

Fuzzy Comprehensive Evaluation of Safety Management by Hazardous Chemicals Manufacturing Enterprises

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Abstract. Since the chemicals, as regular raw materials and products of chemical industry, are increasingly used and manufactured, accompanied by more and more hazardous waste produced, it is necessary to attach more importance to the safety management of hazardous chemicals. This paper is intended to study the current situation of management conducted by a hazardous chemical enterprise, by using the analytic hierarchy process and fuzzy comprehensive evaluation method. Firstly, determine the proportions of different indicators by using the scoring method combined with the results from the discussion of experts; secondly, build a model for evaluating the safety management of hazardous chemicals, namely the fuzzy comprehensive evaluation model; and finally, demonstrate upon the evaluation results that the safety management grade of this chemical enterprise is "good", which means that this enterprise has carried out and implemented the relevant safety management policies, rules and regulations successfully. However, specific safety management measures are still proposed based on the current situation of this enterprise in its production and management, in order to ensure to the maximum extent the safety of the hazardous chemical enterprise during its production and later disposal processes.

1. Introduction

More and more hazardous solid waste is produced by all industries along with the rapid development of economy and continual improvement of industrialization in China. According to the statistical data, the hazardous solid waste produced in China during a seven-year period from 2001 to 2007 had reached 10 million tons in total, and reached 34.31 million tons by 2011. During the past few decades, there were no specific requirements available for the safety management for each industry due to the deficiencies and incompleteness of the conventional regulations or administration systems in China. Since all departments used to remove themselves from the management responsibilities, an enterprise always could not establish scientific and practical management regulations or develop the relevant disposal technologies. Under this circumstance, some enterprises which had established their own disposal sites still caused pollution to the environment due to they failed to pay attention to the penetration of micro scale waste and failed to carry out strict control on the discharge of waste. The accidents caused by pollution related to hazardous chemicals and hazardous waste occurred frequently in recent years, and the disputes arising from environmental matters also became common to our life.



Great improvements have been achieved by China in renewing and upgrading the relevant laws, regulations, rules and technologies, though we began to pay more attention to the control of hazardous waste just years ago.

The chemical industry is one of the major pillars supporting the economic development of China, and produces more, even more complicated, hazardous waste than other industries since the chemicals are the most common raw materials and products of this industry. At present, the government is paying more and more attention to the hazardous waste related pollution. Most of large scale chemical enterprises have realized the significance of hazardous chemicals in their production and the importance of hazardous waste in their safety management, and have established corresponding safety management rules. Since a preliminary system has been built for the administration of hazardous waste, and laws and regulations have been enacted for effectively controlling the pollution; the reasonable disposal and efficient operation of hazardous waste will be conducted in a more professional way. But we find that numerous small and medium chemical enterprises are relatively lacking in the awareness of safety management on hazardous chemicals, often pay more attention to production than safe disposal, and fail to properly dealt with the relations among production, safety and development [2]. Therefore, this paper selects the factors and indicators related to the safety management of hazardous chemicals and the disposal of hazardous waste in a chemical plant; establishes a manufacturing enterprise safety management indicator system by using the analytic hierarchy process; determines the major factors affecting the hazardous waste safety management of enterprise by combining the fuzzy comprehensive evaluation method; and thereby helps the enterprise in carrying out the relevant management and support tasks against such factors.

2. Research Methods

This paper adopts the analytic hierarchy process to extract the goal level, criteria level and alternatives level from the elements relevant to decision making, then utilizes the expert scoring method to compare the alternatives in pairs to rank the importance of alternatives, thereby calculates the final ranking weight of each factor relative to the goal, and finally use the fuzzy comprehensive evaluation method to evaluate the effects of management conducted by this enterprise on its production of hazardous chemicals and on its disposal of hazardous waste.

2.1. Analytic hierarchy process

Basic steps of analytic hierarchy process [4]:

(1) Define the goal of decision making, determine and reasonably classify the factors affecting the decision making [5]; (2) Compare different factors of one level with the same factors of the upper level, and determine their relative importance by numerical scale from 1 to 9 to build the pairwise comparison matrix; (3) Calculate the pairwise comparison matrix and check its consistency; adjust and modify the pairwise comparison matrix if it does not have satisfactory consistency; and (4) After the checking of consistency, work out the characteristic vector corresponding to the most obvious characteristic of pairwise comparison matrix, then work out the weight of each factor relative to the same factor of the upper level, and finally work out different weights of each factor for making decisions.

