Study on the Risk Early Warning Index System of Typical Chemical Production Process Based on Three Dimensional Factors

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Abstract. Prevention and control in advance embodies the essence of risk management, and risk early warning index system is the key link of implementing risk early warning. In order to construct risk early warning index system of typical chemical production process, the risk identification, analysis and early warning theory are closely combined in this paper, the accident risk factors are extended to three aspects, as possibility, severity and sensitivity. Based on the common accidents of typical chemical production process, the risk factors of the production process are comprehensively analysed and the risk early warning index system is put forward based on three dimensional factors. Through the index screening methods for interval estimation, the primary warning indicators are screened. Finally, the risk early warning index system of typical chemical production process is determined.

1. Introduction
The inherent risk of typical chemical processes determines its high risk characteristics. The production process is the highest accident rate and the most serious phase of accidents in chemical enterprises. According to incomplete statistics, the number of accidents and death toll in chemical production process is 81% and 83% respectively. Research on the construction of the existing risk early warning index system is mainly based on "human - machine - material - environment -management", or is set directly according to relevant standards and operating norms. The method is simple and subjective is strong. Based on this, the author takes the possibility, the severity and the sensitivity as the premise, and based on the risk factor identification and analysis, constructs the risk early warning index system based on the three dimensional factor.

2. Factors of three dimensional risk
Three dimensional risk factors refer to the possibility, severity and sensitivity of the accident, and use it as a risk evaluation index to establish a three-dimensional risk model, which is used to study the risk classification of major hazard sources and use $R = f(P, L, S)$ to represent the risk where $P$ indicates possibility, $L$ indicates severity, $S$ means sensitivity). The research on the risk early warning of typical chemical production process is based on the related research of typical chemical production risk. The possibility, severity and sensitivity of accidents are taken as construct the basic elements of early warning indicators, and combines the characteristics of typical chemical process to divide the three dimensional risk factors.
3. typical chemical production process risk analysis
The Interpretative Structural Modelling Method (ISM) is to decompose the complex system into several subsystems or elements, use multi-element, multi-level hierarchical structure to express the relationship between the various factors of the complex system, and to solve the related problems of the complex social and economic system. The ISM risk analysis of the typical chemical production process is as follows:

3.1. Determine the set of key factors of the accident
On the basis of three-dimensional risk factors, possibility, severity, and sensitivity are used as the main risk modules, and $S=(S_1, S_2, \ldots, S_{21})$ 21 main factors affecting the safe operation of typical chemical production systems are summarized, and see Table 1.

| Number | Risk factor description | Number | Risk factor description |
|--------|-------------------------|--------|-------------------------|
| S1     | Inherent hazard of unit | S2     | Dangerous substance accident susceptibility |
| S3     | Accident susceptibility to process | S4 | Site operator risk |
| S5     | Safety technician risk | S6     | Management decision makers risk |
| S7     | Equipment status factors | S8     | Natural environmental factors |
| S9     | Process conditions and operating environment | S10 | Hazard risk |
| S11    | Human vulnerability | S12    | Property vulnerability |
| S13    | Environmental vulnerability | S14 | Evolution of accident dynamics |
| S15    | Security management offsetting Factor | S16 | Hazardous substance isolation measures |
| S17    | Fire security measures | S18    | Time characteristic factor |
| S19    | Spatial characteristic factor | S20 | System sensitivity factors |
| S21    | Personnel sensitivity factors |

3.2. Establish an adjacency matrix and calculate the reachable matrix
According to the overall structure of the accident risk and the correlation relationship among the factors, the adjacent matrix of the related risk factors is established, which is expressed by $A=[a_{ij}]_{n \times n}$ (where $n$ is the number of major risk factors, $a_{ij}$ denotes the relationship between element $S_i$ and element $S_j$). The rule is: If $S_i$ has an effect on $S_j$, then $a_{ij}=1$, if $S_i$ has no effect on $S_j$, then $a_{ij}$ is 0. Based on this, the influence relationship between various factors is judged.

We use Boolean algebra rules to carry out the power operation of the adjacency matrix $A$ until we satisfy the formula (1). Then we call the matrix $M=[b_{ij}]_{n \times n}$ in the formula (2) the adjacency matrix $A$ corresponding reachable matrix.

$$
(A+I)^k = (A+I)^{k+1}, k \leq n - 1
$$

$$
M = (A+I)^k
$$

Among them, for $I$ unit matrix, $K$ is the number of operations, and $N$ is the number of main risk factors. According to the adjacency matrix $A$, we call the related program of matrix operation in Matlab, and calculate the $k=5$, that is, the reachable matrix $M=(A+I)^5$. 
3.3. decomposition of reachable matrix and hierarchical partition
The hierarchical relationship among the elements is analyzed to represent the degree of association among the factors. According to the formula (3) and (4), the hierarchical extraction of the reachable matrix $M$ is carried out.

$$A(S_i) = R(S_i) \cap Q(S_i)$$  \hspace{1cm} (3)

$$R(S_i) \cap A(S_i) = R(S_i)$$  \hspace{1cm} (4)

The reachable set $R(S_i)$ represents that the element corresponding to the element $S_i$ in the reachable matrix corresponds to the set of column elements corresponding to 1, and antecedent set $Q(S_i)$ represents the set of row elements corresponding to the elements $S_i$ containing 1 in the column corresponding to the elements of the reachable matrix. The common set $A(S_i)$ is the intersection of reachable set and antecedent set $i=1,2,... N$. When the common set and the reachable set are exactly the same, all the elements $S_i$ that satisfy the condition are extracted, and the rows and columns of the extracted elements are deleted, and continue to extract the above elements and the feature set of all hierarchy are obtained successively. For the reachable matrix $M$, the basic element sets of five levels are obtained by multiple extraction, which are $L_1 = \{S_1, S_2, S_3, S_{10}, S_{14}\}$, $L_2 = \{S_{11}, S_{17}, S_{18}, S_{19}\}$, $L_3 = \{S_4\}$, $L_4 = \{S_5, S_6, S_7, S_{11}, S_{16}, S_{20}, S_{21}\}$, $L_5 = \{S_{15}, S_9, S_{12}\}$.

