

Risk Assessment on Storage Security of Hazardous Chemicals Based on AHP-fuzzy Comprehensive Evaluation Approach

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ABSTRACT

To solve the uncertainty and complexity problems in hazardous chemical storage risk assessment, this paper constructs the evaluation index system and proposed the risk assessment model based on AHP-fuzzy comprehensive evaluation approach, which organically integrate the quantitative and the objectivity of the analytic hierarchy process (AHP) and the inclusive advantage of fuzzy comprehensive evaluation approach. In the end, an application example was given to verify the effectiveness of the proposed approach.

Keywords

Hazardous chemicals; storage security; analytic hierarchy process; fuzzy comprehensive evaluation approach;

1. INTRODUCTION

With the rapid development of global economic, the scale and production of hazardous chemical industry has been growing and extending. Hazardous chemicals which have complicated properties, various species and intensive stored usually have features of explosive, inflammable, poisonous, corrosive and radioactive. Storage security as one of the crises processes of the hazardous chemical's produce is more professional with high risk and heavy responsibility. Accidents happened to the hazardous chemicals storage most probably leads to catastrophic casualty and tremendous property loss. According to the statistics, 76.3 percents of the hazardous chemicals accidents are caused by storage problems and had caused enormous economic loss as well as environment pollution. In a word, frequent accidents had alerted us to pay more attention to the security of hazardous chemical storage problem.

Hazardous chemical's storage security is one of the key dangerous sources in chemical industry. Supervision and management of the chemical industry must strictly observe relevant laws and technical specification. An effective and reasonable evaluate approach about the hazardous chemical storage's safety grade is an important measure to strengthen the storage's security supervision and management. Current evaluate approaches about hazardous chemical's storage security are mainly qualitative, while the quantitative study are seldom involved. On the same time, the evaluation criteria systems are nonstandard. Present quantitative evaluate approaches are sets pair analysis [1-2], fuzzy comprehensive evaluation approach [3-4] and the extended assessment approach [5]. Those approaches to some extent can realize the quantitative evaluation for the safety assessment problems however they have shortcomings in getting the criteria weights and the membership degree, which made the evaluation result not reasonable enough. Besides, for various of

partial factors, we can't get an satisfied result with a single approach. Wu [6] proposed 10 first indexes and 44 secondary indexes to evaluate the hazardous chemical industry's security grade by using the AHP and the fuzzy comprehensive evaluation approach and give the fundamental steps of evaluating the hazardous chemical company's security grade. Liu [7] build the model to evaluate hazardous chemical company's safety based on AHP approach and take a coating industry as an example to verify the effectiveness of the approach and the evaluate result coincides well with the security actuality of the industry. This approach can objectively reflect the hazardous chemical industry's safety situation. Cheng [8] use AHP approach and combine qualitative and quantitative to calculate the criteria weights and then use fuzzy comprehensive evaluation theory proposed the chemical industry's secondary grade fuzzy comprehensive evaluation approach based on industry's security actuality. In the end, this approach was used to evaluate the security grade of a chemical industry park and the result had verified its feasibility and easy operating. The approach can be widely used in other hazardous chemical industry's evaluation. For the shortcomings and insufficient of the present study, this paper collect lots of documents and date related to hazardous chemical industry include some laws and the safety standardization of hazardous chemical industry and combined with the present relevant literature, we build the hazardous chemical storage Evaluation criteria system. Due to the complexity and uncertainty of the storage's information, we proposed the risk assessment approach on storage security of hazardous chemicals based on AHP-fuzzy comprehensive evaluation model, which organically integrate the quantitative and the objectivity of the analytic hierarchy process (AHP) and the inclusive advantages of fuzzy comprehensive evaluation approach. This approach to some extent can avoid people's objective judgments and preference and make up for the shortcomings of single quantitative comparative analysis or single qualitative comparative analysis. In the end, an application example verified the reasonable and feasible of the approach, which makes the evaluation of the hazardous chemical storage more operational and objectivity. This approach to a certain degree can effectively support the managers to reduce the hazardous chemical storage's security risk.

