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Research on Safety Risk Assessment and Response Strategies for Chemical Industry Enterprises

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Abstract: Safe production is the cornerstone for the sustainable development of enterprises, directly related to the safety of employees' lives, the economic benefits of the enterprises, and social stability. Scientifically identifying potential risk factors, establishing a quantitative evaluation system, and formulating targeted prevention strategies have become key to improving safety in chemical production. This study develops a risk assessment model for safe production in chemical enterprises by integrating multiple methods, with a focus on evaluation and response strategies. Based on relevant research results, the safety risks of chemical enterprises are analyzed and an evaluation index system is constructed. The weights of risk evaluation indicators are calculated using the analytic hierarchy process and evaluated. According to the final evaluation results, combined with the current situation of the chemical industry, the risk management response strategies for safe production are proposed, which helps to achieve pre-control of risks and precise allocation of resources, and provides certain reference significance for the risk management of safe production in the chemical industry.

Keywords: Analytic hierarchy process; Chemical industry; Safe production; Response strategies

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1. Introduction

The chemical industry has the characteristics of complex production processes, high professional requirements for operation, and dangerous production raw materials. During the production process, there are many potential hazards. If they are not detected in time or prevented in advance, serious safety accidents may occur. Continuous scientific progress has introduced new processes and technologies, leading to expanded production scales and increased safety risks. To ensure the stable development of the economy and society, people's awareness of safety risk management has been continuously enhanced.

The concept of risk management was first proposed in Germany in 1930, and in 1931, the Insurance Department of the American Management Association raised the issue of enterprise risk management regarding insurance problems. It was not until 1963 that Mel and Hedges published the article "Enterprise Risk Management" that the issue of risk management received widespread attention in various industries in Europe and America. In the 1980s, some scholars and enterprise managers began to attempt to conduct systematic risk management within enterprises, but it was still in the initial stage of research. In recent years, relevant scholars have increasingly emphasized the importance of safety risk management in production, and have conducted extensive research on risk management measures and evaluation methods in multiple aspects, achieving fruitful results.

This study applies the analytic hierarchy process to quantitatively evaluate safety risk factors in the chemical industry and proposes corresponding response strategies. This is helpful for chemical enterprises to detect or prevent potential safety problems in production in advance, which is conducive to the sustainable development of the industry and provides certain reference significance for chemical enterprises in safety risk management.

2. Current research status

2.1. Research status of safety production risk factors

For conducting research on safety production risks, the first step is to identify the safety risk factors. From the perspective of single-factor research, the main studies conducted by relevant scholars include as follows. Regarding environmental factors, Udara *et al.* (2020) argued that the working environment in high-risk industries significantly influences safety outcomes [1]. From the perspective of management methods, Huang *et al.* (2019) believed that the use of big data management methods should be utilized to ensure the safety production of enterprises [2]. Parker *et al.* (2015) analyzed the data of 221 enterprises and concluded that establishing a safety committee is of great benefit to safety production [3]. However, in studying the interrelationships among multiple factors, it becomes evident that these factors are interconnected and influence one another. Pačaiová *et al.* (2017) believed that the integrated method of human-machine-environment system risk management can effectively study safety production [4].

2.2. Research status of safety production risk evaluation methods

To assess whether enterprise safety production risk management has achieved its goals, appropriate evaluation methods must be selected. In the related research on qualitative evaluation, Valerie *et al.* (2006) summarized the causes of safety production accidents through a bow-tie diagram and demonstrated the risk control process, presenting the main factors of the accident and proposing measures to reduce the risk [5]. Huang *et al.* (2020) believed that failure mode and effect analysis is an active quality management tool, combined with the concept of interval intuitionistic fuzzy cloud, to study the uncertain risk [6]. Liesel *et al.* (2010) proposed to coordinate various factors and flexibly assess risks [7]. Dimitris *et al.* (2019) proposed a comprehensive assessment system integrating safety culture, human factors, and dynamics to track and feedback the safety production situation [8]. Nyambayar *et al.* (2017) believed that each main element has the resilience of the production process, and focuses on the ability of production units, workers, and support systems to suppress destructive signals occurring both inside and outside the production field [9]. In the related research on quantitative evaluation, Tian *et al.* (2022) proposed a risk assessment method based on Bayesian networks and cross-degree, which can quantitatively calculate the size of operational risks [10]. Karasan *et al.* (2018) introduced a risk assessment method that simultaneously uses four parameters: occurrence possibility, severity, detectability, and frequency to calculate the size of risk, providing a more comprehensive and accurate risk assessment for safety production [11].

