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Research on the Assessment and Control of Enterprise Production Risks Under Uncertain Environments

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Abstract: With the continuous development of my country's economy, the scale of the manufacturing industry is increasing day by day. Regardless of the circumstances, production risks within enterprises are ubiquitous, and are becoming increasingly complex and hidden with the upgrading of technology and the continuous changes in market demand. If enterprises ignore production risks in their daily production and operation, they will eventually face inevitable losses such as equipment failures, damage, and profit contraction. Therefore, in order to achieve long-term development, enterprises must fully recognize the risks existing in production and formulate targeted control plans. To effectively help enterprises determine production risk control schemes in uncertain environments, this paper proposes a risk analysis and evaluation method based on fuzzy comprehensive evaluation. First, brainstorming is used within the enterprise to identify production risks. Then, the Delphi method is used to screen the collected risks and preliminarily determine the important risks, which are then classified by attributes to form a risk list. Second, fuzzy comprehensive evaluation is introduced in the risk assessment stage to quantify the importance of risk factors. The weight of each risk factor is calculated by constructing a judgment matrix. Third, the top five risk factors with the highest weights are selected as key risk factors and used as evaluation indicators in the scheme selection stage. Then, based on the analytic hierarchy process, the weighted scoring method is used to determine the optimal production risk control scheme. Finally, the feasibility of the proposed method is verified using Company A as an example.

Keywords: Production risk; Uncertain environment; Risk control; Fuzzy comprehensive evaluation method.

1. Introduction

Since the reform and opening up, my country's vast land, abundant raw materials, and relatively cheap labor have provided ample nourishment and a favorable environment for the rise of "Made in China." In just a few decades, China has become the world's largest manufacturing country thanks to its rapid growth, large scale, and high output value. However, in contrast to the steady development of my country's manufacturing industry, the incidence of safety accidents during production is also constantly increasing. Although many enterprises have taken measures to strengthen safety production in response to the Party Central Committee's decisions and deployments on safe production, the long-term insufficient investment in safety and weak targeted measures in operation and management have resulted in many key risks not being effectively addressed. These uncertain hidden dangers may not only cause economic losses to enterprises and threaten the health and safety of employees, but may also have a serious impact on social order. Therefore, the selection of risk control solutions has received increasing attention. Risk control scheme evaluation research involves identifying production risk factors, determining key risks based on the severity of potential harm, conducting in-depth comprehensive analysis based on the feasibility of the scheme and the expected effects to be achieved by the enterprise, and ultimately selecting the optimal control scheme.

However, in actual research, the production environment of enterprises is complex, and personnel activities and equipment operations are often accompanied by interference from uncertain events. In order to minimize the adverse effects of uncertain factors on the research, this paper introduces the fuzzy comprehensive evaluation method. Its core idea is to transform fuzzy and uncertain information into a mathematical model, and obtain the final evaluation result by fuzzy comprehensive analysis of the weights of each indicator. In this process, the fuzzy comprehensive evaluation method can effectively handle the interrelationships between indicators and avoid the assumption of independence between indicators in traditional evaluation methods.

2. Risk Control Process and Methods for Enterprise Production

2.1. Management and Control of Production Risks

Risk management refers to the enterprise management method in which production and operation units take safe production as the overall goal, identify risk factors in the production process, analyze the severity of risk factors through quantitative or qualitative research methods, take the most effective measures for the characteristics of risks, and proactively and systematically control risks to ensure production safety at the lowest cost [1]. Excellent risk management methods can help enterprises create a safe production environment, effectively avoid and reduce the incidence of enterprise safety production accidents, thereby reducing losses [2].

The main goal of risk management is to effectively handle and control risks, avoid safety accidents in the production process as much as possible, and obtain safety guarantees in production with relatively low investment. It is the foundation for enterprises to carry out production and operation activities smoothly.

The main process of risk management and control is: risk identification, risk assessment, risk response and improvement.

(1) Production risk identification is to use various methods and means to identify the main dangerous factors that cause safety accidents in the production process and the possible

production risks. Risk identification is the foundation of risk management. Only by comprehensively and accurately identifying risks throughout the entire production process can we ensure that risk analysis achieves good results. Risk identification plays a crucial role in risk control.

