Risk evaluation of China's coal mine production logistics system under coal supply assurance

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Abstract: In order to scientifically and rationally assess the safety condition of coal mine production logistics system, this paper establishes a risk assessment model of coal mine production logistics system based on BWM-Vague set. On the basis of reviewing a large amount of literature and combining the main contributing factors of coal mine production safety accidents in practice, a relatively complete set of safety evaluation index system for coal mine production and logistics system was established, including 4 primary indexes of personnel safety, machine and equipment safety, environmental safety and management safety, and 16 secondary indexes such as the proportion of professional and technical personnel, and the fuzzy comprehensive evaluation method was applied to evaluate the index system. Firstly, the BWM assignment method is used to determine the weights of each index, after which Vague set theory is introduced and experts are invited to evaluate and score each index, and then the two are combined to determine the final comprehensive evaluation. Finally, the model was empirically tested in the context of a coal mine enterprise in Beijing, with a view to improving the safety of the production logistics system in coal mines.

1 Introduction

Since late September 2021, more than 20 provinces in China have suffered a severe "power supply shortage". Under the huge pressure on coal supply, the National Energy Administration put forward the work requirements on October 11 to further liberalize advanced coal production capacity, increase coal supply, strengthen equipment operation and maintenance management, and ensure stable and full generation of units while ensuring safe production and laws and regulations [1]. However, tapping into efficiency does not mean that you can relax safety, under the enormous pressure of ensuring supply, coal safety production is still facing a severe test [2]. Therefore, it is imperative to conduct a safety assessment of the coal production logistics system so that risks can be identified in a timely manner, and then effective measures can be taken to reduce the frequency of safety incidents and safeguard coal production. Sun Yaxuan [3] et al. applied AHP-fuzzy comprehensive evaluation method to assess the safety situation of coal mine production logistics system from four perspectives of management, environment, technology and subsystem safety. Zhou Xuanchi [4] believes that coal mine production logistics is a system that consists of people, equipment and environment. Using the AHP-entropy power method, Li Yuanyuan [5] established a safety evaluation index system for coal mine production logistics in terms of material transportation and supply, accident prediction and rescue. Zhang Dianmin [6] proposed a set of methods using information management as a way to optimize the coal production logistics system. Erniu Zhang [7] found that the main contributing factors include production technology, corporate philosophy, personnel awareness, corporate regulatory failures, and safety hardware factors. Wang Jinfeng [8] further studied the coal production logistics system using the theories of system, reliability, electromechanical engineering, mining engineering, human factors engineering, and information management. Cui Wei [9], on the other hand, considered that the coal mine production logistics system includes coal mine logistics, human, air, water and waste logistics, and designed evaluation indexes based on the input-output approach. Using the MCDM method, Chao Zhang [10] et al. established a DMIP-based security resource evaluation method. Although the above-mentioned literature has some significance, there are still relatively few studies on the safety evaluation of coal mine production logistics system, and the evaluation indexes are not perfect.

Therefore, based on a comprehensive analysis of the factors affecting coal mine safety production, this paper decided to establish a relatively complete safety evaluation index system from four aspects: human, machine, environment and management, and applied the fuzzy hierarchy analysis method to comprehensively evaluate it, with a view to providing reference for enterprises to improve the coal mine production logistics system.

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2 Evaluation model for coal mine production logistics system

2.1 Evaluation index system design

In this paper, on the basis of reviewing a large amount of literature and combining the main contributing factors of coal mine production safety accidents in practice, the safety evaluation system of coal mine production logistics system is finally established in four aspects: personnel safety, machine and equipment safety, environmental safety and management safety, as shown in Figure 1.

