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Research on Construction method of Change Risk Basedata in Chemical Industry

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Non-standard management of change and inadequate risk identification may lead to catastrophic accidents. In view of this, this paper proposes a construction method of change risk base based on multiple safety evaluation theories. Through the analysis of typical change cases and accident cases of domestic and foreign chemical industry, the subject words that can characterize the risk characteristics of various changes were determined, and the framework of multi-level and multi-chain change risk base was established by different devices. The method of fault tree analysis, analytic hierarchy process and set pair analysis is used to determine the key event inducing factors and control measures, complete the construction of the device change risk base, and provide basic data support for the comprehensive risk identification of the change process and the subsequent risk intelligent reasoning and push technology research.
Keywords: Management of change, fault tree analysis, analytic hierarchy process, set pair analysis

1. Introduction

According to statistics, the proportion of change accidents in chemical enterprises is high. The main causes of accidents are not in place of Management of change（MOC）and inaccurate risk identification. In 1974, an explosion occurred in Nypro, a company in the UK. A set of cyclohexane oxidation device leaked, and the steam cloud formed by the leakage exploded, resulting in 28 deaths and more than 600 injuries (C. Sadee 1977). The process system of Nypro was temporarily changed, but no hazard analysis was carried out, leading to the accident. In 1984, methyl isocyanate leakage occurred in Bhopal pesticide factory in India, resulting in 6,495 deaths, 125,000 poisoning, and 50,000 lifelong injuries (Eckerman 2019). The accident is the largest chemical safety accident in the world so far. The root cause of the accident is the manager change. A new plant manager with a financial background but a weak sense of safety replaced the old one with a good sense of safety and rich operational experience. They did not take into account the risk by the change of the manager. In order to save costs, the new manager took measures to shorten the staff training time, reduce the number of employees, cut corners, reduce the frequency of equipment maintenance and so on, which led to the accident. Therefore, it is important to formalize change management.

However, risk identification in MOC relies on experience, lacking objective and comprehensive safety evaluation. It is easy to cause managers do not understand the risks of change, resulting in frequent accidents (Gerbec 2017). Therefore, safety evaluation theory should be used to fully analyze the accident of change, determine the weakness of MOC, identify the risk of change, improve the Personnel level of risk identification, to effectively carry out change management.

Based on the analysis of the typical change accident cases of chemical industry, this paper determines the subject words that can represent the characteristics of change risks, and sets up the multi-level and multi-chain change risk database framework. Based on the improved AHP-SPA method, the key factors and control measures of change accident cases were determined to complete the construction of the change risk database to provide data support for MOC.

2. Construction method of risk database

Fifty-one cases involving changes from the CSB and a petrochemical company were collected. This paper refers to HAZOP, FMEA, JSA and other methods, to determine five keywords including "subject", "influence factor", "possible causes", "possible consequences", "control measures". Based on topic analysis, characteristic subjects of typical change types are determined, common subjects are summarized, and accident cases are analyzed with subjects as guidance. The change risk database framework is formed based on keywords to represent the characteristics of each risk. Analyze a large number of cases based on accident tree analysis, hierarchical analysis and set pair analysis, constantly improve the risk database, and finally form the standard change risk database.

2.1. *Fault tree analysis*

Fault tree analysis （FTA） is a logical tree that represents the cause of an accident and its logical relationship, and is a commonly used method in safety evaluation (Navid Hosseini 2020). In the tree, the bottom event is the cause of the top event, and the bottom event is the basic event that causes the accident. Fault tree has a minimum cut set and a minimum path set, which represent the risk and safety of the system respectively. The structural significance can also be calculated through the minimum cut set and the minimum path set, which is used to represent the importance of basic events to the occurrence of accidents. In this paper, the Fault tree is used as one of the methods of safety evaluation, the cause of the accident is obtained by analyzing the change accident, and the key inducing factors and control measures of the accident are determined, so as to improve the risk database, and the key factors analyzed and the calculated structural importance are taken as the basis for the construction of analytic hierarchy process.

