Safety evaluation of chemical production based on AHP-fuzzy comprehensive evaluation method

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Abstract. In order to prevent fire and explosion accidents in the production process of chemical companies and ensure the production safety of chemical companies, taking the styrene production process of a chemical company as an example, according to the production characteristics of chemical companies and the hazardous factors in production, combined with industry expert opinions, 17 safety evaluation indexes affecting the safety in production of chemical enterprises are analyzed and summarized from the aspects of human, machine, material, environment and management, the second level safety evaluation index system is established, and AHP-fuzzy comprehensive evaluation method is used for production. The safety evaluation of the process showed that the production status of the chemical enterprise was relatively dangerous. The danger mainly came from management and materials. The enterprise did a good job in terms of human, machine and environment. This evaluation method can objectively and accurately evaluate the risk of chemical production, help companies find the key prevention direction of accidents, strengthen safety supervision, and prevent the occurrence of fire and explosion accidents. It provides a reference for the application of AHP-fuzzy comprehensive evaluation method in chemical engineering evaluation in the future.

1. Introduction
As one of the pillar industries of China's national economy and the basic industry of industrial development, the chemical industry has a significant influence on China's economic development [1]. With the rapid development of economy and technology, the chemical industry has developed rapidly, but it has also brought many hidden safety hazards, leading to frequent fire and explosion accidents in the production process of chemical companies, which seriously affects the national economy, enterprise development, and social harmony and stability [2]. The frequent occurrence of accidents has become a prominent problem that restricts the health and safety development of chemical enterprises [3]. These major accidents have prompted people to choose appropriate safety evaluation methods to conduct safety evaluations on the production process of chemical companies to prevent fire and explosion accidents in the production process.

The factors that affect the safety of chemical production are unpredictable, uncontrollable, and undeterminable. The evaluation of the production process of chemical companies requires comprehensive consideration of their multi-level and multi-factor problems. The evaluation factors
and evaluation criteria in the evaluation process are vague. Or a series of problems such as uncertain, qualitative indicators are difficult to quantify [4], AHP-fuzzy comprehensive evaluation method is used to evaluate the production process of chemical enterprises, which can take into account the impact of various factors on the evaluation object and integrate the opinions of multiple evaluation bodies to effectively solve the problem of ambiguity in the evaluation process, not only can the level of the evaluation object be considered to standardize the evaluation process, but also the subjective experience of people can be used to make the evaluation result conform to the previous experience and conform to the actual situation [5-6]. Therefore, it is appropriate and effective to choose AHP-fuzzy comprehensive evaluation method to evaluate the production process of chemical enterprises.

At present, the AHP-fuzzy comprehensive evaluation method is widely used in safety, education, economy, management and other fields, and satisfactory evaluation results have been obtained. However, after consulting the literature, it is found that AHP-fuzzy comprehensive evaluation method is not widely used in the field of chemical safety evaluation. Among them, L L Yang[7] applied the AHP-fuzzy comprehensive evaluation method to the evaluation of occupational hazards in chemical enterprises, and tested the practicability of the method, and objectively and accurately evaluated the occupational hazards of chemical enterprises; Y X Li [8] used AHP-fuzzy comprehensive evaluation method to evaluate the explosion accident in Tianjin Port obtains the risk level of the explosion; H R Han and Y Wang [9] applied the AHP-fuzzy comprehensive evaluation method to the safety evaluation of hazardous chemical production enterprises, and obtained the comprehensive safety status of the enterprise, and proposed enterprise prevention accident safety measures countermeasures. This paper uses the AHP-fuzzy comprehensive evaluation method to evaluate the production process of chemical companies, aiming to prevent fire and explosion accidents in the production process of chemical companies, to ensure the production safety of chemical companies, and provide reference for the application of AHP-fuzzy comprehensive evaluation method in chemical safety evaluation.

2. AHP-fuzzy comprehensive evaluation method

AHP-fuzzy comprehensive evaluation method is an evaluation method that combines qualitative evaluation method and quantitative evaluation method. The single fuzzy evaluation method depends too much on the subjective judgment of experts when determining the index weight, and the evaluation result is greatly affected by subjective factors [10]. And the AHP-fuzzy comprehensive evaluation method combines the analytic hierarchy process and the fuzzy evaluation method organically, using the analytic hierarchy process (Analytic Hierarchy Process, AHP) to find the sub-goals and each index weight more accurately, and then use the fuzzy method quantitative evaluation by the evaluation method can minimize the disadvantages caused by subjective judgment, improve the accuracy and credibility of the evaluation results, and make the evaluation objective and accurate [11]. The evaluation steps of AHP-fuzzy comprehensive evaluation method are as follows:

2.1. AHP analysis steps [12-13]

① Building a hierarchical structure model

The hierarchical structure model of general security evaluation includes three layers: the target layer (the highest layer or the top layer), the criterion layer (the middle layer) and the index layer (the lowest layer or the scheme layer).

