Study on comprehensive index system of production safety accident in chemical enterprise

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Abstract. This paper classified, extracted and characterized the causes of accidents based on accident statistics of chemical enterprises in Jiangsu Province from 2015 to 2019. The internal relationship between the accident result and various causes is analyzed from the aspects of human, machine, material, method, ring and pipe; and using the analytic hierarchy process to establish the comprehensive evaluation index system of the accident, which was applied to predict the accident probability of chemical enterprise. The probability of production safety accident in a chemical enterprise is predicted by using this method, and the probability of the accident is at level of "more likely to happen". The example showed that the analytic hierarchy process has strong operability and good effect, and can be used to predict the accident risk of chemical enterprises.

1 Introduction

Since most of the raw materials and products in the chemical industry are flammable, explosive, toxic and harmful substances, and most of the production processes have characteristics of high temperature, high pressure, continuity and large-scale [1], it is more dangerous than other industries. Research on chemical enterprise safety evaluation is one of the important content of the safety science research. At present, a variety of evaluation methods have been widely used in the chemical enterprise safety risk assessment, such as safety check list (SCL), preliminary hazard analysis (PHA) and fault tree (FTA), dow chemical index method, mond process. But, at present, the theoretical analysis of accident causes is mostly qualitative or quantitative analysis from a single aspect [2, 3], while the occurrence of safety accidents in enterprises is probably the result of the joint action of many accident factors [4].Based on the collected data of the production safety accidents of chemical enterprises in Jiangsu Province in recent years, this article carried out theoretical research on accident causes. The accident causes are classified, extracted and characterized; and the comprehensive evaluation index system of the accident is established, which reflects the internal relationship between accident results and various causes and can realize the accident probability prediction of chemical enterprises.

2 Analytical method based on analytic hierarchy process

Analytic Hierarchy Process (AHP), also known as multi-level weight analysis method, is an effective method for quantitative analysis of non-quantitative events proposed by American operations researcher Professor T.L.Saaty in the 1970s [5].This method combines quantitative analysis and qualitative analysis, and integrates human experience and subjective judgment with mathematical processing, which can not only effectively analyze the non-sequential relationship among the hierarchy of target criteria, but also effectively measure the judgment and comparison of decision makers comprehensively.

The steps of AHP method to determine the weight are as follows:

1) Establish a hierarchy structure. The simplest structure has three layers: the goal layer, the criteria layer, and the metrics layer.

2) Construction of judgment matrix. The relative importance of each index belonging to the same index is compared to form a judgment matrix.

Table 1 General form of judgment matrix

V	V_1	V_2	…	V_m
V_1	b_{11}	b_{12}	…	b_{1m}
V_2	b_{21}	b_{22}	…	b_{2m}
…	…	…	…	…
V_m	b_{m1}	b_{m2}	…	b_{mm}

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B_{ij} in the above table represents the relative importance of pair-to-pair-comparison among all indicators belonging to index V. The 1-9 scale method is generally adopted, as shown in Table1.

Table 2 Judgment matrix scale and its meaning

scale	implication
1	It means that the two factors are of equal importance compared to each other
3	It means that one factor is slightly more important than the other
5	It means that one factor is significantly more important than the other
7	Indicates that one factor is more strongly important than the other
9	It means that one factor is more important than the other
2，4，6，8	It is between the median of the above two adjacent judgments
count backwards	V_i compared to V_j is b_{ij}，V_j compared to V_i is b_{ji}=1/b_{ij}

3) Solve eigenvalues and eigenvectors. Judgment matrix $\boldsymbol{B}=(b_{ij})_{m\times m}$,$b_{ji}=1/b_{ij}$(i，j=1，2，…，m)，$b_{ij}>0$，$b_{ii}=1$，且 $b_{ij}=b_{ik}*b_{kj}$(k=1，2，…，m)

According to the theory of positive matrix, the judgment matrix has the maximum eigenvalue Amax，The other eigenvalues are 0.The summation product method is adopted in this paper. The method is as follows:

(a) Normalize the judgment matrix B according to columns to get the matrix $\boldsymbol{Q}=(q_{ij})_{m\times m}$.