2. THE HAZARDOUS CHEMICAL STORAGE EVALUATION CRITERIA SYSTEM

Establishment of the evaluation criteria system is the foundation of the security evaluation. Evaluation of the hazardous chemical storage is a complicated multi-index system which involves various heterogeneous elements. Make sure that the

evaluation criteria system is all-round, scientific and reasonable, we firstly collect lots of documents and date related to hazardous chemical include some laws (standard of safety technique AQ3013-2008 《General Safety Standardization of Hazardous Chemicals Industry》, 《Production License of Hazardous Chemical Materials Safety》), security theory, characteristic of the hazardous chemical industry, safety technology criterion and so on. Besides, we analysis various risk elements about the hazardous chemical's safety management [9], and consider staff's comprehensive quality, industry's facility, the equipment of the storage, environment factors and the management patterns and then propose the preliminary evaluation criteria system. In order to guarantee that the evaluation criteria system is reasonable acceptable and in accord with practical, we use the Delphi Method [10], by the process of consulting some experts, information feedback, statistical treatment, synthetically induce we got the flow chart of constructing the evaluation criteria system in the Figure 1.

To build the evaluation criteria system, we set the target layer as "Evaluation criteria system of hazardous chemical's storage security (A)". Based on the collected date and documents the criteria layer are about staff's comprehensive quality, industry's facility, equipment of the storage, environment factors and the management patterns. Then we make further subdivision of the criteria layer and got the sub-criteria layer. For staff's comprehensive quality, we subdivision it into "Professional skills", "Capability of emergency response" and "Safety consciousness". In the same way, we subdivision facility and equipment of the storage into "Regular overhauling of the storage facility", "Monitor of the storage risk resources", "Equipping of the storage alarm facility" and "Equipping of emergency response facility". For environment factors of the storage we subdivision it into "Inner storage environment" and "Outer storage environment". For the management patterns we subdivision it into "Information management levels", "Security management levels" and "Daily training of staffs and managers". Finally we got the evaluation criteria system and tabulated it in the Table 1.

3. MODEL OF AHP-FUZZY COMPREHENSIVE EVALUATION APPROACH

American operational research experts T.L.Saaty [11] proposed the analytic hierarchy process approach in 1971. AHP is a multi-objective decision making approach which combines qualitative analysis with quantitative analysis. This approach first decompose the complicate problem into some elements, and then builds a multi-hierarchical evaluation model and decides the membership relation of different hierarchies, and gets criteria weights of each related index. With the combine of AHP method with fuzzy comprehensive evaluation approach, we can avoid people's objective judgments and preference which will impact the objectivity and fairness of the evaluation results. In this paper we propose AHP-fuzzy comprehensive evaluation approach [12]. The fundamental steps of the evaluation approach are as follows:

Step1. (Build judgment matrix) We have m goals (scheme or elements), based on the proposed criteria, we make a pairwise comparison of the goals. In the matrix a_{ij} ($j = 1, 2, \dots, m$) is the pairwise comparison of relative importance of criteria i to criteria j . We get the pairwise comparison matrix $A = (a_{ij})_{m \times m}$:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1m} \\ a_{21} & a_{22} & \cdots & a_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mm} \end{bmatrix}$$

$$\textcircled{1} a_{ij} > 0; \textcircled{2} a_{ij} = \frac{1}{a_{ji}}; \textcircled{3} a_{ii} = 1.$$

When we make a pairwise comparison, we use 1-9[13] to scale the importance.

Step2. (Calculate criteria weights) Compute the largest eigenvalue of the pairwise matrix we get λ_{\max} and the eigenvector W and normalize it we can get the single hierarchy structure's eigenvector w , in this case we need to identify the consistency ratio of a matrix, first the matrix's consistency index (CI) is found by:

$$CI = (\lambda_{\max} - n) / (n - 1)$$

The consistency index of a randomly generated reciprocal matrix with reciprocal forces is called the random index (RI) and is calculated using the matrix order (n). So we get the matrix's consistency ratio (CR) by:

$$CR = CI / RI$$

A consistency ratio of 0.1 or less is considered acceptable.

Step3. (Build the evaluation matrix R) Set $U = \{u_1, u_2, \dots, u_m\}$ is made up of elements of the evaluation criteria system, and set $V = \{v_1, v_2, \dots, v_n\}$ contains all the possible results that judgments give. Firstly, we evaluate the single index of set U and get the value to make up of the judgment matrix R .