② Establishing a judgment matrix

In the hierarchical hierarchical structure, comparing the importance of all factors in the same layer that affect the previous layer, listing the importance of each factor, and constructing a judgment matrix according to the 1-9 scale method. The factors of each layer less than or equal to 9, the elements of the judgment matrix are denoted by $a_{ij}$, comparing the influence of n factors $X = (X_1, X_2, \ldots, X_n)$ on the target $Y$, and determining the weight of these factors in $Y$. Taking two factors $X_i$ and $X_j$ uses $a_{ij}$ to express the ratio of the degree of influence of $X_i$ and $X_j$ on $Y$. Setting the judgment matrix
The scale method of judging matrix elements is shown in Table 1:

Table 1. Scale method of judging matrix elements.

| Scale | Comparing results                                      |
|-------|--------------------------------------------------------|
| 1     | $X_i$ and $X_j$ are equally important                  |
| 3     | $X_i$ is slightly more important than $X_j$            |
| 5     | $X_i$ is obviously more important than $X_j$          |
| 7     | $X_i$ is much more important than $X_j$               |
| 9     | $X_i$ is more important than $X_j$                    |
| 2/3, 4/6, 8 | The intensity of $X_i$ and $X_j$ is between the two adjacent levels |
| 1/3   | $X_i$ is second to $X_j$                              |
| 1/5   | $X_i$ is clearly inferior to $X_j$                    |
| 1/7   | $X_i$ is strongly inferior to $X_j$                   |
| 1/9   | $X_i$ is definitely inferior to $X_j$                 |
| 1/3, 1/5, 1/7, 1/9 | The intensity of $X_i$ and $X_j$ is between the two adjacent levels |

3 Calculating the weight.

The MATLAB software is used to calculate the maximum eigenvalue $\lambda_{\text{max}}$ of the judgment matrix $A$ and the corresponding eigenvector $W$, and after normalizing it, the ranking weights are obtained.

4 Consistency test

Random consistency ratio CR is used for consistency testing. The smaller the CR, the better the consistency of the judgment matrix. When CR < 0.1, the consistency of the judgment matrix is considered satisfactory. When CR ≥ 0.1, the judgment matrix is considered to deviate from consistency requirements, the matrix needs to be readjusted. The calculation methods of CR and CI are as follows:

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

(1)

\[
\text{CR}——\text{Random consistency ratio} \\
\text{CI}——\text{Consistency index} \\
\text{RI}——\text{Average random consistency index}
\]

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

(2)

$\lambda_{\text{max}}$——Maximum eigenvalue of judgment matrix $A$

$n$——Judgment of the order of matrix $A$

The average random consistency index RI is determined according to the order of the judgment matrix $A$. The values are shown in Table 2.

Table 2. The RI values of order 1-10 were calculated 1000 times.

| Order | RI  |
|-------|-----|
| 1     | 0   |
| 2     | 0   |
| 3     | 0.52|
| 4     | 0.89|
| 5     | 1.12|
| 6     | 1.26|
| 7     | 1.36|
| 8     | 1.41|
| 9     | 1.46|
| 10    | 1.49|
⑤ The total order of the hierarchy
Using the result of single sorting, calculating the weight of the importance of the previous layer to all factors of this layer, and sorting from top to bottom layer by layer.

2.2. Fuzzy evaluation method steps [14-15]
① Determining the evaluation target factor set \( U = \{u_1, u_2 \ldots \ u_m\} \), where there are m evaluation indexes.
② Establishing the judgment level set \( V = \{v_1, v_2, \ldots \ v_m\} \), where \( v_i \) represents the i-th evaluation result.
③ Constructing fuzzy relation matrix. According to the evaluation of the subset of the evaluation level, the fuzzy evaluation is carried out, and the judgment matrix is obtained:

\[
R = \begin{bmatrix}
  r_{11} & r_{12} & \cdots & r_{1m} \\
  r_{21} & r_{22} & \cdots & r_{2m} \\
  \vdots & \vdots & \ddots & \vdots \\
  r_{n1} & r_{n2} & \cdots & r_{nm}
\end{bmatrix}
\]

The \( r_{ij} \) in the matrix represents the membership of \( u_i \) to \( v_j \)-level fuzzy subsets.
④ Determining the fuzzy weight vector of each evaluation factor. The weight vector here is the feature vector \( W \) obtained by the analytic hierarchy process.
⑤ Performing fuzzy comprehensive evaluation. Synthesizing the fuzzy matrix of the evaluation object and the fuzzy weight vector, and setting the evaluation vector \( B = W \cdot R = \{b_1, b_2 \ldots \ b_m\} \). According to the principle of maximum membership, fuzzy comprehensive evaluation results can be obtained.

