comprehensive evaluation method [2], analytic hierarchy process [3], and grey comprehensive evaluation method [4] and so on. The results of the fuzzy comprehensive evaluation method are relatively intuitive and clear, but it is difficult to guarantee the accuracy in the calculation process, and there is strong subjectivity in determining the degree of fuzzy membership; the calculation process of the indicators in the gray comprehensive evaluation method is simple, but it involves multiple evaluation levels when the task is heavy and the amount of calculation is large [5]. This article attempts to combine AHP and entropy weight method to obtain combined weights [6], to solve the problem of one-sided absoluteization in weight distribution; then build occupational disease evaluation models based on
unascertained measurement theory and apply them to towns Risk assessment of occupational diseases in Chengdi coal mine.

2. Coal mine occupational disease risk assessment based on "AHP+entropy method"

2.1. Occupational disease risk evaluation index system for coal mine employees

According to the status quo of coal mine occupational diseases and safety management factors, referring to the previous special research, the coal mine occupational disease risk evaluation index system shown in Figure 1 is constructed.

2.2. Apply "AHP+entropy method" to determine the combined weight of risk evaluation indicators

2.2.1. AHP method weight determination (subjective weight). AHP (Analytic Hierarchy Process) is a method of decomposing decision-making problems into different hierarchical structures according to the overall goal and sub-goals of each level, and then using the feature vector of the judgment matrix to find the priority of each element of each level to an element of the previous level Weight, finally use the weighted sum method to determine their final weight to the overall goal. First construct each judgment matrix, such as the first level of indicators to construct a judgment matrix for the total target A.

The eigenvector of the maximum eigenvalue $\lambda_{\text{max}}$ of A is calculated according to the evaluation index and calibrated with the consistency check coefficient CR.
2.2.2. Entropy weight determination (objective weight). The basic idea of the entropy method is to determine the objective weight according to the variability of the index, and the evaluation result is more real. The steps are as follows:

Build a matrix of numbers. The criterion-level evaluation object $M_i$ ($i=1, 2, 3,...,m$). Index level evaluation index $N_j$ ($j=1, 2, 3,...,n$). The evaluation value of the evaluation object under the evaluation index is $R_{ij}$, which forms a matrix $R$.

$$R = \begin{bmatrix}
    r_{ij} & r_{ij} & \cdots & r_{ijn} \\
    r_{i1} & r_{i2} & \cdots & r_{in} \\
    \vdots & \vdots & \ddots & \vdots \\
    r_{im} & r_{im} & \cdots & r_{mn}
\end{bmatrix}_{mn}$$

(2)

Determine the entropy weight of each indicator $e_j = -\frac{1}{\ln m} \sum_{i=1}^{n} p_{ij} \ln p_{ij}$

(3)

Among them, $p_{ij} \in [0, 1]$, it has no meaning when the denominator is 0, the revised $p_{ij}$ is as follows

$$p_{ij} = \frac{r_{ij} + 10^{-4}}{\sum_{j=1}^{m} r_{ij} + 10^{-4}}$$

(4)

Determine the index weight

$$w_j = \frac{1-e_j}{\sum_{j=1}^{n} (1-e_j)}$$

(5)

Among them, $w_j \in [0, 1]$, and $\sum_{j=1}^{n} w_j = 1$

2.2.3. Determination of combination weight. In order to obtain reasonable weights to make occupational disease risk assessment more realistic, the author constructed the Euclidean distance function and Lagrangian function based on the subjective and objective weights, and established the decision-making model.

Use Varangian function to build decision model.

$$W_j = \alpha w_{Aj} + \beta w_{Bj}$$

$$\alpha + \beta = 1$$

(6)

Among them, $W_j$ is the comprehensive weight, $w_{Aj}$ is the subjective weight, $w_{Bj}$ is the objective weight, and $\alpha, \beta$ are the preference coefficients of the main and objective weights respectively.

The Euler distance function is introduced, and the equations of subjective and objective weights and preference coefficients are established as follows, and the comprehensive weight $W_j$ of the evaluation index is combined.
The combined weight of each evaluation index obtained in this paper is shown in Table 1.