There are many relevant research results on enterprise safety production risk management, but the proportion of research results that combine specific chemical industry-related regulations for theoretical verification and empirical analysis is relatively small. Therefore, it is still necessary to conduct research on safety production risk evaluation and response strategies for the chemical industry based on the existing research, in order to provide certain reference significance for the safety production risk evaluation of chemical enterprises.

3. Safety risk evaluation index system for chemical enterprises

3.1. Selection of safety risk factors

Safety risk identification refers to the process of identifying, discovering, and describing the dangerous sources, hazardous factors, and other undesirable events (accidents, hazards) that may directly or indirectly lead to casualties, health damage, property loss, environmental damage, or other adverse consequences in the production system (including people, machines, materials, methods, environment, etc.) before or during production activities. It is not accident investigation, but proactive prevention, which requires considering the entire system rather than isolated issues.

There are various methods for safety risk identification in current practice, such as the safety checklist method, job safety analysis method, case analysis method, fault analysis method, etc. The selection of the identification method can be based on the complexity of the identification object, its stage, and the available resources at present. However, no single method is universally applicable. An effective risk identification system is usually the result of combining multiple methods. This study selects safety analysis method, case analysis method, combined with current safety general standards for chemical industry and related research results to select safety risk evaluation indicators.

3.2. Analytic hierarchy process (AHP)

The analytic hierarchy process is a method for solving multi-factor problems. It was proposed in the 1970s. The analytic hierarchy process conducts systematic and comprehensive analysis of the proposed problem through a combination of qualitative and quantitative methods. The analytic hierarchy process establishes a system model and divides specific indicators into different levels according to specific circumstances. It compares the importance of indicators within the same level and quantifies them; it also builds connections between indicators at different levels and links indicators at different levels. After calculating the weights of indicators at the same level, it calculates the comprehensive weights between different levels. During the calculation process, consistency testing should be conducted to ensure that the calculated results are in line with standards and thus valid.

3.3. Construction of safety risk evaluation index system for chemical enterprises

3.3.1. Principles for constructing the evaluation index system

The principles for constructing the evaluation index system are as follows:

(1) Scientific principle: This is the most fundamental principle guiding the construction of the index system. The index system must be based on scientific theories and can truly and objectively reflect the internal mechanism and laws of safety production in the chemical industry;

(2) Systematic principle: Safety risks arise from multiple interrelated dimensions. The index system should comprehensively cover all key areas and reflect the logical relationships and hierarchical structure among various factors;

(3) Operability principle: Indicators must be obtainable, measurable, and verifiable. Indicators that cannot be practically measured or for which data cannot be collected lose their applicational value;

(4) Dynamic and forward-looking principle: The processes, equipment, and risks of chemical enterprises are constantly changing. The index system should not be static but should be able to adapt to such changes and predict and reflect future risk trends;

(5) Hierarchical and independence principle: The index system should have a clear structure with a top-down hierarchy (such as the target layer, criterion layer, and indicator layer). At the same time, indicators should minimize overlap and information redundancy as much as possible to maintain relative independence;

(6) Comparability principle: Indicators should be comparable within different time periods, within different departments of the enterprise, or among similar enterprises.

Constructing the evaluation index system is not a simple list task but a systematic design process. Following these principles can ensure the effectiveness of the established index system.

3.3.2. Selection of evaluation indicators

During the selection process of indicators, in addition to consulting a large number of relevant literature and chemical industry-related standards, experts in the field (including safety production managers of chemical enterprises, experienced front-line production personnel of chemical enterprises, and researchers in chemical engineering at universities, etc.) were invited to analyze the safety risk factors of relevant chemical enterprises. The safety risk evaluation indicators for the chemical industry were identified and screened out. There were four first-level indicators and fifteen second-level indicators, as shown in **Table 1**.