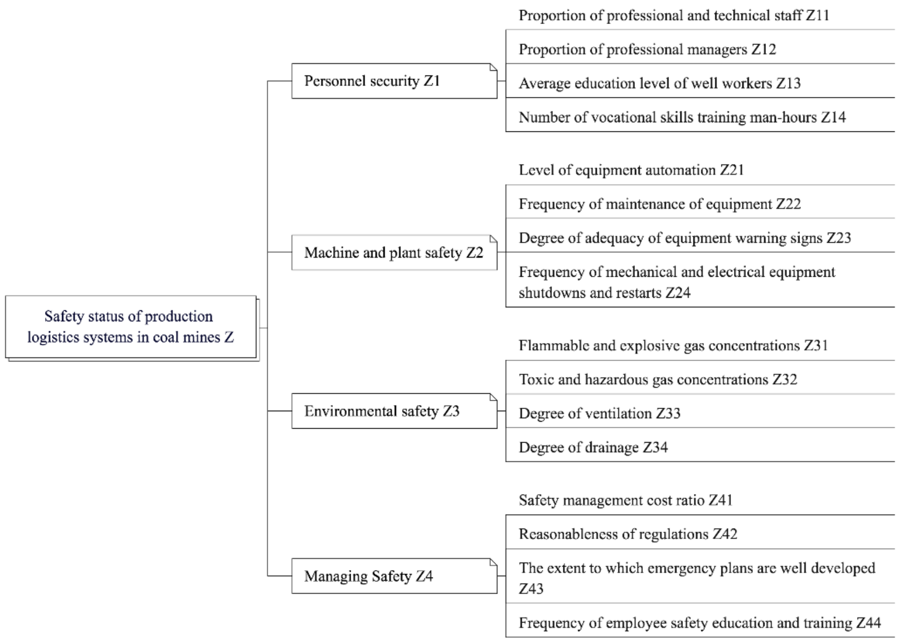

Fig.1. Coal mine production logistics system safety evaluation index system

2.2 BWM-Vague based index weight determination method

First, the weights of each indicator in the evaluation system need to be determined. The specific calculation steps are shown below:

(1) Determine the best and worst indicators

The best indicator C_B and the worst indicator C_W are selected in the indicator set $\{C_1, C_2, \ldots, C_n\}$.

(2) Comparing the preference level of the optimal indicator with all indicators

The expert compares the optimal indicator with other indicators in a two-by-two comparison, determines the degree of preference of the optimal indicator over other indicators, and selects a number from 1 to 9 for scoring. All indicators are evaluated and finally an optimal comparison vector $A_B = (a_{B1}, a_{B2}, \ldots, a_{Bn})$ is constructed.

(3) Comparing the preference of the worst indicator with other indicators

Same as step (2), finally, a worst comparison vector $A_W = (a_{1W}, a_{2W}, \ldots, a_{nW})^T$ is constructed.

(4) Construct a mathematical programming model to solve for the optimal weights $(w_1^*, w_2^*, \ldots, w_n^*)$.

The comparison of indicator preferences, the comparison of indicator weights, has, for any criterion j with weight W_j: $\frac{w_B}{w_j} = a_{Bj}$, $\frac{w_j}{w_w} = a_{jw}$

Therefore, in order to determine the optimal weights, the following mathematical planning problem can be constructed.

$$\min K \tag{1}$$

$$\text{s.t.}\begin{cases} \left|\frac{w_B}{w_j} - a_{Bj}\right| \le K, \text{for all j} \\ \left|\frac{w_j}{w_w} - a_{jW}\right| \le K, \text{for all j} \\ \sum_j W_j = 1 \\ W_j \ge 0, \text{for all j} \end{cases} \tag{2}$$

The optimal weights $(w_1^*, w_2^*, \ldots, w_n^*)$ can be obtained by solving the mathematical program.

2.3 Vague-based comprehensive evaluation method

The fuzzy comprehensive evaluation method based on Vague set is selected in this paper.

The specific steps are as follows:

(1) Set evaluation statements. In this paper, the set of rubrics $V = (V_1, V_2, V_3, V_4, V_5)$= (excellent, good, moderate, rather poor, poor) 5 levels are given, while a certain number of experts are invited to choose appropriate rubrics to express their evaluation opinions.