2.2. Fuzzy mathematics comprehensive evaluation method

Conduct field investigations of occupational health and measurements of hazards in the object enterprise, and utilize the fuzzy comprehensive evaluation method to evaluate the occupational health risk level. The fuzzy comprehensive risk evaluation method is an evaluation model based on the principle of "membership" applied in the fuzzy mathematics, which is used to describe the potential fuzzy information during the evaluation, determine the weights of factors assigned with selected threshold values, and then utilize certain mathematical methods for statistical and processing to obtain the scientific conclusions of evaluation [6]. The fuzzy mathematics evaluation included the basic steps of selection of indicators, determination of weights, building of evaluation matrix, etc., as follows [7]:

(1) Selection of indicators. Before the evaluation, screen the influencing factors, determine the effective evaluation factors, and build the factor set U , wherein, $U = \{U_1, U_2, U_3, \dots, U_n\}$, with U_i ($i=1, 2, \dots, n$) representing a certain number of influencing factors therein. (2) Determination of weight set. Assign different weights to different elements in the factor set upon their evaluated importance, wherein, such weights shall be convergent to 1 and non-negative, and the evaluation weight set is determined herein by using the analytic hierarchy process. (3) Building of evaluation set. Several grades are determined herein according to the conditions of each indicator level in the management evaluation system of hazardous chemicals. (4) Building of fuzzy evaluation model. After the determination of evaluation set for each single factor in the set, build the fuzzy evaluation model on the basis of fuzzy mathematics principles, and calculate (4), expressed by using the following equation:

$$B=A \times R = (a_1, a_2, a_3, \dots, a_m) \times \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1m} \\ r_{21} & r_{22} & \dots & r_{2m} \\ \dots & \dots & \dots & \dots \\ r_{n1} & r_{n2} & \dots & r_{nm} \end{bmatrix} = (b_1, b_2, b_3, \dots, b_m)$$

According to the mathematical model $C=B \times P$, wherein, B indicates the membership degree in the comprehensive evaluation; P indicates the point scored during the grade evaluation; and C , which is calculated by using B values as transverse line and P as vertical row, indicates the indicator for the final fuzzy comprehensive rating. Express by using the following equation:

$$C=B \times P = (b_1, b_2, b_3, \dots, b_m) \times \begin{bmatrix} P_1 \\ P_2 \\ P_3 \\ \dots \\ P_n \end{bmatrix}$$

Wherein, P_n indicates the value assigned during grade evaluation.

The main flow of fuzzy comprehensive evaluation is shown below (take two-level comprehensive evaluation as example) [4]:

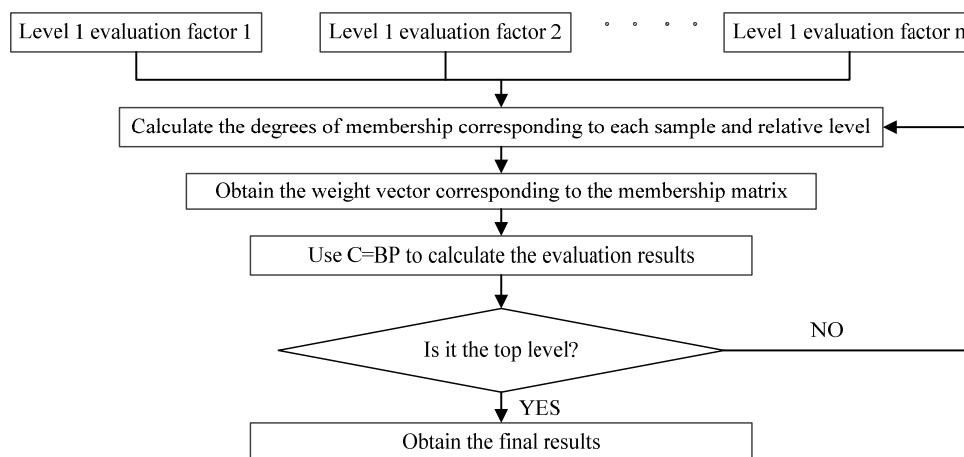


Figure 1. Multilevel fuzzy comprehensive evaluation algorithm flow

3. Results

The potential hazards of a typical manufacturing enterprise may be caused by two kinds of factors: unsafe behaviors by humans and unsafe conditions of things [8]. The enterprise may achieve its accident prevention objectives effectively only after takes preventive actions against any potential hazards. It is found in this paper during the study and selection of indicators that the safety