4. Construction of risk early warning index system based on three dimensional factors
The construction of risk early warning index system is guided by the principles of scientificity, systematization, hierarchy, feasibility and accuracy. It combines the risk identification, analysis and early warning theory to identify the hazard factors and the accident hidden dangers in the typical chemical production process, and select the possibility factor, the severity factor and the sensitive factor as the criteria layer of the index system. In order to realize the coverage of the hidden danger of the accident to chemical production process, the redundancy of the indicators are fully considered, the construction includes 13 first level early warning indicators, 63 level two early warning indicators, for details see Table 2.
Table 2 calculation result of the judgment matrix of the second level index

| Judgement matrix | $i_{max}$ | CI    | CR    | Whether meet the consistency requirements | The eigenvector corresponding to the maximum eigenvalue |
|------------------|-----------|-------|-------|--------------------------------------------|-----------------------------------------------------|
| P1               | 4.1471    | 0.0490| 0.0551| Yes (0.4661, 0.3302, 0.0724, 0.1513)$^T$    |
| P2               | 5.3175    | 0.0794| 0.0710| Yes (0.0594, 0.0675, 0.2309, 0.5255, 0.1166)$^T$ |
| P3               | 12.9692   | 0.4961| 0.3422| No -                                        |
| P4               | 9.8164    | 0.2271| 0.1611| No -                                        |
| P5               | 4.1502    | 0.0501| 0.0563| Yes (0.0589, 0.5554, 0.2661, 0.1195)$^T$    |
| L1               | 4.3034    | 0.1011| 0.1136| No -                                        |
| L2               | 11.3680   | 0.296 | 0.2041| No -                                        |
| L3               | 4.1076    | 0.0359| 0.0403| Yes (0.3132, 0.4633, 0.0714, 0.1522)$^T$    |
| L4               | 7.6172    | 0.3234| 0.2888| No -                                        |
| S1               | 2         | 0     | 0     | Yes (0.1999, 0.8001)$^T$                    |
| S2               | 2         | 0     | 0     | Yes (0.7501, 0.2499)$^T$                    |
| S3               | 3.0735    | 0.0367| 0.0707| Yes (0.6144, 0.2684, 0.1172)$^T$           |
| S4               | 3.0536    | 0.0268| 0.0515| Yes (0.3446, 0.5469, 0.1085)$^T$           |

The calculation results of Table 2 show that the judgment matrices of P1, P2, P5, L3, S1, S2, S3 and S4 meet the consistency requirements, and the relative weights of each index $\omega_j$ are more than 0.05, and all of them have a certain contribution in the index system, and this part of the index is the optimum indicator. The second level judgement matrix of P3, P4, L1, L2 and L4 does not meet the requirement of consistency. The result is shown in Table 3.

Table 3 Interval estimation value of weight vector of second level indicator

| The second level Indicator | the lower limit of the index weight $\omega^L_j$ | the upper limit of the index weight $\omega^U_j$ | $\Delta_j$ | The index weight of EM |
|---------------------------|-----------------------------------------------|-----------------------------------------------|------------|------------------------|
| P11                       | 0.01229506                                   | 0.01229507                                    | 0.000000001| 0.0122                 |
| P12                       | 0.01084823                                   | 0.01084824                                    | 0.000000001| 0.0108                 |
| P33                       | 0.058894426                                  | 0.058894427                                   | 0.000000001| 0.0589                 |
| P34                       | 0.08350342                                   | 0.08350350                                    | 0.000000008| 0.0835                 |
| P35                       | 0.02352953                                   | 0.02352954                                    | 0.000000001| 0.0235                 |
| P36                       | 0.335611245                                  | 0.335611302                                   | 0.000000057| 0.3356                 |
| P37                       | 0.2371566897                                 | 0.2371566898                                   | 0.000000001| 0.2372                 |
| P38                       | 0.12930827                                   | 0.12930889                                    | 0.00000062 | 0.1293                 |
| P39                       | 0.10885335                                   | 0.10885340                                    | 0.00000005 | 0.1089                 |
| P41                       | 0.28733946                                   | 0.28736247                                    | 0.00002301 | 0.2874                 |
| P42                       | 0.05773218                                   | 0.05773262                                    | 0.00000044 | 0.0578                 |
| P43                       | 0.01961609                                   | 0.01962734                                    | 0.00001125 | 0.0196                 |
| P44                       | 0.19946115                                   | 0.19949053                                    | 0.00002938 | 0.1995                 |
5. Conclusion
The fluctuation and change of the risk early warning index value can depict the risk state of the production process, and it is a more complicated work to carry out the research on the risk early warning of the typical chemical production process. Risk early warning control is mainly from reducing the possibility of accident risk, controlling the seriousness of the accident consequences and improving the sensitivity of the system accident risk and so on.

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