(2) Constructing the Vague set evaluation matrix. That is, experts are asked to select the appropriate set of comments to evaluate all secondary indicators one by one, denote any secondary indicator by Z_{ij}, set the set of comments as $V_k (k = 1,2,3,4,5)$, and construct the Vague set evaluation matrix R between the evaluation indicator system Z and the set of comments V.

$$\boldsymbol{R}=\begin{bmatrix} r_{i11} & r_{i12} & r_{i13} & r_{i14} & r_{i15} \\ r_{i21} & r_{i22} & r_{i23} & r_{i24} & r_{i25} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ r_{in1} & r_{in2} & r_{in3} & r_{in4} & r_{in5} \end{bmatrix}$$

(3) According to the Vague operation rules, the indicator layer is calculated first, and then the criterion layer is calculated based on the results of the indicator layer.

$$B_i = W_i \otimes R \quad (3)$$

where B_i is the Vague-valued rubric of the object to be evaluated on the rubric level V_j, W_i is the corresponding weight vector, $\otimes$ is the operator symbol for matrix multiplication in the Vague set, and $\oplus$ is the operator symbol for finite sum in the Vague set. In this paper, two formulas on the Vague set are used in the calculation process: the number multiplication operation and the finite sum operation. Let K be a real number on the interval [0,1],A,B be elements on the set Vague, $A = [t_A,1\text{-}f_A]$, $B = [t_B,1\text{-}f_B]$, then,

$$K \otimes A = [kt_A, k(1 - f_A)] \quad (4)$$

$$A \oplus B = [\min\{1, t_A + t_B\}, \min\{1, (1 - f_A) + (1 - f_B)\}] \quad (5)$$

(4) Calculate the total Vague evaluation matrix. W is the weight vector of the criterion layer, R is the vague set evaluation matrix of the indicator layer, and the total vague set fuzzy evaluation matrix is:

$$P=W \otimes R \quad (6)$$

where $p = (p_1, p_2, p_3, p_4, p_5)$ is the final vague set evaluation vector and $P_i= [t_{pi},1\text{-}f_{pi}]$.

3 Example analysis

In this paper, a coal mine enterprise in Beijing is selected as the research object and evaluated by applying the constructed model. Experts in the relevant fields were asked to score each index by means of a questionnaire to verify and analyze the safety evaluation model of the coal mine production logistics system established above.

3.1 Calculation results of indicator weights

For the constructed safety evaluation system of coal mine production logistics system, this paper applies the BWM method to determine the weights. First, the optimal and inferior indicators are determined based on expert opinions. Accordingly, the degree of preference of each indicator within different evaluation index systems relative to the best and worst indicator was obtained through expert questionnaires, as shown in Table 1.

Table 1. Preference of each evaluation index relative to the best and worst index

Guideline layer Z	Preference		Guideline layerZ_1	Preference		Guideline layerZ_2	Preference		Guideline layerZ_3	Preference		Guideline layerZ_4	Preference	
	A_B	A_W		A_B	A_W		A_B	A_W		A_B	A_W		A_B	A_W
Z_1	3	7	Z_{11}	1	8	Z_{21}	1	8	Z_{31}	4	3	Z_{41}	9	1
Z_2	5	4	Z_{12}	5	6	Z_{22}	6	3	Z_{32}	5	1	Z_{42}	6	3
Z_3	1	9	Z_{13}	2	7	Z_{23}	4	6	Z_{33}	1	8	Z_{43}	3	5
Z_4	8	1	Z_{14}	7	1	Z_{24}	9	1	Z_{34}	3	6	Z_{44}	1	6

According to Table 1and equations (1) and (2), the weights of the indicators in each evaluation index system were obtained by applying Lingo solutions, as shown in Table 2.

Table 2. Comprehensive evaluation index system weights

Guideline layer	Weights	Indicator layer	Weights
Z_1	**0.3103**	Z_{11}	**0.4529**
		Z_{12}	**0.1738**
		Z_{13}	**0.3251**
		Z_{14}	**0.0482**
Z_2	**0.1382**	Z_{21}	**0.5898**
		Z_{22}	**0.0903**
		Z_{23}	**0.2593**

		Z_{24}	**0.0606**
Z_3	**0.4983**	Z_{31}	**0.1087**
		Z_{32}	**0.0743**
		Z_{33}	**0.4854**
		Z_{34}	**0.3316**
Z_4	**0.0532**	Z_{41}	**0.0667**
		Z_{42}	**0.1000**
		Z_{43}	**0.3333**
		Z_{44}	**0.5000**

3.2 Comprehensive evaluation results

In this paper, a total of 20 experts in related fields were invited to evaluate each index by means of a questionnaire. After collating the so results, the Vague set value of each indicator was obtained. The Vague set evaluation values obtained for the machine and equipment safety indicator layer as an example are shown in Table 3.