Step4. (Build the evaluation model) We have got eigenvector w and judgment matrix R , and then we make fuzzy comprehensive evaluation. The evaluation equation is as follow:

$$B = w \circ R$$

Step5. (Calculate the evaluation result) Normalize B we will get B' , and multiple it with judgment vector V , we can get the final evaluation result G :

$$G = B' \circ V^T.$$

4. APPLICATION EXAMPLE

Take Ningbo Zhenhai liquid chemical storage port area for example, which subordinate to Ningbo Zhenhai port stevedoring company, so far, it has 15 storage joint venture enterprise and had built 172 liquid oil tanks. Its storage capacity has reached nearly 610,000 cubic meters. Up to now, it has safely discharge, transfer, stored more than 90 kinds of liquefied products includes arene, alcohols, ester, ketone, oils, nitrile, ether, amine, alkane, olefins and so on and it has established business relationship with more than 40 ports with different countries. To strengthen and improve the security supervision of hazardous chemical storage system, Ningbo port area had actively cooperated with the investigation. Based on the proposed evaluation criteria system,

we use the AHP-fuzzy comprehensive evaluation approach to build the judgment matrix in the Table 2.

Table 2 pairwise comparison matrix A

A	A1	A2	A3	A4
A1	1	1/7	1/4	1/4
A2	7	1	2	5
A3	4	1/2	1	3
A4	4	1/5	1/3	1

Using MATLAB we calculate the largest eigenvalue of the pairwise matrix A and get $\lambda_{\max} = 4.1509$. By normalizing the eigenvector we can get the single hierarchy structure's eigenvector $W_A = (0.0570, 0.5227, 0.2846, 0.1357)^T$

Calculate the matrix's consistency index CI we can get:

$$CI = \frac{\lambda_{\max} - n}{n - 1} = 0.0754$$

Calculate the matrix's consistency ratio CR we can get:

$$CR = \frac{CI}{RI} = 0.0838 < 0.1$$

Therefore, the consistency ratio of the matrix is acceptable. We make the conclusion that the criteria weights can objectively reflect the importance of each index. Using the same steps we can get the criteria weights of first grade indexes and the secondary indexes. The results are summarized in the Table 3.

Based on the criteria weights in the table 2, we calculate the criteria weights of third grade indexes to the first grade indexes, and normalized it we can get:

$$W = W_1 \circ W_2 = [0.0080, 0.0147, 0.0363, 0.3162, 0.0788, 0.0944, 0.0332, 0.1423, 0.1423, 0.0242, 0.1020, 0.0096]$$

To build the judgment matrix R, we make set U which consist of all the third indexes. We grade the evaluation results as "Lower risk", "Low risk", "Average risk", "High risk", "Higher risk". To make the result quantization, we set $V = [90, 75, 60, 45, 30]$, when the evaluation result is above 90, we say the safety grade of the company is "Lower risk" or if the evaluation result is between 75 and 90 we say the safety grade of the company is "Low risk". We invite some experienced experts engaged in hazardous chemical storage and some staffs in the company to make up the evaluate team to build the judgment matrix R:

$$R = \begin{bmatrix} 0.1537 & 0.0475 & 0.2003 & 0.1439 & 0.0845 \\ 0.0144 & 0.0296 & 0.0509 & 0.1063 & 0.0874 \\ 0.1447 & 0.0525 & 0.0980 & 0.1525 & 0.0507 \\ 0.0283 & 0.1405 & 0.0659 & 0.0258 & 0.0107 \\ 0.1241 & 0.1033 & 0.0117 & 0.1187 & 0.0462 \\ 0.0950 & 0.0927 & 0.0591 & 0.0593 & 0.0328 \\ 0.1028 & 0.1127 & 0.1373 & 0.0720 & 0.1616 \\ 0.0695 & 0.0672 & 0.1933 & 0.0061 & 0.0217 \\ 0.0171 & 0.0335 & 0.0082 & 0.0892 & 0.0024 \\ 0.0515 & 0.0458 & 0.1668 & 0.0590 & 0.0651 \\ 0.1059 & 0.1136 & 0.0454 & 0.1257 & 0.1231 \\ 0.0283 & 0.0914 & 0.2030 & 0.1261 & 0.1567 \end{bmatrix}$$

We have got W and R, and then we use equation $B = W \circ R$ to make fuzzy comprehensive evaluation:

$$B = W \circ R = [0.9929 \quad 0.0957 \quad 0.0771 \quad 0.0628 \quad 0.0384]$$

Normalize B we will get B' :

$$B' = [0.7837, 0.0755, 0.0609, 0.0496, 0.0303]$$

multiply it with the judgment vector $V = [90, 75, 60, 45, 30]$, we can get the final evaluation result G:

$$G = B' \circ V^T = 83.15$$

Therefore, we can make the conclusion that the safety grade of Ningbo Zhenhai liquid chemical storage port area can be graded as "Low risk".