$$q_{ij}=b_{ij}/\sum_{k=1}^{m} b_{kj} \quad (i，j=1，2，…，m) \qquad (1)$$

(b) Add the matrix Q by rows to get the vector C =(C1, C2..., cm)T, where

$$c_i=\sum_{j=1}^{m} q_{ij} \quad (i=1，2，…，m) \qquad (2)$$

(c)Put c=(c1, c2..., cm)T normalization, that is, the eigenvector corresponding to the maximum eigenvalue is obtained, ω=(ω1, ω2..., omega T m) :

$$\omega_j=c_j/\sum_{j=1}^{m} c_k \quad (j=1，2，…，m) \qquad (3)$$

(d) Calculate the maximum eigenvector λ Max of the judgment matrix:

$$\lambda_{max}=\sum_{i=1}^{m}\frac{(B\omega)_i}{m\omega_i} \qquad (4)$$

Where, $(B\omega)_i$ is the $\boldsymbol{B\omega}$ element of the vector.

4) Consistency test. In order to avoid producing inconsistent conclusions in the pairwise comparison of a large number of factors, consistency test should be carried out for each judgment matrix to investigate whether it has satisfactory consistency. When the order is greater than 2, this can be verified by calculating the random consistency ratio CR. When $CR=\frac{\lambda_{max}-m}{(m-1)RI}<0.1$, the judgment matrix has an acceptable inconsistency. Otherwise, reassign the value until the consistency check passes.

5) Calculation of composite weight. The total ranking coefficient of the hierarchy is calculated, and the weight of the single criterion is synthesized from top to bottom, layer by layer, until the weight of each element in the bottom layer and the total consistency test are calculated.

3 The establishment of comprehensive evaluation index system of chemical enterprise accident

The comprehensive index system of chemical enterprise accident is a set of parameters to describe and determine the factors that affect the accident of a chemical enterprise. The reasons of production safety accidents in enterprises are various. The selection of accident indexes plays a very important role in the accuracy of the comprehensive evaluation index system. Through the analysis of 2016-2019, 81 chemical enterprises in the province's production safety accident case and part of the accident investigation report, we sort chemical enterprise production safety accident characteristics. The accident causes were classified, extracted and characterized, and the comprehensive evaluation index system of chemical enterprise accident was established by taking human, machine, material, method, environment and management as the first-level indexes, 13 second-level indexes and 50 third-level accident impact factors as the first-level indexes.

3.1. The human factor

Human factor is the most fundamental factor of safety. The requirements for modern chemical production is also increasingly high for operators. Operators are required not only to operate the machine accurately and skillfully, but also to have the ability to accurately analyze, judge, make decisions and respond quickly to complex situations. Among GB13861 and GB6441 human factors to cause accident, this paper also selected the main illegal operation, risk into dangerous places and so on included in the accident indicators.

3.2. Machine factors

The equipment in the production plant area of the chemical enterprise mainly includes furnaces, tanks, vessels, towers, caldrons, pumps and so on, which itself has a greater risk. In the production process, material leakage is caused by unreasonable design of equipment and facilities, material defects, abrasion and corrosion and other reasons, it is easy to cause explosions, poisoning and other safety accidents. In this paper, three secondary indexes and nine tertiary indexes of equipment and facilities, tool accessories defects, protection defects, equipment and facilities not properly maintained were counted.

3.3. Material factors

In the process of chemical production, it is inevitable to use a large number of toxic, corrosive, flammable and explosive materials. Once these materials are leaked and reacted or used wrongly, they will easily cause a wide range of harmful effects. Therefore, this paper designs accident impact factors from the quantity, characteristics and management of materials.

3.4. Process method factors

The materials that need to be used in the process of chemical process production exist in their respective states. The material may be hazardous or cause harm under certain conditions. Whether the chemical process been demonstrated, how the production conditions reduced the severity to prevent accidents, and how the design and selection of reaction units may affect safety. Therefore, this paper selects the corresponding impact factor indicators from the perspective of supervision, process parameters, process reliability and risk analysis.

3.5. Environmental factors

As the internal cause or inductive factor of the production safety accident, the environmental factor may lead to the direct cause of the production safety accident (the unsafe state of the material, the unsafe behavior of the person, the defect of the management), thus causing the production safety accident. This paper analyzes the accident cases for many years, and puts forward the main accident impact indexes, such as poor ventilation, disorderly working site, unsafe storage method, and mixing of prohibited substances.

3.6. Management factors

Safety management is an important guarantee for safe production of enterprises. In most of the accident causes, there are related management systems and operating regulations are not complete, daily safety inspection is not in place, project management, operation management is not standardized, etc. This paper has set up 5 secondary indicators and 19 tertiary indicators for safety management.