Table 1. Safety risk evaluation indicators for the chemical industry

Target layer	Criterion layer	Indicator layer	Indicator explanation
A Safety Risk Assessment in the Chemical Industry	B1 Safety Basic Management	C1 Safety Leadership	Leadership ability, leadership goals, resource guarantee and safety culture
		C2 Safety Production Responsibility System	Full staff responsibility, assessment supervision and dynamic revision
		C3 Safety Production Information and Compliance Audit	Chemical information, regulation identification, system and compliance review
		C4 Safety Education and Training	Training plan, capability standard, training effect evaluation
	B2 Risk Management Measures	C5 Construction of Safety Management Prevention Mechanism	Safety factor identification, classification control, hazard investigation and governance
		C6 Chemical Safety	Chemical identification, storage, major hazard source identification assessment and responsibility assignment
		C7 Change Management	Classification and grading of process, equipment and personnel changes and full process control
	B3 Operation Process Control	C8 Equipment Integrity	Equipment full life cycle management including (procurement, inspection, maintenance, scrapping)
		C9 Operational Safety	Operating procedures, start-up and shutdown, alarm, abnormal condition handling
		C10 Job Control	Work permit, risk analysis, special operation control
		C11 Stakeholder Management	Entry and supplier admission, process supervision and performance evaluation
	B4 Emergency Management and Enhancement	C12 Emergency Preparedness and Response	Emergency organization, plan, resources, drills and evaluation
		C13 Accident Management	Accident and near-miss incident reporting, investigation, rectification and lesson sharing
		C14 Performance Evaluation	Performance indicator setting, annual self-assessment
		C15 Continuous Improvement	Implementation of improvement measures, cycle improvement plan

4. Safety risk assessment in the chemical industry

According to the calculation steps of the analytic hierarchy process (AHP), the first step is to construct the judgment matrices corresponding to each level. The construction of the judgment matrices adopts the expert scoring method. Ten experts with rich experience in the field of safety risk assessment in the chemical industry were invited to score the constructed evaluation index system. After several rounds of scoring, a consensus was reached, and the final judgment matrices, accepted by all experts, were established as shown in **Table 2**, **Table 3**, **Table 4**, **Table 5** and **Table 6**.

Table 2. Judgment matrix of A-B

A-B	**B1**	**B2**	**B3**	**B4**
B1	1	1/2	1/3	2
B2	2	1	1/2	3
B3	3	2	1	3
B4	1/2	1/3	1/3	1

Table 3. Judgment matrix of B1-C

B1-C	**C1**	**C2**	**C3**	**C4**
C1	1	3	2	1/2
C2	1/3	1	1/2	1/3
C3	1/2	2	1	1/3
C4	2	3	3	1

Table 4. Judgment matrix of B2-C

B2-C	**C5**	**C6**	**C7**	**B2-C**
C5	1	1/2	2	C5
C6	2	1	3	C6
C7	1/2	1/3	1	C7

Table 5. Judgment matrix of B3-C

B3-C	**C8**	**C9**	**C10**	**C11**
C8	1	1/2	1/2	2
C9	2	1	2	3
C10	2	1/2	1	3
C11	1/2	1/3	1/3	1

Table 6. Judgment matrix of B4-C

B4-C	**C12**	**C13**	**C14**	**C15**
C12	1	1/2	2	2
C13	2	1	3	3
C14	1/2	1/3	1	2
C15	1/2	1/3	1/2	1

After calculation, the consistency ratios (CR) of the judgment matrices for each level were all less than 0.1, indicating that the judgment matrices passed the consistency test. The final indicator weights calculated using the analytic hierarchy process are shown in **Table 7**.

Table 7. Weighting of safety risk evaluation indicators for chemical enterprises

Target layer	Criterion layer	Criterion layer weights	Indicator layer	Indicator layer weights	Weighted weight
A Safety Risk Assessment in the Chemical Industry	B1 Safety Basic Management	0.1650	C1 Safety Leadership	0.2832	0.0467
			C2 Safety Production Responsibility System	0.1072	0.0177
			C3 Safety Production Information and Compliance Audit	0.1650	0.0272
			C4 Safety Education and Training	0.4445	0.0733
	B2 Risk Management Measures	0.2832	C5 Construction of Safety Management Prevention Mechanism	0.2972	0.0842
			C6 Chemical Safety	0.5390	0.1526
			C7 Change Management	0.1638	0.0464
	B3 Operation Process Control	0.4445	C8 Equipment Integrity	0.1872	0.0832
			C9 Operational Safety	0.4118	0.1830
			C10 Job Control	0.2930	0.1302
			C11 Stakeholder Management	0.1080	0.0480
	B4 Emergency Management and Enhancement	0.1072	C12 Emergency Preparedness and Response	0.2596	0.0278
			C13 Accident Management	0.4495	0.0482
			C14 Performance Evaluation	0.1707	0.0183
			C15 Continuous Improvement	0.1202	0.0129

From the calculation results in **Table 7**, it can be seen that the order is as follows: C9 (0.1830) > C6 (0.1526) > C10 (0.1302) > C4 (0.0733) > C5 (0.0842) > C8 (0.0832) > C13 (0.0482) > C11 (0.0480) > C1 (0.0467) > C7 (0.0464) > C12 (0.0278) > C3 (0.0272) > C14 (0.0183) > C2 (0.0177) > C15 (0.0129).

