Fuzzy Comprehensive Evaluation of Occupational Health Risks in a Plastics Processing Enterprise

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Abstract. Conduct field investigation and engineering analysis of a plastics processing and manufacturing enterprise in an industrial park according to the characteristics of chemical industry, to pick out the typical toxic substances, e.g. noise and dust. Adopt the fuzzy comprehensive risk evaluation method to evaluate the occupational health risk level of this enterprise. Utilize the concentration grading of occupational health hazards to determine the weights of indicators at each grade, use the ratio of exposed workers to determine the weight coefficient, and calculate according to the principle of maximum membership degree to determine that the occupational health risk is Grade Ⅰ, which represents the negligible risks. As judged based on the numerical values assigned for the descriptive grade set, determine the result of the comprehensive evaluation of enterprise working environment and occupational health risk as Grade Ⅱ, which represents the "Good, Low risk". As compared with other methods often used at present for evaluating the occupational hazards, the results from the fuzzy comprehensive evaluation can better deal with the fuzzy characteristics of occupational hazard evaluation in addition to the realization of comprehensive evaluation on multiple hazards, more objective and realistic as using fuzzy vectors to replace exact point values in the evaluation results.

1. Introduction
Along with the rapid development of economy, science and technologies in China, novel technological processes and chemical raw materials come out one after another, and the diseases caused by some new factors influencing health now show a tendency to increase. All products produced and developed by a chemical enterprise belong to flammable and explosive hazardous materials. Furthermore, as compared with the traditional industries, the production of chemical industry adopts more complicated technological processes, and the workers are chronically exposed to the toxic and hazardous substances in the whole production process, liable to suffer occupational health risks [1, 2]. According to the statistical data of the Ministry of Health, more than 1.2 million patients all over the nation suffer occupational diseases of chemical industry, such as occupational poisoning and hearing loss, due to the toxic and hazardous working environment, and the direct financial loss caused by various occupational health hazards is up to CNY 8 billion every year [1, 3]. Many historical factors have jointly contributed to the current situation of serious occupational health hazards in the chemical
industry, including the insufficient cognition of occupational hazards in enterprises, inadequate awareness of occupational health protection, underinvestment in occupational hazard control, and deficient environmental management measures.

At present, there are many deficiencies in the health risk evaluation for the workers of chemical enterprises, such as indefinite evaluation scope, incomplete evaluation criteria and only qualitative expressions, and it is hard to reflect the reality of occupational health risks in enterprises. In the method widely adopted for occupational health risk evaluation, the measurement is conducted by using the concentration excursion limit of an occupational hazard. But, during the measurement, it is unable to conduct comprehensive analysis or evaluation on multiple hazards causing occupational diseases or multiple indicators, while the comprehensive evaluation method can be used for evaluating multiple hazards and multiple indicators. In this way, the multilevel problems can be converted into simple and easy model for dealing with, combining with both quantitative and qualitative methods to conduct overall evaluation on the objectives under the joint affection of multiple factors. Therefore, this paper utilizes this method to conduct the occupational health risk evaluation for a plastics processing enterprise to make up to the deficiencies of traditional methods and to obtain more scientific and accurate results. By leveraging the evaluation results, it is possible to help the enterprise in effectively and vigorously carrying out its occupational health related work, in addition to finding out the key control nodes, making rectifications aiming at the problems and adopting comprehensive environmental management measures. This will not only improve the health conditions of workers effectively, but also play an important role in increasing the enterprise's economic benefits and accelerating the enterprise's harmonious and healthy development.

2. Object and Methods

2.1. Object of study
Select a plastic products manufacturing enterprise in an industrial park, and conduct engineering analysis on this project to determine the major occupational health hazards of this enterprise, including noise, chemical hazardous agents and dust, wherein, the chemical hazardous agents exposed to by the workers mainly include ethylene, propylene, non-methane hydrocarbon, benzene, methylbenzene, xylene and n-hexane.

2.2. Investigation and evaluation methods
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.

2.2.1. Occupational health field investigations and measurements. Execute the field monitoring on the enterprise according to the Specifications for Sampling Hazardous Substances in Air of Workplace, and generally select some typical sampling sites to measure the hazardous agents separately according to the Determination of Toxic Substances in Air of Workplace. Determine the total dust concentration, noise and so on according to the requirements.

2.2.2. Fuzzy mathematics comprehensive evaluation method. The so called fuzzy comprehensive risk evaluation method utilizes the theories of fuzzy mathematics to build a novel model, which is used to describe the fuzzy information based on the principle of "membership degree" provided in the fuzzy mathematics evaluation theories, select the threshold values in a scientific way to determine the weights, and then process with the statistical methods of traditional mathematics to draw a scientific evaluation conclusion. The fuzzy mathematics evaluation includes the basic steps of selecting evaluation indicators, determining weights and building evaluation matrix, as follows [5]:

(1) Selecting indicators
Before the evaluation, screen the influencing factors, determine the effective grading indicators, determine the factor set \( U = \{U_1, U_2, U_3, U_N\} \), with \( U_i \) (\( i = 1, 2, n \)) representing a certain number of influencing factors.