2.2. *Analytic hierarchy process*

Analytic hierarchy process (AHP) is a qualitative and quantitative decision-making method that decomposes relevant elements in decision-making into objective, criterion level, scheme level (Saman Aminbakhsh 2013). The general AHP constructs a judgment matrix by directly comparing the importance of indexes in pairs. In this paper, FTA is adopted to construct AHP index, taking the event at the top of the tree as the target, summarizing various factors that should be considered as the criterion level indexes, and taking the basic event obtained by analysis as scheme level indexes. The judgment matrix is obtained through the structural importance of basic events, and the weight of each index is calculated.

2.3. *Set pair analysis*

Set pair analysis (SAP) is a systematic and mathematical analysis of the certainty and uncertainty of two related sets, as well as the interaction between certainty and uncertainty. This method divides the characteristics of a research object according to the certainty and uncertainty, in which the certainty is divided into identity and opposition (Zhang 2023). In this paper, the safety of the three-level indexes is scored according to the levels of safety, uncertainty and danger through the expert scoring method. Combined with the index weight obtained by AHP, the connection degree of each index is evaluated based on the set pair analysis, so as to verify the importance of control measures and get events that should be focused on.

3. Example demonstration

A benzene tank explosion during maintenance in a factory was taken as an example to demonstrate the method proposed in this paper. The information of the case is as follows: During the maintenance and repair work of the benzene tank, the construction content and environment changed, but the new risk identification and construction plan were not carried out.The change management was negligent, which led to the flash of the benzene tank and ultimately resulted in the death of 6 people working in the tank.

3.1.*FTA model*

In this FTA model shown as Fig. 1, the explosion of a benzene tank is taken as the top event, and there are 15 basic events that may cause the top event. Ten minimum cut sets are obtained, and the structural importance is calculated according to the minimum cut sets.

Through this model, the key inducing factors and control measures of accidents can be determined. After desensitization, these contents can be added into the risk database framework of storage tank device to obtain the relevant contents of the inflammable and explosive, operation and other subject words of the device, as shown in Table 1.

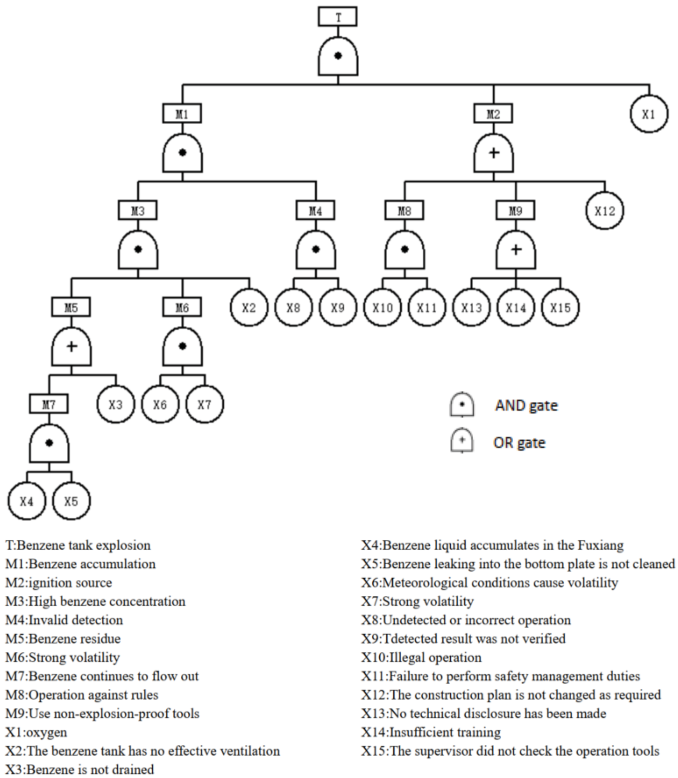

Fig. 1.FTA model

Table 1. Example of risk basedata

Subject	Influence Factor	Possible Causes	Possible Consequences	Control Measures
flammable	physicochemical property	Inflammable exist	explode	Empty inflammables
flammable	environment	volatile temperature	explode	choose a time when volatility is low
flammable	ventilation	underventilated	explode	enhance ventilation
operation	misoperation	use non-explosion-proof tools	explode	do the entrance check
operation	misoperation	No gas detection	explode	strictly supervise

