Study on evaluation of emergency plan for production accident

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Abstract. The emergency plan assessment plays an important role in strengthening production safety accident prevention and improving the ability to respond to emergencies. This paper analyzes the causes of production accidents and the problems existing in the treatment, and combines the existing evaluation system to establish a more practical evaluation index system. Taking project A’s emergency plan as the evaluation object, the project is evaluated by rough set and gray comprehensive evaluation model. The project evaluation grade of A is optimal, and the feasibility of the program implementation needs to be further improved. This paper can evaluate the whole and part of the project more scientifically and accurately, by the establishment of the evaluation index system and method, and it has strong practicability.

1. Introduction

With the advancement of the industrialization process, production safety accidents also occur frequently. Safety accidents not only have a certain impact on the production process, but are also accompanied by huge property damage and casualties. According to statistics, from January to October 2018, a total of 408 production safety accidents occurred, causing 1,501 deaths[1]. The development of a reasonable and fast response to the production safety accident emergency plan has become an urgent problem to be solved. As an important part of safety management, the evaluation of emergency plan plays an extremely important role in improving the practicability, reducing property loss and reducing casualties. Therefore, many scholars have conducted a lot of research on the emergency plan evaluation of production safety accidents, but there are big differences in the research direction[4]. Núñez[5] and Tong[6] established a corresponding evaluation index system based on the actual situation of the evaluation project, and evaluated the emergency plan of the evaluation project. Gou[7] and Yan[8] used Qualitative methods such as TOPSIS, shannon entropy and a coordinated development degree model to evaluate the emergency plan of the evaluation project.

From the existing literature, there are currently problems such as lack of uniform standards, assessment confusion and inaccurate evaluation of the production safety accident emergency plan [9]. Therefore, this paper establishes a new scientific evaluation system. Then, the rough set is used to establish the reference weight, and the index of emergency plan is scored. Finally, the numerical experiment is evaluated based on the grey comprehensive evaluation model combined with the reference weight, draw the evaluation level of the project emergency plan.

2. Establishment of indicator system

Reasonable evaluation index system is directly related to the accuracy of emergency plan evaluation. According to the assessment guidance in the Management Measures for Emergency Plan for
Production Safety Accidents (2016), the author analyzed the causes of safety accidents and problems in the process of handling accidents in specific practical cases, and referred to the achievements of scholars in the emergency plan evaluation system [7]. This paper divides the emergency plan assessment indicators into 5 first-level indicators, and has 16 secondary indicators evaluation factor, the specific content is shown in Figure 1.

![Production safety accident emergency plan evaluation system](chart)

Figure 1  Production safety emergency plan evaluation index system chart.

The evaluation system is divided into integrity ($B_1$), feasibility ($B_2$), pertinence ($B_3$), economy ($B_4$) and scientific ($B_5$) which can be used to screen the evaluation indexes of emergency plan. The secondary indicators of $B_1$, $B_2$ and $B_3$ mainly investigate the rationality of the "safety first, prevention first" policy of emergency plan. The indicators set under $B_4$ and $B_5$ mainly examine the rationality of the comprehensive management policy of emergency plan.

3. Model details

The model is divided into six steps as follows:

Step1: The condition attribute set $C$ is constitutes with each evaluation index, and each index importance score value constitutes the decision attribute set $D$. Then the index value and the index score constitute the relational data model to be evaluated.

Step2: Determining indicator weights:

1). The index is processed numerically, and the dependence of $R_D$ on $R_C$ was calculated:

$$\gamma_{RC} (R) = \frac{\sum_{\{y \in R_C \wedge y \in R_D\}} \text{card} (y \in R_D)}{\text{card} (U)}$$  \hspace{1cm} (1) $$

Where: $\text{card} (U)$ represents the number of elements in set $U$.

2). For the index $c_{ij}$, calculate the degree of dependence of $R_D$ on $R_{C_{(c_{ij})}}$:

$$\gamma_{R_{C_{(c_{ij})}} - R_D} = \frac{\sum_{\{y \in R_{C_{(c_{ij})}} \wedge y \in R_D\}} \text{card} (y \in R_D)}{\text{card} (U)}$$  \hspace{1cm} (2) $$

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3). Calculate the importance of index $c_{ij}$. After normalization, calculate the weight of each index.

$$\omega_i = \frac{\sigma(c_{ij})}{\sum_{j=1}^{n} \sigma(c_{ij})}$$  \hspace{1cm} (4)

Step3: The evaluation level set as $E=\{E_1, E_2, E_3, E_4\}=\{\text{optimal, general, poor, bad}\}$, and the level standard is shown in table 1. Then the sample matrix $H$ is established according to the scoring results.

Table 1. Evaluation score and the corresponding grade standard.

| Rating | [4,3) | [3,2) | [2,1) | [1,0) |
|--------|-------|-------|-------|-------|
|        | optimal | general | poor | bad |

Step4: The grey level is divided into 4 categories and the whitening weight function is constructed.