2.3. Carrying out occupational disease risk assessment based on unascertained measurement theory

2.3.1. Unascertained measure of single index. The single index measurement $\mu$ is the most detailed index factor in the entire index system, and it satisfies the following three conditions:

$$0 \leq \mu(x_{ij} \in U) \leq 1$$

$$R = \left( x_{ij} \in U \right) = 1$$

$$R\left[ x_{ij} \in \bigcup_{k=1}^{p} C_1 \right] = \sum_{k=1}^{p} R\left( x_{ij} \in C_1 \right) (k=1,2,...,p)$$

| Evaluation index | Subjective weight | Objective weight | Combination weight |
|------------------|-------------------|------------------|-------------------|
| **Management factors** | **(0.380)** | | |
| Use of anti-virus facilities | 0.265 | 0.170 | 0.227 |
| Use of dustproof facilities | 0.146 | 0.143 | 0.145 |
| Use of noise prevention facilities | 0.129 | 0.229 | 0.169 |
| Use of dust removal facilities | 0.283 | 0.238 | 0.265 |
| Local ventilation system | 0.177 | 0.219 | 0.194 |
| **Environmental factor** | **(0.435)** | | |
| Respiratory dust concentration | 0.423 | 0.284 | 0.360 |
| Total dust concentration | 0.125 | 0.214 | 0.165 |
| Noise | 0.125 | 0.244 | 0.179 |
| Toxic and harmful substances | 0.327 | 0.258 | 0.296 |
| **Personal protection factors**(0.185) | | | |
| Occupational health monitoring | 0.350 | 0.499 | 0.392 |
| Employee safety awareness | 0.101 | 0.157 | 0.117 |
| Receive safety education and training | 0.159 | 0.191 | 0.168 |
| Effective use of personal products | 0.155 | 0.121 | 0.145 |
| Personal protective equipment distribution | 0.235 | 0.031 | 0.178 |

Among them, $C_1$ and $C_k$ represent the divided levels, and $U$ represents the level set. The single index measurement evaluation matrix corresponding to the unascertained measurement is as follows.
\[(R_{ijk})_{m \times p} = \begin{pmatrix}
R_{i11} & R_{i12} & \ldots & R_{i1p} \\
R_{i21} & R_{i22} & \ldots & R_{i2p} \\
\vdots & \vdots & \ddots & \vdots \\
R_{im1} & R_{im2} & \ldots & R_{imp}
\end{pmatrix} \quad (11)\]

2.3.2. Multi-index comprehensive measurement. In the coal mine occupational disease risk assessment, the influencing factors of the index layer and the reference layer have different influence on the target layer. Normalize the evaluation index to obtain the weight vector \(w_j\) of the impact factor, then

\[U_{ik} = \sum_{j=1}^{m} w_j R_{ijk} \quad (i=1,2,\ldots,n; \ k=1,2,\ldots,p) \quad (12)\]

2.3.3. Confidence. In order to make the results of the risk assessment clearer and more intuitive, the occupational disease assessment results are divided into five levels, namely "safe" (0,1], "safer" (1,2], "medium" (2,3], "Dangerous" (3,4], "Dangerous" (4,5]. Establish an evaluation set \(A = (c_1, c_2, c_3, c_4, c_5)\), corresponding to five levels, the evaluation set \(A\) is the overall evaluation space \(U\) the orderly segmentation category. The evaluation level is determined by the confidence evaluation criterion

\[k_0 = \left\{ k: \sum_{i=1}^{n} u_{ik} \geq \mu, (k=1,2,\ldots,p) \right\} \quad (13)\]

Among them, \(k_0\) is the level of membership, \(\mu\) is the confidence level, and \(\lambda = 0.7\).

3. Simulation research on occupational disease risk of coal mine workers

3.1. Simulation preparation

The simulation step of the model is set to months, and the initial running time is set to 100 months. Scholars such as Wang Song used risk entropy to quantify risk and established an accident system model to study the transmission law of risk in the system. This paper draws on their research experience, intends to build a coal mine occupational disease system model, and uses the simulation software Arena to perform simulation analysis to find an effective strategy to control the coal mine occupational disease risk.