(2) Determining weight set
Assign different weight value to each influencing factor in the factor set based on their different importance determined during the evaluation, provided that such weights shall be convergent to 1 and non-negative. In this paper, the weight set is built upon the proportion of workers exposed to different occupational hazards.

(3) Building evaluation set
The evaluation set is a collection of the results from scientific evaluation on the object, represented by \( V = \{V_1, V_2, V_3, V_m\} \), wherein \( V_i \) (\( i = 1, 2, m \)) represents the scientific evaluation on a certain number of influencing factors. In this paper, use \( V \) as the set of m descriptive grades, classify the risk factors into 5 grades based on the risk rating standards and respectively corresponding to the negligible risk, low risk, moderate risk, high risk and extremely high risk, namely \( V = \{\text{negligible risk, low risk, moderate risk, high risk, extremely high risk}\} \).

(4) Fuzzy evaluation
After the determination of the set risk factor evaluation model, conduct the comprehensive evaluation on the model, and calculate according to the mathematical principle by using the following equation:

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

\( B_m \) is the indicator for fuzzy comprehensive evaluation.

(5) Mathematical model comprehensive evaluation
According to the mathematical model \( C = B \times P \), wherein, \( B \) indicates the membership degree; \( P \) 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 grading. Express by using the following equation:

\[
C = B \times P = (b_1, b_2, b_3, b_m) \times \begin{bmatrix}
    P_1 \\
    P_2 \\
    \vdots \\
    P_m
\end{bmatrix}
\]

Wherein, \( P_n \) indicates the value assigned during grade evaluation.

3. Results

3.1. Measuring occupational health hazards and building membership degree matrix
It is found, upon the field investigation, engineering analysis and hazards measurement conducted to the enterprise, that: the enterprise has evident health hazards, including noise, dust and some toxic chemicals. Select the most important toxic chemicals in the production process, such as xylene, benzyl, dichlorodiphenyltrichloroethane and n-hexane. The dust is mainly the plastic dust generate from the fiber glass and asbestos used for reinforcing the plastics.

Finish all measurements of hazardous chemicals within 15min, use the results for rating and evaluating based on the ratio of STEL to PC-STEL in relation to the limited hazardous substances exposed to in short term, and express the toxic substances without PC-STEL in excursion limits similar to the results of dust [7], so as to determine the evaluation grades by using the values of excursion limits. Establish the criteria according to the definitions of single factor evaluation ranking and grades, including the excursion limit and exposure limit corresponding to each occupational
hazard value. Then determine the distribution of the evaluation of each occupational hazard to build
the single factor matrix, as shown in Table 1.

### Table 1. Occupational Health Hazard Membership Degree Matrix

| Evaluation Grades | Hazardous Chemicals | Dust | Noise |
|-------------------|---------------------|------|-------|
|                   | Benzene             | Chloroethylene | n-hexane |       |
| I                 | 0.326               | 0.461 | 0.167 | 0.458 | 0.896 | 0.461 | 0.167 |
| II                | 0.433               | 0.258 | 0.5   | 0.396 | 0.104 | 0.258 | 0.5   |
| III               | 0.241               | 0.142 | 0.167 | 0     | 0     | 0.142 | 0.167 |
| IV                | 0                   | 0.069 | 0.167 | 0.146 | 0     | 0.069 | 0.167 |
| V                 | 0                   | 0.069 | 0     | 0     | 0     | 0.069 | 0     |

3.2. Fuzzy comprehensive evaluation

Establish 5 grades for the workplace occupational health risk, represented by C, including "Very Good, Negligible Risk" ($9 \leq C < 10$), "Good, Low Risk" ($7 \leq C < 9$), "Average, Moderate Risk" ($5 \leq C < 7$), "Poor, High Risk" ($3 \leq C < 5$) and "Very Poor, Extremely High Risk" ($C < 3$). Calculate C according to the mathematical model, and then determine the concrete grade based on the value range of C to obtain the results of fuzzy comprehensive evaluation.