3.2.*AHP model*

Factors of human,management and environment are taken as criterion level, and 15 basic events obtained from FTA model are taken as scheme level, thus establishing the safety evaluation index system of benzene tank explosion,shown as Table. 2. Based on the structural importance of each basic event of FTA model, the judgment factors of each index are calculated using formula (1):

$\chi(i) = I_{\varphi}(i) \cdot g \cdot LCM$ (i=1,2,3…n) (1)

Where $I_{\varphi}(i)$ is the structural importance of basic event Xi, LCM is the lowest common multiple of the denominator of structural importance, n is the number of basic events, g is the coefficient that can calculate for integer results.

Table 2. Index system of benzene tank explosion risk

Objective	Criterion Level	scheme Level	Judgment factor
Benzene tank explosion	Human factor	X8	5
		X9	5
		X10	1
		X11	1
		X15	1
	Management factor	X2	5
		X3	3
		X5	2
		X12	1
		X13	1
		X14	1
	Environment	X1	5
		X4	2
		X6	5
		X7	5

The judgment matrix is formed by pairwise comparison of the judgment factors of each index, and consistency verification is carried out. The index weight is calculated by sum-value method, and the consistency of judgment matrix is verified. The judgment matrix of the criterion level indexes is shown in Table 3. The judgment matrixes of scheme level indexes is shown in Table 4 to Table 6.

Table 3.Judgment matrix of the criterion level indexes

C	A1	A2	A3	weight
A1	1	1	13/17	0.3
A2	1	1	13/17	0.3
A3	1 4/13	1 4/13	1	0.4

λ_{max}=3 CI=0 CR=0<0.1

Table 4.Judgment matrix of human factor

A1	X8	X9	X10	X11	X15	weight
X8	1	1	5	5	5	0.39
X9	1	1	5	5	5	0.39
X10	1/5	1/5	1	1	1	0.08
X11	1/5	1/5	1	1	1	0.08
X15	1/5	1/5	1	1	1	0.08

λ_{max}=5 CI=0 CR=0<0.1

Table 5.Judgment matrix of management factor

A2	X2	X3	X5	X12	X13	X14	weight
X2	1	1 2/3	2 1/2	5	5	5	0.38
X3	3/5	1	1 1/2	3	3	3	0.23
X5	2/5	2/3	1	2	2	2	0.15
X12	1/5	1/3	1/2	1	1	1	0.08
X13	1/5	1/3	1/2	1	1	1	0.08
X14	1/5	1/3	1/2	1	1	1	0.08

λ_{max}=6 CI=0 CR=.00071<0.1

Table 6.Judgment matrix of environment factor

A3	X1	X4	X6	X7	weight
X1	1	2 1/2	1	1	0.29
X4	2/5	1	2/5	2/5	0.13
X6	1	2 1/2	1	1	0.29
X7	1	2 1/2	1	1	0.29

λ_{max}= 4 *CI*= .00325 *CR*=0<0.1

3.3.*SPA model*

SPA model is constructed by using the index weights obtained by AHP. The set pairs of X and Y are U= (X, Y). I In this paper, the problem is the safety degree of indexes and safety standard for set pair analysis In this problem, 15 scheme level indexes in AHP model are studie. *S* is the number of the same characteristics of the two sets in the U set pair, *P* is the number of the opposite characteristics in the set pair, and the remaining characteristics *F=M-S-P* are the uncertain characteristics of the two sets, $\frac{S}{M}$、$\frac{F}{M}$、$\frac{P}{M}$ are the unity degree, difference degree and opposition degree.

