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The Risk Assessment System of Chemical Industry Park based on Analytic Hierarchy Process

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The research on risk control of chemical industrial park is one of the most important research contents in the management of chemical enterprises. As the chemical industry park is a very complex system, the risk control involves many problems, and it is necessary to consider the relative importance of each index. There are many methods to evaluate the risk control in chemical industrial park, and some methods have been applied in practice. Analytic hierarchy process (AHP) is a classical multiple attribute decision making method, which has been applied in many fields. In the analytic hierarchy process, the construction of judgment matrix is the key in the whole analysis process, which determines the success or failure of the analysis process. In this paper, we propose an adaptive method for constructing judgment matrix, which can speed up the construction of judgment matrix. First of all, this paper introduces the principle and implementation steps of analytic hierarchy process. Secondly, the calculation principle of the maximum eigenvector root and weight vector is described. Thirdly, an adaptive method of constructing judgment matrix is proposed. By calculating the steering matrix, we can locate the problem elements of the judgment matrix, which can improve the reconstruction efficiency of the judgment matrix. Finally, an example is given to verify the improved algorithm, and the results show that the improved algorithm has a good effect.

1. Introduction

Chemical industrial park has many incomparable advantages, which determine that it will be the major trend in the development of chemical industry. Because that the raw materials, intermediate products and final products in chemical enterprises contain a large number of dangerous chemicals, the chemical industry park has a large number of security risk. Once the event occurred in chemical park, hazardous chemicals will spread through various channels, which will threat to the safety of the surrounding environment and the health of the population (Tian, 2015).

There are many risk control methods, such as AHP, fault tree method and risk index method. Helland (2009) establishes the environmental risk assessment system based on the quantitative analysis on raw materials, products and production processes. Husain (2001) established a set of weighted risk index method, which includes dangerous goods, operating conditions, security management and external environment. Through the analysis and calculation of the four kinds of factors, he divided the environmental risk into grades. Achour (2005) puts forward the method of risk management for different objects at the same time, which includes the possibility of environmental risk accident, the intensity of risk and the duration of risk. Gupta (2002) uses the method of environmental risk map to study the location and risk management of industrial park, which achieves the goal of minimizing the risk of regional environmental planning. Zhang (2015) analyses the characteristics of the development in chemical industry and expounds the necessity of risk control in chemical industry. In addition, he discusses the problems and countermeasures of environmental risk assessment in chemical industry. Hu (2011) uses AHP to establish a comprehensive evaluation model for the safety of hazardous chemicals, which uses the comprehensive risk score as the risk grading standard of the evaluation model.

In this paper, we propose an adaptive method for constructing judgment matrix, which can speed up the construction of judgment matrix. First of all, this paper introduces the principle and implementation steps of analytic hierarchy process. Secondly, the calculation principle of the maximum eigenvector root and weight vector is described. Thirdly, an adaptive method of constructing judgment matrix is proposed. By calculating the steering matrix, we can locate the problem elements of the judgment matrix, which can improve the reconstruction efficiency of the judgment matrix. Finally, an example is given to verify the improved algorithm, and the results show that the improved adaptive algorithm has a good effect.

2. Basic theory and method

2.1 Analytic hierarchy process

Analytic hierarchy process (AHP) is a method of quantitative analysis on problems. It is an effective method to make decision for some complicated and fuzzy problems, especially for the problems which are difficult to analysis completely. It embodies the thinking mode of decomposition, judgment and synthesis. The basic idea of AHP is to decompose the elements related to decision making into different layers and then make quantitative or qualitative analysis (Zhao, 2015).The analytic hierarchy process is usually divided into four steps.

(1) Establishment of hierarchical structure model.

In AHP, the problems need to be solved are divided into three levels, which are the target layer, the criterion layer and the scheme layer. The target layer generally refers to the target or desired results of the problem. The criterion layer contains the intermediate links for the realization of the goal, which can be composed of several levels. The criterion layer is also called the middle layer, which usually includes the factors and the sub elements need to be considered. The scheme layer includes a variety of indicators, measures and solutions to achieve the goal.

(2) Construction of judgment matrix.

By comparing the relative importance between different elements in the same layer about a certain criterion, a comparison matrix is constructed. The value of judgment matrix directly reflects the relative importance of each element. Usually, we use proportional scale to evaluate the importance degree.

Table 1: Scale and the meaning

Scale	Meaning
1	The element a and b are of the same importance
3	The relative importance of a to b is small
5	The relative importance is serious than scale 3
7	The relative importance is serious than scale 5
9	The relative importance of a to b is absolute
2,4,6,8	The relative importance of element a and b is between adjacent levels

We assume that the judgment matrix is P .

$$P_{ij} = \begin{pmatrix} p_{11} & \cdots p_{1j} \cdots & p_{1m} \\ \vdots & & \vdots \\ p_{i1} & \ddots & p_{im} \\ \vdots & & \vdots \\ p_{m1} & \cdots p_{mj} \cdots & p_{mm} \end{pmatrix} \tag{1}$$

The judgment matrix is also usually called positive reciprocal judgment matrix, which has the following three characteristics.

$$\begin{cases} p_{ij} > 0 \\ p_{ji} = \dfrac{1}{p_{ij}} \\ p_{ij} = 1 \quad (i = j) \end{cases} \tag{2}$$

(3) Hierarchical single sort and the consistency check.