Managers of the company has analyzed this evaluation result and compared it with the primary comprehensive qualitative evaluation results. It concludes that risk assessment on storage safety of hazardous chemicals based on AHP-fuzzy comprehensive evaluation is reasonable and effectiveness. This approach can effectively support managers to make decisions of how to reduce the hazardous chemical storage's security risk.

5. CONCLUSION

An effective and reasonable assessment about the hazardous chemical's storage security is an important measure in the storage's safety supervision. This paper builds the evaluation criteria system about hazardous chemical's storage safety. Due to the complexity and uncertainty of the storage's information, we proposed risk assessment about the storage safety of hazardous chemicals based on AHP-fuzzy comprehensive evaluation approach, which organically integrate the quantitative and the objectivity of the analytic hierarchy process (AHP) and the inclusive advantage of fuzzy comprehensive evaluation approach. This approach to some extent can avoid people's objective judgments and preference and make up for the shortcomings of single quantitative comparative analysis or single qualitative comparative analysis. In the end, the application example verified the reasonable and feasible of the approach, which make the evaluation of the hazardous chemical storage more operational and objectivity. This approach can be widely used in the hazardous chemical industry and effectively support the managers to reduce the hazardous chemical storage's security risk.

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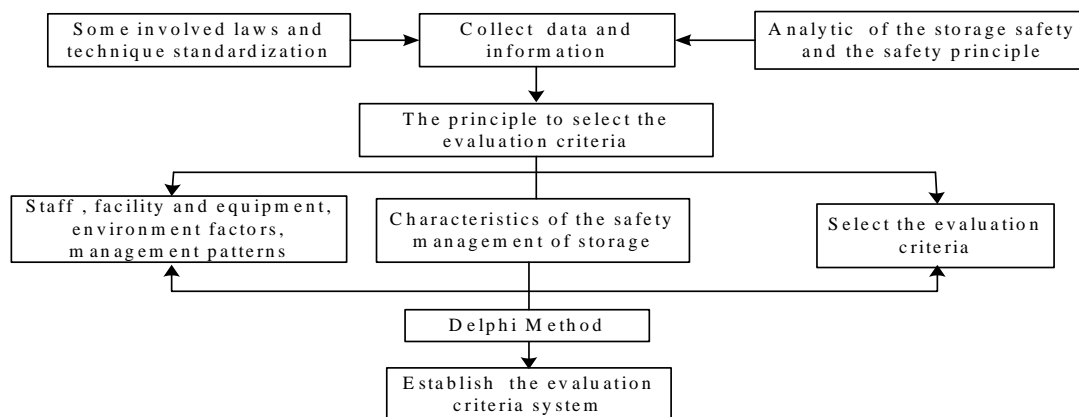


Figure.1 Process of establishing the evaluation criteria system

Table 1 Evaluation criteria system of hazardous chemical

Target layer	Criterion layer	Sub-criterion layer
Evaluation criteria system of hazardous chemical's storage security (A)	Staff's comprehensive quality (A_1)	Professional skills (A_{11})
		Capability of emergency response (A_{12})
		Safety consciousness (A_{13})
	Facility and equipment of the storage (A_2)	Regular overhauling of the storage facility (A_{21})
		Monitor of the storage risk resources (A_{22})
		Equipping of the storage alarm facility (A_{23})
		Equipping of emergency response facility (A_{24})
	Environment factors of the storage (A_3)	Inner storage environment (A_{31})
		Outer storage environment (A_{32})
		Information management levels (A_{41})
	Management patterns (A_4)	Security management levels (A_{42})
		Daily training of staffs and managers (A_{43})

Table 3 Criteria weights of hazardous chemical storage evaluation criteria system

Criteria Weights of first grade indexes											
A1 0.0570			A2 0.5227				A3 0.2846		A4 0.1357		
Criteria Weights of secondary grade indexes											
A11 0.1407	A12 0.2583	A13 0.6370	A21 0.6050	A22 0.1508	A23 0.1806	A24 0.0635	A31 0.5	A32 0.5	A41 0.1782	A42 0.7514	A43 0.0704