(2) Production risk assessment is based on the completion of risk identification. It uses quantitative methods to analyze risks, estimate the probability of accidents, and the potential losses to the enterprise. Specific indicators are used to represent the importance of production risks, and key risks are identified to provide a scientific basis for risk response.

(3) Risk control and improvement require the development of different risk-specific countermeasures, such as reduction, transfer, and acceptance, based on the different attributes of production risks.[3]When determining control plans, the degree to which the plan meets multiple evaluation indicators is comprehensively considered, and the plan with the highest comprehensive satisfaction is ultimately selected as the optimal plan.

2.2. Production Risk Identification Methods

2.2.1. Brainstorming

Brainstorming is a method of collective discussion and creative generation, designed to stimulate the imaginationand creativity of team members. Through brainstorming, team members can freely express their ideas and opinions, and engage in unrestricted discussion and exchange [4]. This method can help teams quickly find solutions to problems, promoting teamwork and innovation [5]. In practice, brainstorming is widely used in various fields, such as business management, marketing, and product design. Through brainstorming, teams can think together, inspire each other, and quickly identify risk factors in the production process in a short period of time, which is beneficial for obtaining first-hand information at a lower cost. However, this method is often affected by a certain degree of subjective factors in actual operation. In order to avoid this adverse factor as much as possible, it is necessary to invite people from various fields to analyze the problem from multiple perspectives during the implementation phase.

2.3. Production Risk Assessment Methods

2.3.1. Delphi Method

The Delphi method, also known as the expert survey method, was first applied to actual production by the RAND Corporation in the United States in 1946. The Delphi method process usually includes the following steps: first, identify the problem or issue, and then invite a group of experts or stakeholders to conduct an independent opinion survey. Secondly, all survey results are integrated and analyzed to form a consensus. Finally, the consensus is fed back to the participants to facilitate a final decision [6].

The advantage of the Delphi method is that it can fully utilize expert knowledge and experience, avoiding the influence of personal subjective bias and groupthink. In addition, the Delphi method can promote cooperation and communication among participants, thereby improving the quality and feasibility of decision-making. Although the Delphi method may have certain errors and uncertainties because the opinion survey is based on expert subjective judgment, it can effectively solve real-world problems. In this paper, the Delphi method is used to assess identified risks, using expert experience to determine important risks in production that have a high frequency of inducing accidents and have a serious impact on enterprises when they occur. The aim is to narrow the research scope and improve research accuracy.

2.3.2. Fuzzy Comprehensive Evaluation Method

Professor Zadeh of the University of California, Berkeley, founded fuzzy theory. Based on fuzzy set theory, a new discipline, fuzzy system theory, was formed. In recent years, fuzzy system theory has received widespread attention and developed rapidly, and has been widely applied in the natural sciences and humanities. Fuzzy control has become an important branch of intelligent control [7].

The fuzzy comprehensive evaluation method is a means of comprehensively evaluating system events using fuzzy set methods. It evaluates events after fuzzy transformation based on given judgment indicators and measured values. The approach is as follows: clarify the evaluation grading scale and weights among evaluation elements and factors, construct the fuzzy boundary of risk elements through membership degrees, obtain the fuzzy evaluation matrix, determine the evaluation object level through calculation, and thus obtain the fuzzy comprehensive evaluation conclusion [8].

The general process of the fuzzy comprehensive evaluation method is as follows:

① Define the factor set U and the evaluation set V. The factor set U is the set of evaluation items or indicators, let U = {ui}, i = 1, 2, 3...n, where n are evaluation indicators, representing the evaluation perspective of the evaluated object. The evaluation set V is the set of evaluation levels, let V = {vj}, j = 1, 2, 3...m. Where v represents the j-th evaluation level, and m is the number of evaluation levels.

② Determine the membership vector for single-factor evaluation and form the membership matrix R. The membership degree rij refers to the probability that multiple evaluation subjects will rate a certain evaluation object vj in terms of ui. The membership vector R = (ri1, ri2, ..., rim), i = 1, 2...n. When determining membership relationships, experts generally vote based on the evaluation level.