According to Perron-Frobenius theorem, the maximum eigenvalue of the judgment matrix must be positive, and the eigenvector must be a positive vector too. When the judgment matrix is not consistent, λ_{max} satisfies the condition that λ_{max}>n, and the eigenvector can not truly reflect the proportion. We define a measure of inconsistency as follows.

$$CI = \frac{\lambda_{max} - m}{m - 1} \tag{3}$$

In the above formula, λ_{max} is the largest eigenvalue of matrix, m is the number of elements of judgment matrix. When CI=0, the matrix can be considered to be consistent. For the judgment matrix with no consistency, the greater the CI is, the more serious the inconsistency is. In order to check whether the judgment matrix has a satisfactory consistency, it is necessary to compare with the average random consistency index.

$$CR = \frac{CI}{RI} \tag{4}$$

If CR<0.1, we can consider that the matrix is consistent, and the normalized eigenvector can be used as the weight vector. Otherwise, we need to consider the reconstruction of the judgment matrix.

(4) Hierarchical total sort and the consistency check.

In order to obtain the importance between elements at the same level, we need to sort the hierarchy based on a single sort.

$$CR = \frac{p_1 \cdot CI_1 + p_2 \cdot CI_2 + \cdots + p_m \cdot CI_m}{p_1 \cdot RI_1 + p_2 \cdot RI_2 + \cdots + p_m \cdot RI_m} = \frac{\sum_{i=1}^{n} p_i CI_i}{\sum_{i=1}^{n} p_i RI_i} \tag{5}$$

Similarly, the judgment matrix will be considered to be consistent when CR<0.1, and the normalized eigenvector can be used as the weight vector. Otherwise, we need to consider the reconstruction of the judgment matrix.

2.2 Sum-product method

In the analytic hierarchy process, the most critical step is to construct the judgment matrix. Because the judgment matrix is the result of the quantitative analysis of the problem, there must be a certain error range. Therefore, researchers often use some approximation algorithms to get the maximum eigenvalue and the corresponding eigenvector. The commonly used methods for calculating eigenvector are the root finding method and the sum-product method. In this paper, we mainly introduce the sum-product method, and the following calculations are performed using this method.

Suppose $P=(P_{ij})_{m\times m}$ as the judgment matrix and we can get a normalized matrix $Q=(q_{ij})_{m\times m}$ by the following formula.

$$q_{ij} = \frac{p_{ij}}{p_{1j} + p_{2j} + \cdots + p_{mj}} = \frac{p_{ij}}{\sum_{i=1}^{m} p_{ij}} (i, j = 1, 2, 3, \cdots m) \tag{6}$$

We define γ_j as the normalized vector of the column j in the judgment matrix.

$$\gamma_j = \begin{pmatrix} q_{1j} \\ q_{2j} \\ \vdots \\ q_{mj} \end{pmatrix} \tag{7}$$

By calculating the average value of each row in the normalized matrix, we can get the sort vector $W = (w_1, w_2, \cdots w_m)$ as follows.

$$w_i = \frac{\sum_{j=1}^{m} q_{ij}}{n} (i = 1, 2, 3, \cdots m) \tag{8}$$

Finally, the approximate value of the largest eigenvalue of the matrix can be obtained by the following formula

$$\lambda_{max} = \frac{1}{m} \cdot \sum_{i=1}^{m} \frac{Pw_i}{w_i} \tag{9}$$

3. Improved adaptive matrix construction algorithm

When s_{ij}=1, we can get that q_{ij}=w_i, so the normalized vectors of each column in judgment matrix are equal and the judgment matrix is completely consistent. In a word, the necessary and sufficient condition for the judgment matrix to be a completely consistent matrix is that each element of the steering matrix is 1. In a steering matrix, the elements conform to the normal random variable with 1 as the mean. By finding the maximum deviation of each element, we can locate the position of the element in the judgment matrix. The flow chart of whole process can be shown in the following figure.

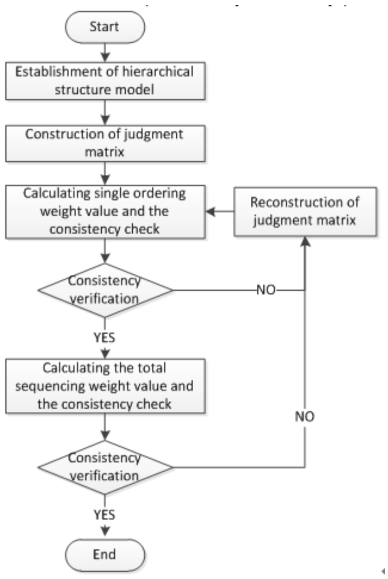

Figure 1: The flow chart of the improved analytic hierarchy process

A. Check the consistency of matrix, if CR<0.1, turn to step B, otherwise, turn to step C.
B. Get the normalized vector r_j of the judgment matrix Pand get the rank vector W= (w_1, w_2, w_m) by sum-product method.
C. Get the steering matrix $s = (s_{ij})_{m \times m}$, and then turn to step D.
D. Find the maximum by formula $|s_{ij} - 1|(i, j = 1,2, \dots m)$. Assume that the maximum value corresponding to the element s_{kl}, turn to step E.
E. Adjust the value of the element P_{kl} in the judgment matrix P, and set the element $p_{lk} = \frac{1}{p_{lk}}$, turn to step A.