Table 2. Each grey classifications and its corresponding whitening weight function.

| Grey classifications | Grey number | Definite weight functions |
|----------------------|-------------|-------------------------|
| e=1                  | $\otimes_1 \in (0,4,+\infty)$ | $f_i(h_{ijk}) = \begin{cases} h_{ijk} / 4, & h_{ijk} \in [0,4] \\ h_{ijk} / 3, & h_{ijk} \in [0,3] \\ h_{ijk} / 2, & h_{ijk} \in [0,2] \\ 1, & h_{ijk} \in [0,1] \\ 0, & h_{ijk} \notin [0,1] \end{cases}$ |
| e=2                  | $\otimes_2 \in (0,3,6]$ | $f_i(h_{ijk}) = \begin{cases} (6 - h_{ijk}) / 3, & h_{ijk} \in [3,6] \\ (6 - h_{ijk}) / 2, & h_{ijk} \in [2,4] \\ (6 - h_{ijk}), & h_{ijk} \in [1,2] \\ 0, & h_{ijk} \notin [0,3] \end{cases}$ |
| e=3                  | $\otimes_3 \in (0,2,4]$ | $f_i(h_{ijk}) = \begin{cases} (2 - h_{ijk}) / 2, & h_{ijk} \in [2,4] \\ (2 - h_{ijk}), & h_{ijk} \in [1,2] \\ 0, & h_{ijk} \notin [0,2] \end{cases}$ |
| e=4                  | $\otimes_4 \in (0,1,2]$ | $f_i(h_{ijk}) = \begin{cases} (1 - h_{ijk}) / 2, & h_{ijk} \in [1,2] \\ (1 - h_{ijk}), & h_{ijk} \in [0,1] \\ 0, & h_{ijk} \notin [0,1] \end{cases}$ |

Step5: According to the grey evaluation weight of the evaluation index, the grey evaluation weight vector is calculated as $r_{ij}=r_{ije}$, and the grey weight matrix of each secondary index is obtained.

$$r_{ije} = \frac{\sum_{k=1}^{n} f_i(h_{ijk}) \sum_{e=1}^{4} X_{ije}}{\sum_{e=1}^{4} X_{ije}}$$ \hspace{1cm} (5)

$$R_i = \begin{bmatrix} r_{i1} \\ r_{i2} \\ r_{i3} \\ r_{i4} \end{bmatrix} = \begin{bmatrix} f_{i11} & f_{i12} & f_{i13} & f_{i14} \\ f_{i21} & f_{i22} & f_{i23} & f_{i24} \\ \vdots & \vdots & \vdots & \vdots \\ f_{i41} & f_{i42} & f_{i43} & f_{i44} \end{bmatrix}$$ \hspace{1cm} (6)

Where: $X_{ije}$ is grey evaluation coefficient.

Step6: Firstly, the evaluation result of the lowest level index is calculated, and then the evaluation result of the upper level index is calculated according to the evaluation result and weight of the index. Finally the total evaluation result of the item is obtained.

$$Z_i = C_i \cdot Z_{ci}$$ \hspace{1cm} (7)

$$Z = Z_i \cdot \omega^T$$ \hspace{1cm} (8)

$$Z_i = R_i \cdot E^T$$  \hspace{1cm} (9)
4. Numerical experiment

4.1. Weight determination

By inviting nine technicians and safety experts who are in charge of production safety for many years, the importance of the evaluation index is scored. The processing results are shown in Table 3.

Table 3. The attributes of indicators are quantified.

| U | B₁ | B₂ | B₃ | B₄ | B₅ | C₁₁ | C₁₂ | C₁₃ | C₁₄ | C₂₁ | C₂₂ | C₂₃ | C₂₄ | C₃₁ | C₃₂ | C₃₃ | C₃₄ | C₄₁ | C₄₂ | C₄₃ | C₄₄ | C₅₁ | C₅₂ | C₅₃ | C₅₄ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 4 | 3 | 2 | 3 | 4 | 3 | 3 | 4 | 3 | 2 | 4 | 3 | 2 | 4 | 3 | 3 | 2 | 4 | 3 |
| 2 | 4 | 4 | 3 | 2 | 4 | 2 | 3 | 4 | 3 | 3 | 3 | 2 | 3 | 2 | 3 | 4 | 3 | 3 | 2 |
| 3 | 3 | 4 | 3 | 2 | 3 | 3 | 2 | 3 | 3 | 2 | 2 | 3 | 4 | 3 | 3 | 4 | 3 | 3 | 2 |
| 4 | 4 | 3 | 3 | 3 | 3 | 4 | 3 | 3 | 3 | 2 | 3 | 3 | 4 | 3 | 4 | 2 | 3 | 3 | 3 |
| 5 | 3 | 3 | 3 | 2 | 3 | 4 | 2 | 3 | 3 | 3 | 4 | 3 | 2 | 4 | 2 | 3 | 4 | 3 | 2 |
| 6 | 3 | 4 | 3 | 2 | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 3 | 3 | 3 | 2 |
| 7 | 4 | 3 | 3 | 3 | 2 | 4 | 3 | 2 | 3 | 2 | 4 | 3 | 3 | 4 | 3 | 4 | 2 | 3 |
| 8 | 3 | 3 | 2 | 3 | 3 | 4 | 3 | 3 | 3 | 2 | 4 | 2 | 3 | 2 | 3 | 4 | 3 |
| 9 | 4 | 4 | 2 | 3 | 4 | 3 | 2 | 3 | 4 | 3 | 3 | 2 | 4 | 3 | 3 | 2 | 2 | 3 |

The weights of the first-level indicators $B₁, B₂, B₃, B₄, B₅$ obtained by the formulas (1), (2), (3) are: $wᵢ=(0.3334, 0.2222, 0.2222, 0.1111, 0.1111)$. Similarly, the weight of each secondary index can be obtained. According to formula (4), the weight of each secondary index is shown in Table 4.