The previous article has summarized the influencing factors of occupational diseases, laying a foundation for constructing the dynamic model of occupational diseases in coal mines. In this section, refer to Figure 1 to determine the main causal relationships existing in the system; when conducting simulation research on the risk of occupational diseases in coal mines, graphs are also used. The evaluation index shown in 1 serves as the simulation boundary.

3.2. Construction of a dynamic model of coal mine occupational diseases.

The Causality Diagram of System Dynamics (SD) can analyze the dynamic process of interaction between various factors in the system. In the real world, the entire system is in a state of dynamic change. Therefore, it is necessary to establish a coal mine occupational disease dynamic model, determine the specific variable types and representative variables in the system and construct the coal mine occupational disease dynamic SD shown in Figure 2. Model.
The inventory and parameters in the system need to be set with initial values. The initial value of occupational disease risk is set to 100, and the initial value of reduced risk is set to 0. The interaction coefficients between the various influencing factors of occupational disease risk are calculated by using the analytic hierarchy process. As for the initial value of each influencing factor (respiratory dust concentration, laws and regulations, etc.), it must be scored by experts according to the actual situation of different enterprises. The divisions are (0, 10). This article relies on the risk assessment report and the relevant experts the influencing factor scores are averaged to obtain the initial value of each influencing factor (subdivide the index system).

3.3. **Initial model analysis**

After the model is built, run the initial model to observe and analyze the occupational disease risk, reduced risk, and risk reduction rate. The initial operating results are shown in Figure 3. It can be seen that under the initial intervention measures, the occupational disease risk fluctuates, and the fluctuation range gradually decreases with time. The model is basically stable after 60 months of operation. In the actual production process, due to the negative feedback and the delay in the system, the risk in the system also changes in a fluctuating manner, and eventually tends to be stable, that is, the structure of the system determines the behavior of the system, so the model is consistent with the actual situation. For further analysis. Since the model basically stabilized at 60 months, the running time was adjusted to 60 months.

![Diagram of Dynamic SD model of coal mine occupational diseases](image-url)
4. Engineering application and analysis

Zhenchengdi Coal Mine is located on the northwestern edge of Xishan Coalfield. Its administrative division belongs to Gujiao City, Taiyuan City, about 64km away from Taiyuan City and 11km from Gujiao City. The mining area is run through by Taijia Highway and Tailan Railway. The design service life of the mine is 117 years. The total area of Zhenchengdi mining area can reach 23.8 square kilometers, which is a large-scale coal mine producing coking coal. The main coal-bearing strata are the Carboniferous Taiyuan Formation and the Permian Shanxi Formation. There are 8 mineable coal seams. The main coal seams are 2-3# and 8#. The main coal quality is fat coal and coking coal. Zhenchengdi Mine is a low-gas mine developed with a pair of inclined shafts at a single level. The main roadway is arranged in three wings in geese, and the return air shaft is arranged at the end or middle of each wing. The geological structure is complex and changeable, and the collapsed columns in some areas are relatively developed. The entire mining area is dominated by faulted structures, the hydrogeological conditions are medium, the roof management is all caving, and the coal mining method is the strike long arm comprehensive mechanized coal mining method.

In order to prove that the evaluation method proposed in this article is true and effective. According to the evaluation system proposed in this paper, by using the relevant data of Zhenchengdi Coal Mine, the coal mine occupational disease risk assessment is carried out on the main coal seams 2-3# and 8#. By comparing the theoretical evaluation results of the unascertained measurement of the “AHP+entropy weight method” proposed in this paper with the actual occupational disease situation in Zhenchengdi Mine, it verifies that the evaluation method proposed in this paper is true and effective.

4.1. Unascertained measure calculation

Combining the evaluation values of occupational disease risk indicators (Table 2) and the single-indicator unknown measurement of the two coal mining faces in Zhenchengdi Coal Mine, the single-indicator vector matrix $R_1, R_2, R_3$ of 2-3# working face can be obtained.