③ Determine the weight vector. A is the weight or weight coefficient vector of the evaluation indicators. Define the fuzzy subset of the factor set as A = {ai}, i = 1, 2, 3...n. That is, the measure of the role of factor ui in the evaluation factors, and the sum of ai reflects the importance of each factor. In addition, the evaluation set B can also be represented by numerical results.

④ Calculate the comprehensive evaluation vector S (comprehensive membership vector) and comprehensive evaluation value according to fuzzy calculation.μ(Comprehensive Score). $S=A\circ R$ $\mu=B*S^T$ [9].

Finally, the comprehensive evaluation vector S (comprehensive membership vector) and comprehensive evaluation value can be used.μ(Comprehensive score) is used to describe the comprehensive evaluation result of the evaluation object.

2.4. Control Scheme Selection Method

2.4.1. Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is a decision analysis method that combines qualitative and quantitative approaches to solve complex multi-objective problems. Its basic principle is to decompose the entire objective into multiple sub-objects, construct a multi-level structure based on the correlation and subordinate relationships between objectives, compare indicators at the same level to determine the importance of each indicator, and finally determine the relationship between lower-level objectives and upper-level objectives through quantitative calculation. When using the Analytic Hierarchy Process (AHP) to build a model, it generally involves four steps: constructing the judgment matrix, hierarchical single ranking and its consistency test, hierarchical overall ranking and its consistency test [10]. In this paper, the relative importance of risk indicators at each level is compared, and the weight of each risk indicator is reasonably calculated by constructing a judgment matrix. The evaluation indicators for risk control scheme selection are determined by the weights, and then the control scheme is selected by analyzing the interaction between the scheme layer and the criterion layer.

2.4.2. Weighted Scoring Method

The weighted scoring method is a commonly used decision analysis method. In the process of decision-makers comparing and selecting multiple schemes, the weighted scoring method divides the various factors affecting the scheme into different levels by assigning weights. The analysis assesses the degree to which the proposed solutions meet the various factors, and scores each factor accordingly. Finally, a weighted comprehensive score is calculated for each solution. The effectiveness of the solution is judged based on the comprehensive score, thus helping decision-makers select the appropriate solution [11].

3. Case Study of Risk Control Solution Evaluation in Enterprise Production

3.1. Analysis of the Current Situation of Company A

Company A is a small and medium-sized enterprise in China whose main business is plastic packaging. In the current context of China's vigorous development of manufacturing and continuous efforts to support local manufacturing enterprises, Company A has enjoyed opportunities in terms of policy, talent supply, technological change, and market demand. However, Company A still faces numerous obstacles and challenges in its development, including insufficient market competitiveness, lack of core technologies, and high production costs. The unpredictable nature of risks in the production process frequently brings uncertain losses to Company A, causing decision-makers to hesitate and become overly cautious, thus hindering their ability to make timely and correct decisions and even causing the company to miss development opportunities.

To address Company A's current predicament and promote its sustainable and long-term development, it is necessary to take measures to reduce the risks in Company A's production process based on its actual situation. This chapter will use the risk control scheme selection method proposed above, from risk identification to risk assessment, then identifying key risks, and finally determining the optimal risk control scheme, to improve Company A's production process step by step and ultimately solve its practical problems.

3.2. Risk Identification for Company A's Production

Using brainstorming to identify production risks for Company A,

Step 1: Organize a meeting and introduce the issues. A special discussion meeting was held within Company A to eliminate production risks and improve safety. Five production line operators, three technicians, two managers, and two supervisors were invited to participate. The facilitator introduced the meeting theme and issues as shown in Table 1, ensuring that participants fully understood the meeting's intent and improving the discussion's effectiveness.

Table 1. Meeting Questions

1. What production risks do you believe exist in your current position and job content?
2. Based on your observations, what production risks exist in the job content of other personnel in the production scenario?

Step 2: Organize discussion and data collection. The facilitator encourages everyone to think carefully and speak freely, listing one or two accident cases to broaden the participants' thinking. Participants discuss the risks in their work based on the cases and their own practical experience, or connect and supplement others' statements. A designated person records the content of the discussions, as shown in Table 2.