4.2. Evaluation results

Select a construction company A project emergency plan as the evaluation object. Questionnaires were distributed to project managers, safety directors, supervisors, owners' representatives of the project, and the evaluation indexes were scored. The sample matrix $H$ is obtained as follows:

$$H = \begin{bmatrix}
4 & 4 & 4 & 4 & 3 & 3 & 3 & 4 & 4 & 3 & 4 & 3 & 4 & 4 & 3 & 4 \\
2 & 4 & 2 & 2 & 3 & 2 & 2 & 2 & 2 & 2 & 3 & 2 & 2 & 2 \\
3 & 2 & 2 & 3 & 2 & 3 & 2 & 3 & 2 & 3 & 4 & 3 & 3 & 3 \\
2 & 3 & 3 & 3 & 2 & 3 & 3 & 2 & 3 & 3 & 4 & 3 & 4 & 4 \\
3 & 4 & 4 & 3 & 3 & 3 & 2 & 3 & 3 & 4 & 3 & 3 & 3 & 2 \\
3 & 3 & 3 & 3 & 2 & 3 & 3 & 4 & 3 & 3 & 4 & 2 & 2 & 3 
\end{bmatrix}^T$$

According to the sample matrix, the grey weight matrix of each second-level index can be obtained by formula (6) and (7). The evaluation results of each secondary index and primary index can be obtained by formula (8) and (9). Then, the comprehensive evaluation results are calculated according to formula (10). The calculation results are shown in Table 4.

Table 4. Comprehensive evaluation results.

| Evaluation results | Level indicators | Weight | Evaluation results | Secondary indicators | $Bᵢ$'s weight | System weight | Evaluation results |
|--------------------|------------------|--------|--------------------|----------------------|----------------|---------------|--------------------|
|                    | $B₁$             | 0.3334 | 3.1503             | $C_{11}$             | 0.2667         | 0.0889        | 3.0588             |
|                    |                  |        |                    | $C_{12}$             | 0.3334         | 0.1112        | 3.2572             |
| 3.0939 (A)         |                  |        |                    | $C_{13}$             | 0.2667         | 0.0889        | 3.1236             |
|                    |                  |        |                    | $C_{14}$             | 0.1333         | 0.0444        | 3.1172             |
|                    |                  |        |                    | $C_{21}$             | 0.3000         | 0.0667        | 2.9434             |
|                    |                  |        |                    | $C_{22}$             | 0.4000         | 0.0889        | 3.0000             |
|                    |                  |        |                    | $C_{23}$             | 0.3000         | 0.0667        | 2.9434             |
|                    |                  |        |                    | $C_{24}$             | 0.4286         | 0.0952        | 3.0588             |
|                    |                  |        |                    | $C_{31}$             | 0.4286         | 0.0952        | 3.0588             |
|                    |                  |        |                    | $C_{32}$             | 0.1428         | 0.0351        | 3.0588             |
|                    |                  |        |                    | $C_{33}$             | 0.3158         | 0.0351        | 3.1236             |
|                    |                  |        |                    | $C_{41}$             | 0.3158         | 0.0351        | 3.1844             |
|                    |                  |        |                    | $C_{42}$             | 0.3684         | 0.0409        | 3.2432             |
|                    |                  |        |                    | $C_{43}$             | 0.3500         | 0.0389        | 3.3333             |

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According to the calculation of the established index system and evaluation model, the evaluation grade of this project is optimal and the value is 3.0939. Among the evaluation that in the feasibility index of accident prevention and emergency measures, \( C_{12} = 3.2572 \) is the highest score, \( C_{31} = 3.0588, C_{32} = 3.0588, C_{33} = 3.0588 \) are optimal except \( C_{22} = 3.000 \) is general. Among the other indicators, \( C_{21} = 2.9434, C_{23} = 2.9434, C_{52} = 3.0000 \) is general. This shows that the emergency plan of production safety accident of this project meets the requirements, but there is a large room for improvement in each index, among which the \( C_{22}, C_{23} \) and \( C_{32} \) need to be revised urgently.

5. Conclusion

This paper establishes an evaluation index system, based on the existing evaluation and by analyzes the problems existing in specific cases of production safety accidents. The rough set is used to establish the reference weight, and then the project emergency plan is evaluated based on the optimized grey comprehensive evaluation model. The evaluation level of the production safety emergency plan of project A is optimal, the comprehensive results of the evaluation project and the results of each indicator are presented. It is more grasp to the overall state of the evaluation project, and provides an important reference value for enterprises to prepare emergency plans.

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