Combining the combination weights and formulas in Table 1 can get the multi-index unascertained measure vector index of 2-3# working face as:

$$U_{2-3} = (0.4478, 0.4764, 0.0724, 0, 0)$$

(14)

Similarly, the multi-measure vector index of 8# working face can be obtained as:

$$U_{8} = (0.1029, 0.2307, 0.6664, 0, 0)$$

(15)
Table 2. Evaluation values of occupational disease risk indicators in coal mines of 2-3# and 8# face

| Evaluation index                                      | Evaluation value |
|------------------------------------------------------|------------------|
| Use of anti-virus equipment X5                      | 5                |
| Use of dustproof equipment X6                        | 2                |
| Use of noise prevention equipment X7                 | 1                |
| Use of dust collector X8                            | 1                |
| Local ventilation facilities X9                      | 1                |
| Respiratory dust concentration X1                    | 2                |
| Total dust concentration X2                          | 1                |
| Noise X3                                             | 74.95            |
| Toxic and harmful substances X4                      | 2                |
| Occupational health monitoring X10                   | 2                |
| Employee safety awareness X11                        | 3                |
| Receive safety education and training X12            | 4                |
| Effective use of personal products X13               | 2                |
| Personal protective equipment distribution X14        | 3                |

4.2. Confidence recognition
According to the confidence evaluation criteria, the 2-3# working face and 8# working face of Zhenchengdi Coal Mine are classified, and the confidence is 0.7 to obtain:

\[ k_{2-3} = \min(0.4478 + 0.4764 \cdot 0.7) = 2 \]  \hspace{0.5cm} (16)

\[ k_{8} = \min(0.1029 + 0.2307 + 0.6664 \cdot 0.7) = 3 \]  \hspace{0.5cm} (17)

According to the actual field data and the evaluation model proposed in this article, it is concluded that 2-3# working face is “safer” and 8# working face is “medium”. From the evaluation results, it can be seen that the occupational disease risk of 2-3# working face is lower than that of working face 8#, which is shown to be safer, which is the same as the actual occupational disease situation of the mine.

4.3. Model simulation-parameter sensitivity analysis
In the coal mine occupational disease risk, the various factors of the risk are related to each other and will have an impact on the occupational disease risk. After establishing the system model, by changing the initial values of different influencing factors, the changes in the occupational disease risk can be observed at the system level to understand the sensitivity of each parameter. Interventions on more sensitive influencing factors can effectively reduce risks.

The parameter sensitivity analysis was carried out on the initial value of the influencing factors. The initial value of each factor has a change step of 1, and the range of change is 0~4. Through observation, it can be seen that the more sensitive influencing factors are the use of dust-proof facilities (X6), Use of dust removal facilities (X8), toxic and hazardous substances (X4), respiratory dust concentration (X1), noise (X3), employee safety awareness (X11), receiving safety education and training (X12) and effective use of personal products (X13), each The sensitivity analysis results of influencing factors are shown in Figure 4.

Through the results of parameter sensitivity analysis, it can be found that when the initial values of the above eight influencing factors change, they will all have a significant impact on the level of occupational disease risk, so these eight influencing factors are regarded as the key influencing factors of occupational disease risk. Therefore, when considering control countermeasures, we should focus on the above eight aspects, and combine the actual situation of the coal mine to propose reasonable and effective control countermeasures.
5. Conclusion

1) Occupational diseases in coal mines are caused by a variety of factors, making the evaluation indicators of occupational diseases have uncertainties such as unknowns and grayness. This paper introduces combined weighting to make the weight distribution more reasonable, and then uses the unascertained measurement theory to establish a model for occupational disease risk assessment. The actual evaluation and verification of Zhenchengdi Coal Mine show that the evaluation results are consistent with the actual situation, which indicates that the evaluation method and model proposed in this paper are feasible and reliable.

2) This paper has carried out a simulation study on occupational disease risk in coal mines. According to theoretical calculations and parameter sensitivity analysis results, the key influencing factors of occupational disease risk are eight types of factors including respiratory dust concentration, use of dust-proof facilities, noise, employee safety awareness, toxic and hazardous substances, and acceptance of safety education and training. Based on the simulation results, the coal mine occupational disease risk control countermeasures are proposed to effectively reduce the coal mine occupational disease risk level, including the use of production methods and production equipment that can reduce dust, noise and toxic and hazardous substances in the production process, improve the coal mine production management level, and qualify employees, Effective personal protective equipment, etc.

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