management of hazardous chemicals will be influenced by three kinds of factors, namely the human factors, institutional factors and environmental factors, wherein, the human factors, as the major objects of hazardous chemicals management, is critical to the effective safety management, mainly including the knowledge level of managerial personnel and operators, the subjective consciousness of the leaders of a chemical plant about the safety management of hazardous chemicals, and the techniques of operators for conducting safe production and orderly management. The institutional factors refer to a series of practical and effective safety management regulations established by the enterprise, and are important to ensure the proper use and disposal of hazardous chemicals. The institutional factors include: a) the safety management system to define the leaders and managerial personnel for each level; b) the accountability system to define the responsibilities for each department concerning the safe production; c) the education, training and performance assessment system for employees; d) the implementation of special work management system; and e) the rehearsals and drillings of emergency response plans. The environmental factors mainly include the storage and disposal of hazardous chemicals, and among others, the temperature, humidity, ventilation, noise, vibration and light, as well as the fire ratings of plant buildings and warehouses, will influence the safe production of hazardous chemicals. Therefore, a chemical enterprise shall provide proper production, storage and disposal environments according to the classification of hazardous chemicals [2].

3.1. Selecting indicators and building model for hazardous chemicals management evaluation system

Adopt a "flashback" approach to establish a hazardous chemicals safety management evaluation system for the targeted enterprise, and calculate the indicators. Determine the evaluation values for the alternatives level mainly by expert discussion and scoring. Adopt the pairwise comparison matrix shown below and the standard row averaging method to calculate the weight values for each factor.

Table 1. Expert evaluation results during factor importance comparison

Factors	B1	B2	B3
B1	1	2	8
B2	1/2	1	6
B3	1/8	1/6	1
Weights	0.593	0.341	0.066

Calculate as follows:

Calculate weights and vectors:

$$(0.593 \ 0.341 \ 0.066) \times \begin{bmatrix} 1 & 2 & 8 \\ 1/2 & 1 & 6 \\ 1/8 & 1/6 & 1 \end{bmatrix} = (1.803 \ 1.034 \ 0.197)$$

$$(2) \text{ Calculate mix: } \text{mix} = \frac{1.803}{0.593} + \frac{1.034}{0.341} + \frac{0.197}{0.066} = 3.019$$

$$(3) \text{ Calculate the consistency indicator: } CI = \frac{\lambda_{\max} - n}{n - 1} = 0.01$$

(4) Calculate the consistency rate: $CR = \frac{CI}{RI} = 0.017 < 0.1$. It can be seen from the results that the comparison matrix meets the requirements for consistency, which means that the characteristic vector and weight are valid.

3.2. Fuzzy comprehensive evaluation

To execute the safety management evaluation in a scientific and objective way, hereby provide a checklist for the indicators used for evaluating the management on hazardous chemicals production

and hazardous waste disposal. Table 2 lists the results obtained from field inspections, and the mark "√" indicates the corresponding the descriptive grade, with the membership degree given for each level.

Table 2. Checklist for descriptive grades

Factors	Items		Descriptive grades				
			1 Very good	2 Good	3 Average	4 Poor	5 Very poor
Management on hazardous chemicals production and hazardous waste disposal (A)	Human factors(B1)	Knowledge level(C1)			√		
		Safety management consciousness(C2)		√			
		Safe production consciousness(C3)		√			
	B1's membership degree			0.6667	0.3333		
	Institutional factors(B2)	Safe production accountability system(C4)		√			
		Hazardous waste safety management syste(C5)			√		
		Emergency response plan system(C6)			√		
		Special work system(C7)		√			
		Hazardous waste management personnel performance assessment system (C8)		√			
	B2's membership degree			0.6	0.4		
	Environmental factors(B3)	Fire rating of warehouse(C9)		√			
		Ventilation(C10)		√			
		Temperature(C11)		√			
		Humidity(C12)		√			
	B3's membership degree			1.0			