4 Determine the weight of the index system

The model was established by the analytic hierarchy process (AHP) as described above, and the weight of each impact factor was compared and determined. The weight of each index in the evaluation system was shown in Table 3.

Table 3 Index weights of all levels of the accident index system

Level 1 indicators	Level 1 indicator weights	Level 2 indicators	Level 2 indicator weights	Level 3 indicators	Level 3 indicator weights
human	0.2006	Personnel Qualification Ability	0.4	Personnel educational background, qualifications are not satisfied	0.1282
				Special operators are not licensed to work	0.1382
				Do not master the safety knowledge and operation skills	0.2564
				Safety awareness is weak, risk recognition is insufficient	0.4771
		Personnel behavior error	0.6	Illegal operation/neglect of safety/neglect of warnings	0.3980
				Venture into dangerous places	0.2417
				Using unsafe equipment	0.0788
				Command error	0.1596
				The emergency was mishandled	0.1218
machine	0.1267	Defects of equipment, facilities, tools and accessories	0.5889	Improper design, structure does not meet safety requirements	0.1638
				Insufficient strength/poor sealing/poor corrosion resistance	0.2972
				Abnormal operation of equipment with disease and overload	0.5390
		Protective	0.2518	Lack of effective protection	0.5050

		defects		Safety facilities are not tested for reliability as required	0.0867
				Insufficient protective distance	0.1642
				Missing or defective personal protective equipment	0.2441
		Equipment and facilities are not properly maintained	0.1592	Equipment and facilities are not regularly inspected and maintained	0.4
				Special equipment does not receive the use of the registration certificate and overdue testing and inspection	0.6
material	0.1140	hazardous fluids	1	Involves major hazard sources	0.1373
				It involves key hazardous chemicals under supervision	0.6232
				It involves highly toxic chemicals	0.2395
way	0.0721	chemical process	1	There are key regulatory dangerous chemical processes	0.1058
				The highest operating/reaction temperature exceeds the chemical flash point, boiling point and ignition point	0.4518
				Medium and high pressure reaction process exists	0.0396
				There are either cryogenic or cryogenic reactions	0.1046
				Process reliability is not demonstrated	0.2162
				Did not carry out HAZOPanalyze	0.0819
environment	0.0412	Bad environment	1	improper ventilation	0.4299
				Disordered working site	0.0976
				Unsafe storage method	0.1450
				Prohibited substances are mixed and stored	0.3274
Management	0.4454	management system	0.0774	Safety production responsibility is not clear, the rules and regulations are not sound	0.1416
				The principal responsibility does not abdicate	0.3338
				Rules and regulations are not properly implemented	0.5247
		project management	0.1258	The management of "three simultaneous" is not standard	0.1416
				The project was not formally designed	0.0867
				Change management is inadequate	0.1642
				The supplier management review is not strict	0.0584
		daily management	0.2289	Lack of routine safety checks	0.1747
				Routine maintenance is not in place	0.1409
				Hidden trouble investigation is not in place, hidden trouble is not timely rectification	0.2784
				History of punishment for violations of laws and regulations	0.3476
		safety training	0.1957	Safety training content is not complete, training time is not enough	0.35
				Safety education and training did not achieve the desired effect	0.65
		job management	0.3722	The assignment ticket is not handled according to the standard	0.3134
				Risk analysis is not comprehensive	0.1568
				The operational implementation plan is not demonstrated	0.2043
				No safety verification and disclosure prior to operation	0.1109
				lax supervision	0.0892
				Mismanagement of emergency	0.1253

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5 Examples of accident prediction in chemical enterprises

5.1 vide the indicators of accident assessment

In this paper, the accident evaluation indexes of enterprises are divided into 5 levels [6], as shown in Table 4.

Table 4 Weighted value and standard score of accident probability assessment grade

accident probability	1	2	3	4	5
weighted value	1.0	0.8	0.7	0.5	0.3
The standard score	0.900~1	0.80~0.899	0.60~0.799	0.40~0.599	<0.400
explain	Long-term problem/accident probability is very high	Problems occur frequently/accidents occur with high probability	Problems sometimes occur/accidents are more likely to occur	Less problems/less accident probability	Never/unlikely to have an accident
remark	1. The number of accident probability assessment levels varies according to the actual classification needs, and is generally divided into 5 levels. 2. Weighted values and standard scores were determined empirically.				