4. Experiment and analysis

Set a judgment matrix P as follows.

$$P = \begin{pmatrix} p_{11} & p_{12} & p_{13} \\ p_{21} & p_{22} & p_{23} \\ p_{31} & p_{32} & p_{33} \end{pmatrix} = \begin{pmatrix} 1 & 3 & 5 \\ \frac{1}{3} & 1 & \frac{1}{2} \\ \frac{1}{5} & 2 & 1 \end{pmatrix} \tag{10}$$

The judgment matrix is normalized to get Q .

$$Q = \begin{pmatrix} q_{11} & q_{12} & q_{13} \\ q_{21} & q_{22} & q_{23} \\ q_{31} & q_{32} & q_{33} \end{pmatrix} = \begin{pmatrix} \frac{15}{23} & \frac{1}{2} & \frac{10}{13} \\ \frac{5}{23} & \frac{1}{6} & \frac{1}{13} \\ \frac{3}{23} & \frac{1}{3} & \frac{2}{13} \end{pmatrix} \tag{11}$$

Thus, we can get the sort vector W .

$$w = (w_1, w_2, w_3)^T = \begin{pmatrix} 0.6404 \\ 0.1537 \\ 0.2059 \end{pmatrix} \tag{12}$$

So, we can get the largest eigenvalue λ_{max} .

$$\lambda_{max} = \frac{1}{m} \cdot \sum_{i=1}^{m} \frac{Pw_i}{w_i} = \frac{1}{3} \cdot (\frac{2.131}{0.6404} + \frac{0.47015}{0.1537} + \frac{0.64138}{0.2059}) = 3.1671 \tag{13}$$

The consistency index can be get by the following formula.

$$CI = \frac{\lambda_{max} - m}{m - 1} = \frac{3.1671 - 3}{2} = 0.0836 \tag{14}$$

We obtain the consistency ratio by the following calculation.

$$CR = \frac{CI}{RI} = \frac{0.0836}{0.58} = 0.1441 \tag{15}$$

As the result of $CR>1$, the consistency of judgment matrix does not meet the requirements, so it is necessary to reconstruct the judgment matrix. In order to locate the matrix elements that need to be corrected, we need to compute the steering matrix of the judgment matrix.

$$S = \begin{pmatrix} \frac{q_{11}}{w_1} & \frac{q_{12}}{w_1} & \frac{q_{13}}{w_1} \\ \frac{q_{21}}{w_2} & \frac{q_{22}}{w_2} & \frac{q_{23}}{w_2} \\ \frac{q_{31}}{w_3} & \frac{q_{32}}{w_3} & \frac{q_{33}}{w_3} \end{pmatrix} = \begin{pmatrix} 1.0183 & 0.7807 & 1.2011 \\ 1.4144 & 1.0844 & 0.5004 \\ 0.6335 & 1.6189 & 0.7472 \end{pmatrix} \tag{16}$$

According to the principle of adaptive matrix construction algorithm, we can see that the largest deviation of the element is s^{32}, so the value of the element p^{32} and p^{32} in the judgment matrix need to be reset. We assume that the new judgment matrix is set as follows.

$$P' = \begin{pmatrix} p'_{11} & p'_{12} & p'_{13} \\ p'_{21} & p'_{22} & p'_{23} \\ p'_{31} & p'_{32} & p'_{33} \end{pmatrix} = \begin{pmatrix} 1 & 3 & 5 \\ \frac{1}{3} & 1 & 2 \\ \frac{1}{5} & \frac{1}{2} & 1 \end{pmatrix} \tag{17}$$

The consistency of the new judgment matrix is calculated.

$$CR(P') = \frac{CI(P')}{RI(P')} = \frac{0.005}{0.58} = 0.009 \tag{18}$$

Due to $CR(P')<0.1$, the new judgment matrix has a high consistency.

Through the experiment we can get that the improved adaptive algorithm can accurately locate the elements which need to be reset. In practical work, the risk management model is much more complex than the experimental model. The improved adaptive algorithm can avoid the blindness of matrix reconstruction, which can effectively improve the level of risk management and control in chemical industry park.

5. Conclusion

The risk management in chemical industry park is a very complicated work, which plays a key role in the overall management of the chemical industry park. In this paper, the risk management on chemical industry park is analyzed by AHP. In order to solve the problem of reconstruction of judgment matrix in AHP, this paper presents an improved adaptive matrix construction method. Through the example analysis, we find that the new adaptive algorithm improves the efficiency of reconstruction.

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