Calculate in section 3.1 the weights for all indicators of the goal and criteria levels, and verify all results meeting the consistency principle by using the consistency check method, to obtain the weights $W=(0.593 \ 0.341 \ 0.066)$. Execute the fuzzy comprehensive calculation as follows:

$$A = W \times R = (0.593 \ 0.341 \ 0.066) \times \begin{bmatrix} 0 & 0.6667 & 0.3333 & 0 & 0 \\ 0 & 0.6 & 0.4 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \end{bmatrix}$$

$$= (0, 0.6656, 0.4922, 0, \text{ and } 0)$$

According to the maximum membership degree principle, select $A=0.6656$, and then determine the grade of management conducted by this enterprise on its safe production and hazardous waste disposal as "good".

3.3. Measures for improving enterprise safety management

According to the fuzzy evaluation results, the hazardous chemicals safety production and management of this enterprise is rated as "good", which means that this enterprise has successfully implemented its existing safety and protection measures. But it is found during this field investigation that there are several aspects to be improved and perfected by this enterprise:

(1) The disposal of toxic and hazardous waste gas waste, solid waste and liquid waste produced and discharged by the enterprise during its operation shall be executed in strict accordance with the applicable rules and standards of China, to essentially eliminate the spillage and leakage. For this purpose, the enterprise should focus on the systematicness and comprehensiveness of its policies when establishes its safety management measures.

(2) All hazardous waste should be strictly reported for the purposes of safety management and disposal, without any omissions. In consideration that some hazardous waste of the enterprise is not provided with reasonable outlets, it is suggested that the enterprise should be equipped with corresponding disposal and recycle facilities.

(3) A hazardous waste information management platform should be built for facilitating the management and statistical work of the enterprise, and for ensuring the accurate supervision on and timely update of the information about the hazardous waste during generation, management and transportation.

4. Discussion

Accidents take place more frequently in various enterprises along with the expansion of hazardous chemical industry and increase of hazardous chemicals in China. At present, most of the relevant studies focus just on the hazardous chemicals or hazardous waste, namely just focus on the analysis and evaluation of unsafe condition of "things", lacking of analysis or evaluation of the safety management of hazardous chemicals. In light of such a situation in which more importance is attached to things than management, this paper has great practical significance since it focuses on the evaluation and study of safety management of hazardous chemicals [4]. During this study, building the hazardous chemicals safety management evaluation model is not only to determine the safety management level and grade of an enterprise, but also, more than that, to help the enterprise, through the safety management analysis and evaluation, in promoting its management level, reducing potential hazards during production, and ensuring the safe and reasonable disposal of hazardous waste. The enterprise is expected to conduct its production and management activities according to the following suggestions. Firstly, stick to the basic principle of "people first", since the final purpose of the safety management system of enterprise is to protect its employees and workers against any injuries caused by the hazardous chemicals, and the purpose of disposing hazardous waste safely and reasonably is to protect our living environment and finally our health. Secondly, improve the safety related abilities and capabilities of the management, and ensure the "people" vigorously pushing forward the implementation of safety management system, since an excellent system is only an imagination without the participation by people. In addition, strengthen the safe production awareness of the workers at production line, and intensify the safety training for the workers, in order to effectively control the potential accidents and environmental risks by ensuring the safe and proper operation and disposal of hazardous chemicals by each shift at each step at each second. Finally, because most of the conventional safety management belongs to lag control corresponding to actual outcomes, we should act proactively and take measures preventively. The enterprise should strengthen the information management of hazardous waste to optimize the safety management system. The enterprise may also consider a hazardous waste information management platform, which will enable the enterprise to learn about the information of hazardous waste quickly and accurately, to greatly improve the efficiency and accuracy of management work upon more reliable information, reducing the troubles arising from exchanging exchange vouchers during transportation in addition to simplifying the tedious manual book keeping work [9]. This will effectively facilitate and accelerate the innovation of hazardous waste management, realization of scientific and accurate management. Additionally, these

true and objective data may assist the government to strictly supervise and control the disposal of waste at a high level.

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