3. Example application

3.1. Evaluation target profile
A chemical enterprise's styrene production process includes a total of five process units, namely: alkylation reaction unit, ethylbenzene rectification unit, compressor unit, dehydrogenation reaction unit and styrene rectification unit.

The production process is that the raw material ethylene input from the external pipeline and the raw material benzene from the benzene tank in the liquid tank area are input into the ethylbenzene unit of the combined device through the pipeline, and the intermediate product ethylbenzene is obtained after the alkylation reaction and separation for the dehydrogenation of the styrene unit; The ethylbenzene from the ethylbenzene unit enters the styrene unit to undergo a dehydrogenation reaction. After separation, the product styrene is obtained for sale. The by-product dehydrogenation tail gas and styrene tar are used as fuel in the steam superheater. Toluene is sold as a commodity.

3.2. Establishing a safety evaluation index system
According to the production characteristics of the enterprise and the hazardous factors in production, combined with the opinions of industry experts, comprehensively considering the five aspects of human, machine, material, environment and management, 17 safety evaluation indexes affecting the safety in production of chemical enterprises are analyzed and summarized. The secondary safety evaluation index system as shown in figure 1.
3.3. Determination and ranking of weights of safety evaluation indexes
Inviting experts to use the 1-9 scale method to judge the importance of each factor in the criterion layer to the target layer, and constructing a judgment matrix

\[
A = \begin{bmatrix}
1 & 3 & 3 & 5 & 5 \\
1 & 1 & 1 & 3 & 3 \\
\frac{1}{3} & 1 & 3 & 5 & 3 \\
\frac{1}{3} & 1 & 1 & \frac{1}{3} & 1 \\
\frac{5}{3} & \frac{5}{3} & 3 & 1 & 3 \\
\frac{5}{3} & \frac{1}{3} & 1 & 3 & 1 \\
\end{bmatrix}
\]

Using the MATLAB software to find the maximum eigenvalue \(\lambda_{\text{max}}\) of the judgment matrix \(A\) and the corresponding eigenvector \(W\), and normalizing it to get:

\[
\lambda_{\text{max}} = 5.355 \\
W = (0.319, 0.119, 0.169, 0.107, 0.286)
\]

Conducting consistency check:

\[
CI = \frac{\lambda_{\text{max}} - n}{n-1} = \frac{5.355 - 5}{5 - 1} = 0.089
\]

\[
CR = \frac{CI}{RI} = \frac{0.089}{1.12} = 0.079
\]
CR <0.1, which meets the requirements of consistency, indicating that the matrix has good compatibility, and the weight assigned by each factor is in line with reality.

In the same way, calculating the weight of each evaluation index at the index level and making a total order of all indexes that affect the safety production of chemical enterprises, as shown in table 3.

| C layer index | Personnel factors | Machine factors | Material factors | Environmental factors | Management factors | C-level index total ranking weight |
|---------------|-------------------|-----------------|-----------------|-----------------------|--------------------|----------------------------------|
| Employee safety awareness awareness C1 | 0.343 | — | — | — | — | 0.109 |
| Employee safe operation | 0.187 | — | — | — | — | 0.060 |
| Employee emergency ability | 0.296 | — | — | — | — | 0.094 |
| Employee safety protection | 0.174 | — | — | — | — | 0.068 |
| Machine engineering design | — | 0.317 | — | — | — | 0.038 |
| Machine safety protection | — | 0.285 | — | — | — | 0.034 |
| Machine control linkage | — | 0.398 | — | — | — | 0.047 |
| Flammability | — | — | 0.357 | — | — | 0.060 |
| Explosiveness | — | — | 0.402 | — | — | 0.068 |
| Amount of substance | — | — | 0.241 | — | — | 0.041 |
| Fire and explosion protection | — | — | — | 0.459 | — | 0.049 |
| Public health | — | — | — | 0.367 | — | 0.039 |
| Flat layout | — | — | — | 0.174 | — | 0.019 |
| Safety regulations | — | — | — | — | 0.365 | 0.104 |
| Security organization | — | — | — | — | 0.160 | 0.046 |
| Safety education and training | — | — | — | — | 0.273 | 0.078 |
| Emergency rescue plan | — | — | — | — | 0.202 | 0.058 |