5.2 Score calculation

According to the actual safety situation of a chemical enterprise, the method of experts grading is adopted to assign points to the three-level indicators for calculation in accordance with formula (1) [7].

$$B=A\circ R=(a_{i1}, a_{i2}\cdots a_{in})\circ[r_1,r_2\cdots r_n]^T \quad (1)$$

Where B is the probability of enterprise accident, A is the index weight, " ∘ " Represents the synthesis operation of the matrix, and R is assigned to each index.

The index assigned value of an enterprise is shown in Table 5. After calculation, the score of this enterprise is 0.638. By comparing the possible weighted value of accident with the standard score, the probability of accident of this enterprise is determined to be high.

Table 5 Accident probability calculated by an enterprise

Level 3 indicators	A certain enterprise gives credit	Level 3 indicators	A certain enterprise gives credit
Personnel educational background, qualifications are not satisfied	1.0	Process reliability is not demonstrated	0.3
Special operators are not licensed to work	0.7	Did not carry out HAZOP analyze	0.3
Do not master the safety knowledge and operation skills	0.8	improper ventilation	0.5
Safety awareness is weak, risk recognition is insufficient	0.8	Disordered working site	0.7
Illegal operation/neglect of safety/neglect of warnings	0.7	Unsafe storage method	0.7
Venture into dangerous places	0.5	Prohibited substances are mixed and stored	0.5
Using unsafe equipment	0.5	Safety production responsibility is not clear, the rules and regulations are not sound	0.8
Command error	0.5	The principal responsibility does not abdicate	0.8
The emergency was mishandled	0.5	Rules and regulations are not properly implemented	0.8
Improper design, structure does not meet safety requirements	0.7	The management of "three simultaneous" is not standard	0.5
Insufficient strength/poor sealing/poor corrosion resistance	0.5	The project was not formally designed	0.3

Abnormal operation of equipment with disease and overload	0.7	Change management is inadequate	0.8
Lack of effective protection	0.5	The supplier management review is not strict	0.5
Safety facilities are not tested for reliability as required	0.5	Lack of routine safety checks	0.8
Insufficient protective distance	0.3	Routine maintenance is not in place	0.5
Missing or defective personal protective equipment	0.5	Hidden trouble investigation is not in place, hidden trouble is not timely rectification	0.8
Equipment and facilities are not regularly inspected and maintained	0.8	History of punishment for violations of laws and regulations	0.7
Special equipment does not receive the use of the registration certificate and overdue testing and inspection	0.7	Safety training content is not complete, training time is not enough	0.7
Involves major hazard sources	1.0	Safety education and training did not achieve the desired effect	0.7
It involves key hazardous chemicals under supervision	1.0	The assignment ticket is not handled according to the standard	0.8
It involves highly toxic chemicals	0.3	Risk analysis is not comprehensive	0.8
There are key regulatory dangerous chemical processes	1.0	The operational implementation plan is not demonstrated	0.5
The highest operating/reaction temperature exceeds the chemical flash point, boiling point and ignition point	0.3	No safety verification and disclosure prior to operation	0.5
Medium and high pressure reaction process exists	1.0	lax supervision	0.5
There are either cryogenic or cryogenic reactions	0.3	Mismanagement of emergency	0.5

6 Conclusion

The causes of accidents are very complex, often involving personnel, equipment, materials, technology, environment, management and other factors. Theoretical significance of this paper lies in the combination of accident comprehensive evaluation index and analytic hierarchy process into the accident analysis and prediction of chemical enterprises, which provides a simple and feasible accident prediction method for chemical enterprises.

Combined with typical accident cases, this method objectively and reasonably selects the evaluation indexes, and establishes the comprehensive index model of chemical enterprise accident from the aspects of human, machine, material, method, environment and management, so as to avoid the disadvantage of unilaterally considering the cause of accident. The application of analytic hierarchy process (AHP) to consider all kinds of factors affecting enterprise security, and combine qualitative and quantitative analysis organically, can reduce subjective judgment as far as possible, and the evaluation result is more credible and reliable. According to the prediction results, enterprises can find out the shortcoming and shortage of safety, put forward the key precautionary measures and corresponding countermeasures of enterprise safety management, and improve the intrinsic safety level and accident prevention ability of enterprises.

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