The correlation degree of SPA fully considers the transformation of uncertainty in the two sets, which can be expressed as:

$$\mu = \frac{S}{M} + \frac{F}{M}i + \frac{P}{M}j \quad (2)$$

Where, i is the identification number of difference degree, i ∈ [-1,1]; j is the number marked by the degree of opposition, j=-1. In order to simplify the formula, denoted $\frac{S}{M}$、$\frac{F}{M}$、$\frac{P}{M}$ are a, b, and c. When the set pair has t uncertain characteristics, the formula is:

$$\mu = a + b_1 i_1 + b_2 i_2 + \cdots + b_k k + cj$$

$$(k = 1,2,3 \ldots t) \qquad (3)$$

Where, k is the number of difference degree components, b_1,...... , b_k is the difference degree component, i_k is the identification number of each difference degree component.

The following formula can be obtained by combining this formula with the weight obtained by AHP:

$$\mu=\sum_{k=1}^{S} \omega_k+\sum_{k=S+1}^{S+F} \omega_k i+\sum_{k=S+F+1}^{t} \omega_k j \qquad (4)$$

$$\sum_{k=1}^{t} \omega_k=1 \qquad (5)$$

The safety level of 15 indexes obtained by expert scoring method, including safe, uncertain and dangerous, as shown in Table 7.

Table 7.Safety level of indexes

	Expert 1	Expert 2	Expert 3
X8	uncertain	uncertain	uncertain
X9	uncertain	uncertain	dangerous
X10	uncertain	dangerous	uncertain
X11	uncertain	uncertain	uncertain
X15	uncertain	uncertain	dangerous
X2	uncertain	uncertain	dangerous
X3	safe	uncertain	uncertain
X5	uncertain	dangerous	uncertain
X12	uncertain	safe	uncertain
X13	safe	uncertain	uncertain
X14	uncertain	uncertain	uncertain
X1	dangerous	uncertain	dangerous
X4	uncertain	uncertain	uncertain
X6	uncertain	dangerous	safe
X7	dangerous	uncertain	uncertain

Occasionally, a disagreement of expert opinion occurs such as event X7. If it has a significant impact on the outcome, it should be rediscussed, and if it does not, it can be kept as a focus event. The experience of the three experts selected in this paper are basically the same, so the weight of the three experts is $W=\begin{pmatrix}\frac{1}{3} & \frac{1}{3} & \frac{1}{3}\end{pmatrix}$.According to the comprehensive weights of the three safety levels and each index in the table, the correlation degree corresponding to the safety levels assessed by the three experts can be calculated according to Formula (4). By synthesizing the correlation degree of the safety levels assessed by the three experts, it can be obtained:

$$\mu = \begin{pmatrix}\frac{1}{3} & \frac{1}{3} & \frac{1}{3}\end{pmatrix} \begin{bmatrix} 0.093 & 0.675 & 0.2 \\ 0.024 & 0.677 & 0.299 \\ 0.116 & 0.5 & 0.368 \end{bmatrix} \begin{pmatrix} 1 \\ i \\ j \end{pmatrix}$$

$$= 0.078 + 0.623i + 0.299j \qquad (6)$$

The value range of connection degree was divided into three different sections [-1, -0.333], [-0.333,0.333], and [0.333,1], representing the risk degree of benzene tank explosion: dangerous, relatively safe, and safe. When the index changes from uncertain to dangerous, i=-1, j=-1, and μ= -0.84467, then the system risk level is dangerous. When the index changes from uncertain to safe, i=1, j=-1, and μ= 0.40067, then the system risk level is safe. According to the analysis, when the index with uncertainty is effectively controlled, the security of the system can be improved. Therefore, the index with uncertain level can be selected as the key content in the risk database for MOC.

4. Conclusion

(1) A large number of cases of industry of MOC are collected and analysed, and the framework of the standard risk database was determined.

(2) A safety evaluation model of MOC is established by combining FTA, AHP, SPA and considering factors of human, management, environmental.

(3)The standard database of MOC is formed through the evaluation model, which provides an effective means for the comprehensiveness of risk identification in the change process and makes an early research for the intelligent reasoning technology of change risk.

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