In this paper, use the proportion of workers exposed to occupational hazards as the given principle for calculating the weight coefficients, so as to evaluate in a scientific way the influence of this hazard on a certain worker. This is a weight coefficient selecting method often adopted in evaluating the occupational health risks based on the fuzzy mathematics. In this enterprise, the number of workers exposed to the hazards are 150 in total, including 30 exposed to benzene, 30 exposed to methylbenzene, 25 exposed to xylene, 25 exposed to chloroethylene, 20 exposed to n-hexane, 10 exposed to dust and 10 exposed to noise, and accordingly the assignment of weights is:

- Benzene: Methylbenzene: Xylene: Chloroethylene: n-Hexane: Dust: Noise = $\left[\frac{30}{150}, \frac{30}{150}, \frac{25}{150}, \frac{25}{150}, \frac{20}{150}, \frac{10}{150}, \frac{10}{150}\right] = \left[0.20, 0.20, 0.17, 0.17, 0.13, 0.07, 0.07\right]$

3.2.1. Fuzzy comprehensive evaluation of chemical hazards. Based on the results of hazardous chemical weight analysis and calculation, as well as the membership degree matrix thereof, calculate the result of fuzzy comprehensive evaluation on the toxic and hazardous chemicals as follows:

$$\text{B}_1 = \text{A}_1 \times \text{R}_1 = \begin{pmatrix} 0.231, 0.231, 0.192, 0.192, 0.154 \end{pmatrix} \times \begin{pmatrix} 0.326 & 0.461 & 0.241 & 0 & 0 \\ 0.524 & 0.315 & 0.153 & 0.008 & 0 \\ 0.632 & 0.368 & 0 & 0 & 0 \\ 0.458 & 0.396 & 0 & 0 & 0 \\ 0.896 & 0.104 & 0 & 0 & 0 \end{pmatrix} = (0.544, 0.335, 0.091, 0.030, 0)$$

3.2.2. Fuzzy comprehensive evaluation of chemical hazards, noise and dust. The hazardous chemicals, noise and dust produced during working are the top 3 hazards in the workplace in China, and coexist in the working environment, bringing great risks to the health of workers. Assign weights to the hazardous chemicals, dust and noise based on the above numbers of workers exposed, with 0.867, 0.067 and 0.067 respectively, and conduct the fuzzy comprehensive operation as follows:

$$\text{B} = \text{A} \times \text{R} = \begin{pmatrix} 0.867, 0.067, 0.067 \end{pmatrix} \times \begin{pmatrix} 0.544 & 0.335 & 0.091 & 0.030 & 0 \\ 0.461 & 0.258 & 0.142 & 0.069 & 0.069 \\ 0.167 & 0.5 & 0.167 & 0.167 & 0 \end{pmatrix} = (0.514, 0.341, 0.10, 0.041, 0.004)$$
According to the principle of maximum membership degree, determine the occupational health risk of this enterprise as Grade Ⅰ, which indicates the negligible risk. According to the methods adopted for the fuzzy comprehensive evaluation, establish 5 grades corresponding to the evaluation grade set $P= (9, 7, 5, 3, 1)$, and then calculate the comprehensive evaluation value $C$ of this enterprise.

$$C = B \times P = 7.64$$

According to the value corresponding to the descriptive grade set, determine the working environment and occupational health risk comprehensive evaluation of this plastics manufacturing enterprise as Grade Ⅱ "Good, Low Risk".

The fuzzy relation matrix $U_1$ can be generated from the above values, and finally obtained from the formula that:

4. Discussion
In this study, we apply the fuzzy comprehensive risk evaluation to a plastics processing enterprise to evaluate the health risks of their workers. According to the evaluation results, the result of working environment and occupational health risk comprehensive evaluation of this plastics manufacturing enterprise is Grade Ⅱ "Good, Low Risk". As compared with the checklist method, analogy method, empirical method and quantitative classification method frequently used for evaluating the occupational hazards at present, the results from the fuzzy comprehensive evaluation can better deal with the fuzzy characteristics of occupational hazard evaluation in addition to the realization of comprehensive evaluation on multiple hazards, more objective and realistic as using fuzzy vectors to replace exact point values in the evaluation results.

But many occupational hazards are often coexisting in the real workplace, and have different intensities and exposure durations, resulting in very different occupational health risks. The data measured are only applicable to the monitoring points, and cannot represent the doses absorbed by the workers. Therefore, to further improve the scientific contents of measurement, it is suggested to take into account the methods of mathematical statistics to screen the indicators and correct the weights, to fully consider the ratings and exposure levels related to all hazards, in addition to considering the number of workers exposed. Furthermore, it may be considered to develop software based on this model to simplify the operation, improve the evaluation efficiency, and then to provide certain criteria and references for the enterprise in controlling, preventing and evaluating their occupational hazards [9-10].

The occupational health management is the most important means for mitigating and reducing the occupational hazards. We conduct the occupational health risk evaluation and calculate the risk levels in order to the health risks, reduce the occurrence of occupational hazards, and provide a premise for establishing corresponding risk control measures, and establishing reasonable, effective and specific health management mode. A set of specific, practical and effective evaluation system established by the enterprise will not only facilitate the supervision by the competent authorities, but also improve the occupational health work of enterprise, to finally achieve the objective of protecting the physical and mental health of workers. The enterprise may refer to the domestic and foreign enterprises' cases of occupational health protection [5, 11], establish a series risk control measures, and enhance the management on the occupational hazard sites, to fulfill the objectives of controlling risks and reducing the occurrence of occupational diseases.

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