The weight results obtained through the analytic hierarchy process indicate that in the primary evaluation indicators, the operation process control and risk management measures are the key dimensions determining the overall safety level, and the combined weight of the two exceeds 0.72. The top five weighted weights at the indicator level are: operational safety, weight 0.1830; chemical safety, weight 0.1526; operation control, weight 0.1302; safety management prevention mechanism construction, weight 0.0842; equipment integrity, weight 0.0832. These indicators collectively account for 63.32% of the total weight, and are the core focus of risk prevention and control.

5. Safety risk response strategies for the chemical industry

Due to the complexity of the production process and the concentration of risks in the chemical industry, the safety production of the chemical industry faces significant challenges. To better prevent and control major safety accidents, a systematic and scientific safety risk management system needs to be established. Based on the calculation results of the analytic hierarchy process, some countermeasures and suggestions from multiple aspects are listed.

From the calculation results, it can be seen that operation safety and operation control occupy an extremely important position in the safety production of chemical enterprises. Strengthening operation management and safety management of operations is extremely important. Operational errors in chemical production can easily trigger chain reactions, making the improvement of process safety an urgent priority. Enterprises should implement standardized operations, systematically define key processes such as start-up, shutdown, normal operation, and abnormal situation handling, and establish comprehensive operational safety standards. On this basis, establish an intelligent monitoring system for operational behaviors based on the industrial internet to conduct real-time monitoring of the operation status of key processes, in order to achieve early detection and timely handling of abnormal situations. At the same time, strengthen the management of alarms and the closed-loop management of handling, ensuring that each alarm has a response and a record, forming a closed loop.

In addition, in the calculation results, it is also necessary to attach importance to the full-chain management of major hazard sources, implement the responsibility system of package guarantee, and clearly define the responsibilities of each level of the responsible person. Moreover, strengthen monitoring and early warning, conduct real-time monitoring of the main parameters of operations, strengthen safety interval management, and prevent accidents from happening. At the same time, ensure the integrity of equipment, increase the inspection frequency of key equipment. Strengthen preventive maintenance and online monitoring of equipment, and issue early warnings for abnormal situations.

In terms of risk control, incorporate risk classification control and hidden danger investigation and governance into the digital platform to achieve dynamic management. On top of that, regularly conduct risk analysis and promptly adjust control measures, strictly implement the closed-loop management of hidden dangers to ensure that the rectification is in place, and implement full-process management of processes, equipment, and materials changes to ensure that risks are controllable. After the changes, update operation procedures and train relevant personnel promptly, carry out differentiated and precise training to improve the safety quality of the employees. Moreover, innovate training methods and rely on training bases for simulation training. Strengthen the training of contractor personnel to ensure safe operations.

In terms of continuous improvement, formulate special plans for major hazard sources, regularly organize practical emergency drills to enhance emergency response capabilities, ensure that emergency supplies are complete and effective, and be ready to respond to emergencies, establish a performance-based self-assessment mechanism to promote continuous improvement of safety performance, develop a rectification plan for self-assessment problems to ensure that the problems are resolved, utilize the “industrial internet + hazardous chemical safety production” intelligent control platform to promote the application of advanced technical equipment, reduce personnel exposure risks and utilize big data analysis to mine accident patterns and provide data support for risk warning.

Through the above strategies, strengthen risk control, improve safety management efficiency, and build a systematic prevention and control system of “source control– process control–emergency guarantee–continuous improvement”, effectively preventing and controlling the occurrence of safety risk accidents.

6. Conclusion

This study analyzed existing research and legal frameworks related to safety in chemical production. Based on expert consultations, a set of safety risk evaluation indicators was identified, and an index system was constructed using the AHP to determine indicator weights. Among the first-level evaluation indicators, "operation process control" has the largest weight, and the second-level indicators "operation safety" has the highest degree of impact on the safety risks of the chemical industry. Based on the calculation results and the actual production situation of the chemical industry, propose countermeasures and improvement suggestions for the safety risks of chemical industry production, providing certain reference significance for the risk management of chemical industry safety.

Disclosure statement

The author declares no conflict of interest.

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