3.4. Fuzzy comprehensive evaluation

3.4.1. Determination of factor sets and comment sets
According to the established chemical production safety evaluation index system, determining the factor set U:

\[ U = \{u_1, u_2, u_3, u_4, u_5\} = \{\text{Personnel factors, Machine factors, Material factors, Environmental factors}\]
7

, Management factors};

\[ \mathbf{u}_1 = \{u_{11}, u_{12}, u_{13}, u_{14}\} = \{\text{Employee safety awareness, Employee safe operation, Employee emergency ability, Employee safety protection}\}; \]

\[ \mathbf{u}_2 = \{u_{21}, u_{22}, u_{23}\} = \{\text{Machine engineering design, Machine safety protection, Machine control linkage}\}; \]

\[ \mathbf{u}_3 = \{u_{31}, u_{32}, u_{33}\} = \{\text{Flammability, Explosiveness, Amount of substance}\}; \]

\[ \mathbf{u}_4 = \{u_{41}, u_{42}, u_{43}\} = \{\text{Fire and explosion protection, Public health, Flat layout}\}; \]

\[ \mathbf{u}_5 = \{u_{51}, u_{52}, u_{53}, u_{54}\} = \{\text{Safety regulations, Security organization, Safety education and training, Emergency rescue plan}\}. \]

Using fuzzy language such as "excellent, good, medium, poor, inferior" to describe safety evaluation indicators, dividing the evaluation level into 5 levels, and determining the review set \( \mathbf{V} = \{v_1, v_2, v_3, v_4, v_5\} = \{\text{safety (excellent), Safer (good), fair (medium), relatively dangerous (poor), dangerous (inferior)}\}. \)

3.4.2. Fuzzy evaluation

According to the fuzzy evaluation results of the single evaluation indicators by the invited experts, the evaluation matrix is obtained

\[
\mathbf{R}_1 = \begin{bmatrix}
0.0 & 0.7 & 0.3 & 0.0 & 0.0 \\
0.2 & 0.5 & 0.3 & 0.0 & 0.0 \\
0.0 & 0.0 & 0.4 & 0.6 & 0.0 \\
0.0 & 0.0 & 0.0 & 0.8 & 0.2 \\
\end{bmatrix}
\]

\[
\mathbf{R}_2 = \begin{bmatrix}
0.3 & 0.7 & 0.0 & 0.0 & 0.0 \\
0.0 & 0.2 & 0.4 & 0.4 & 0.0 \\
0.1 & 0.8 & 0.1 & 0.0 & 0.0 \\
0.0 & 0.3 & 0.5 & 0.2 & 0.0 \\
\end{bmatrix}
\]

\[
\mathbf{R}_3 = \begin{bmatrix}
0.0 & 0.0 & 0.2 & 0.6 & 0.2 \\
0.0 & 0.6 & 0.4 & 0.0 & 0.0 \\
0.0 & 0.0 & 0.3 & 0.4 & 0.3 \\
0.0 & 0.0 & 0.4 & 0.5 & 0.1 \\
\end{bmatrix}
\]

According to table 3, we can get: \( \mathbf{W}_1 = (0.343, 0.187, 0.296, 0.174); \)

\( \mathbf{W}_2 = (0.317, 0.285, 0.398); \)

\( \mathbf{W}_3 = (0.357, 0.402, 0.241); \)

\( \mathbf{W}_4 = (0.459, 0.367, 0.174); \)

\( \mathbf{W}_5 = (0.365, 0.160, 0.273, 0.202); \)

Performing first-level fuzzy evaluation:

\[
\mathbf{B}_1 = \mathbf{W}_1 \cdot \mathbf{R}_1 = (0.343, 0.187, 0.296, 0.174)
\]

\[
\mathbf{B}_2 = \mathbf{W}_2 \cdot \mathbf{R}_2 = (0.3740, 0.3336, 0.2774, 0.3168, 0.0348)
\]

\[
\mathbf{B}_3 = \mathbf{W}_3 \cdot \mathbf{R}_3 = (0.3740, 0.3336, 0.2774, 0.3168, 0.0348)
\]

\[
\mathbf{B}_4 = \mathbf{W}_4 \cdot \mathbf{R}_4 = (0.3740, 0.3336, 0.2774, 0.3168, 0.0348)
\]

\[
\mathbf{B}_5 = \mathbf{W}_5 \cdot \mathbf{R}_5 = (0.3740, 0.3336, 0.2774, 0.3168, 0.0348)
\]