Table 3. Criterion layer z weights and Vague set evaluation values

Indicators	Weights	Vague set evaluation value				
		Excellent	Good	Medium	rather poor	Poor
Z_{21}	**0.5898**	[0.25,0.35]	[0.25,0.35]	[0.15,0.25]	[0.1,0.2]	[0.15,0.25]
Z_{22}	**0.0903**	[0.15,0.2]	[0.3,0.35]	[0.2,0.25]	[0.25,0.3]	[0.05,0.1]
Z_{23}	**0.2593**	[0.15,0.2]	[0.25,0.3]	[0.15,0.2]	[0.3,0.35]	[0.1,0.15]
Z_{24}	**0.0606**	[0.15,0.2]	[0.1,0.15]	[0.4,0.45]	[0.25,0.3]	[0.05,0.1]

By multiplying W_i and the Vague set evaluation matrix within R according to the steps in Chapter 2, Based on equations (3) to (5), the vague set evaluation values of all criterion layers can be obtained, as shown in Table 4.

Table 4. Weighting of primary indicators and Vague set evaluation value

Indicators	Weights	Vague set evaluation value				
		Excellent	Good	Medium	rather poor	Poor
Z_1	**0.3103**	[0.2251,0.3715]	[0.2940,0.4405]	[0.1698,0.3163]	[0.0611,0.2076]	[0.1036,0.2501]
Z_2	**0.1382**	[0.2090,0.2885]	[0.2454,0.3249]	[0.1697,0.2492]	[0.1745,0.2540]	[0.1219,0.2014]
Z_3	**0.4983**	[0.2591,0.3294]	[0.3871,0.4574]	[0.1946,0.2649]	[0.0554,0.1257]	[0.0334,0.1037]
Z_4	**0.0532**	[0.0917,0.1633]	[0.3183,0.4150]	[0.2883,0.3600]	[0.1467,0.2183]	[0.0583,0.1300]

From the Vague set evaluation values and weights in Table 4, the Vague setevaluation matrix P=([0.2327,0.3280],[0.3350,0.4316],[0.1884,0.2837],[0.0785,0.1738],[0.0687,0.1640]). According to the Vague set affiliation comprehensive evaluation ranking "good > excellent > medium > poor > poor", according to the principle of maximum affiliation, the coal mine's production logistics risk comprehensive evaluation result is good, which is also consistent with its actual situation.

According to the principle of maximum affiliation, the Vague set of values for the four index levels of personnel safety, machine and equipment safety, environmental safety and management safety are all good, and further analysis of the data shows that the proportions of "poor" and "poor" in machine and equipment safety and management safety are relatively high, which indicates that the coal mine is not doing a good job in risk control in these two areas.

4 Conclusion

(1) In this paper, based on reviewing a large amount of literature and combining the main contributing factors of coal mine production safety accidents in practice, a more complete and reasonable safety evaluation system of coal mine production logistics system is established. The

BWM method is used to determine the weights of each index by means of fieldwork, literature search, and expert scoring, after which the Vague set fuzzy comprehensive judgment is used to determine the assessment matrix, and then the two are combined for a comprehensive assessment. Finally, the model was tested with an actual case, and the results showed that the proposed model can better reflect the safety of coal mine production and logistics system, and the relevant enterprises can selectively apply this model to evaluate their own mine safety according to their own characteristics and needs, so as to improve the safety level in a targeted manner.

（2）The innovation of this paper is that, for the first time, the safety evaluation system of coal mine production and logistics system is constructed from four perspectives: personnel safety, machine and equipment safety, environmental safety and management safety, which realizes the all-round and full coverage of risks and can analyze and reflect the safety condition of coal mine production and logistics system more effectively.

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