Similarly, we can get: \( \mathbf{B}_2 = (0.1349, 0.5973, 0.1538, 0.1140); \)

\( \mathbf{B}_3 = (0.0723, 0.2321, 0.5036, 0.192); \)

\( \mathbf{B}_4 = (0.2754, 0.2155, 0.2063, 0.2569, 0); \)

\( \mathbf{B}_5 = (0.169, 0.4092, 0.3197, 0.1021); \)

Performing second-level fuzzy evaluation:

\[
\mathbf{R} = \begin{bmatrix}
\mathbf{B}_1 & \mathbf{B}_2 & \mathbf{B}_3 & \mathbf{B}_4 & \mathbf{B}_5 \\
0.374 & 0.3336 & 0.2774 & 0.3168 & 0.0348 \\
0.1349 & 0.5973 & 0.1538 & 0.114 & 0 \\
0 & 0.0723 & 0.2321 & 0.5036 & 0.192 \\
0.2754 & 0.2155 & 0.2063 & 0.2569 & 0 \\
0 & 0.169 & 0.4092 & 0.3197 & 0.1021 \\
\end{bmatrix}
\]
According to the principle of maximum subordination, the chemical production safety evaluation result of the enterprise is relatively dangerous.

3.5. Result analysis

(1) According to the weight of each factor at the criterion level, the weight of personnel factors is the largest, the weight is 0.319, the weight of management factors is the second, and the weight is 0.286, indicating that the personnel factors and management factors are the main factors affecting the safety production of the chemical enterprise. Secondly, the material factors is ranked in the middle, the weight is 0.169, and finally, the weight of the machine factors is 0.119, the weight of the environmental factors is the smallest, and the weight is 0.107, indicating that the machine factors and environmental factors have relatively little impact on the safety production of chemical companies.

(2) It can be seen from table 3 that the indicators that have the greatest impact on the safety production of chemical companies are employee safety awareness (0.109), followed by safety regulations (0.104) and employee emergency capabilities (0.094), which are the indicator with the least impact is the flat layout (0.019), followed by machine safety protection (0.034) and machine engineering design (0.038), indicating that employee safety awareness, safety regulations and employee emergency capabilities are the main factors affecting the safety production of the chemical enterprise. And the three indicators of plane layout, machine safety protection and machine engineering design have little impact on the safety production of chemical companies, which also positively verifies the results of article 1.

(3) The evaluation result of the chemical production safety of the enterprise is relatively dangerous. According to the principle of maximum membership, the evaluation results of personnel factors, machine factors, material factors, environmental factors and management factors are "excellent", "good", "poor", "excellent" and "medium", which shows that the production risk of the chemical enterprise mainly comes from management and materials. The enterprise should strengthen safety management, pay attention to the use and supervision of materials, and take corresponding rectification measures to improve its safety. In addition, it also reflects that the company's employees perform well in chemical production, the company has done a good job in the environment and machine, and the company should continue to maintain it.

4. Conclusion

(1) According to the production characteristics of chemical enterprises and the hazardous factors in production, combined with the opinions of industry experts, comprehensively considering the five aspects of human, machine, material, environment and management, 17 safety evaluation indexes affecting the safety in production of chemical enterprises are analyzed and summarized, the second level safety evaluation index system is established. It provides a basis for the comprehensive evaluation of the production process of chemical enterprises using AHP-fuzzy comprehensive evaluation method.

(2) AHP is used to analyze the production process of chemical enterprises, and the weights and rankings of various safety evaluation indicators are obtained, which reflects the impact of each evaluation indicator on the safety production of chemical enterprises, which is helpful for enterprises to find accident prevention priorities and adopt targeted security measures.

(3) According to the established chemical production safety evaluation index system, AHP-fuzzy comprehensive evaluation method is used to comprehensively evaluate the production process of chemical companies. The evaluation results are relatively dangerous, and the evaluation results are
objective and accurate, which helps companies to increase safety awareness, strengthen safety supervision work, take targeted rectification measures to prevent fire and explosion accidents in the chemical production process and ensure safe production. It has a positive reference for the application of AHP-fuzzy comprehensive evaluation method in chemical evaluation in the future.

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