Table 2. Meeting Minutes

Attendees	Operators	Technicians	Management Personnel	Supervisors
	Personnel Competence	Robotic Arm Operation	Quality Assurance	Working Environment
	Safety Awareness	Gas and Open Flame Risks	Production Planning	Employee Mood
	Operational Proficiency	High-Voltage Electricity Risks	Material Warehousing	Equipment Switching
Risk Factors	Load Risks	Equipment Lifting	Finished Product Outbound	Power Management
	High Temperature Risks	Production Material Transportation	Personnel Inflow/Outflow	Material Placement
	Working at Heights	Maintenance Risks	Economic Risks	Facility Planning
	Environmental Light/Darkness	Troubleshooting		Policy Risks

Step 3: Data organization and post-meeting evaluation. The collected risk factors are organized, and after removing duplicate factors, the risks are classified into four categories according to different attributes: personnel risks, equipment risks, and other risks (external risks). Then, the reliability of the identified risk factors is evaluated on the production site, and risk factors with low reliability are eliminated and the reasons for the occurrence of the remaining risks are analyzed.

Table 3. Production Risk List

Main Risk Categories	Risk Factors	Causes of Risks
Personnel Risks	Personnel Competence	Lack of safety awareness among employees, resulting in safety hazards due to blind operation
	Work Proficiency	Employees' unfamiliarity with work processes and tool operation
	Employee Mood	Employees' negative emotions affecting their work state
	Work Focus	Employees' mistakes due to distraction
	Load Risks	Risks when personnel are handling heavy objects
Equipment Risks	Equipment Maintenance	Risks arising from improper operation during equipment maintenance
	Operational Abnormalities	Risks of equipment malfunctions without timely braking
	High-Voltage Electricity Risks	Risks of supply and demand mismatch
	Open Flame Risks	Risks caused to flammable materials by open flame operations
Environmental Risks	High Temperature Risks	Health Risks from Working in High-Temperature Environments
	Risks of Working at Heights	Falls of Personnel or Tools Due to Improper Securing at Heights
	Environmental Light/Darkness	Discomfort Caused by Inappropriate Light Levels
	Noise Risks	Environmental noise affects information transmission
	Material placement	Random placement of materials affects environmental accessibility or unreasonable stacking causes collapse
Other risks	Quality Assurance	Low product qualification rate causes losses
	Production Planning	Risk caused by mismatch between produced products and customer needs
	Policy Risks	Policy changes alter market demand
	Natural disasters	Unpredictable natural disasters cause losses to the enterprise
	Financial risks	Increased raw material procurement costs
	Competition risks	Risk of competing companies seizing market share

Analyzing the table above, it can be concluded that Company A's production risks are mainly concentrated in personnel, equipment, and the environment. The risk identification process initially clarified the key areas for improvement in Company A's risk control, including the need to improve the overall work quality of operators, enhance operators' professional skills in equipment operation, and improve the production environment through on-site management methods to provide operators with a more comfortable working environment and improve work quality.

3.3. Risk Assessment of Enterprise A's Production

Brainstorming was used to collect a large number of risk factors in the production process of Enterprise A. In order to further narrow down the research scope, the key risks were determined by comprehensively judging from multiple perspectives, such as frequency of occurrence, magnitude of negative impact after occurrence, and degree of controllability. The Delphi method was used to analyze the risk list above again. Three production experts, three management experts, and three technical experts were asked to evaluate the risks listed on the risk list. After the above steps, the risk factors that the experts unanimously agreed were selected, as shown in Table 4:

Table 4. Important Risk List

Serial Number	Risk Category	Risk Factors
1	Personnel Risks	Personnel safety awareness
2		Work Proficiency
3		Work Focus
4	Equipment Risks	Equipment Maintenance
5		Operational Abnormalities
6		Use of fire and electricity
7	Environmental Risks	High-temperature operation
8		High-altitude operations
9		Material placement
10	Other risks	Quality Assurance
11		Policy Risks
12		Natural disasters

Through brainstorming and the Delphi method, the production risks of Enterprise A were identified and analyzed, and a list of important production risks was obtained. A total of twelve risks in four categories were collected, which were represented by B1, B2, B3, and B4 to represent personnel risks, equipment risks, environmental risks, and other risks, respectively. The twelve important risks were represented by C1, C2, C3.C12, forming Figure 1, which facilitates the next step of using the fuzzy comprehensive evaluation method for in-depth analysis.

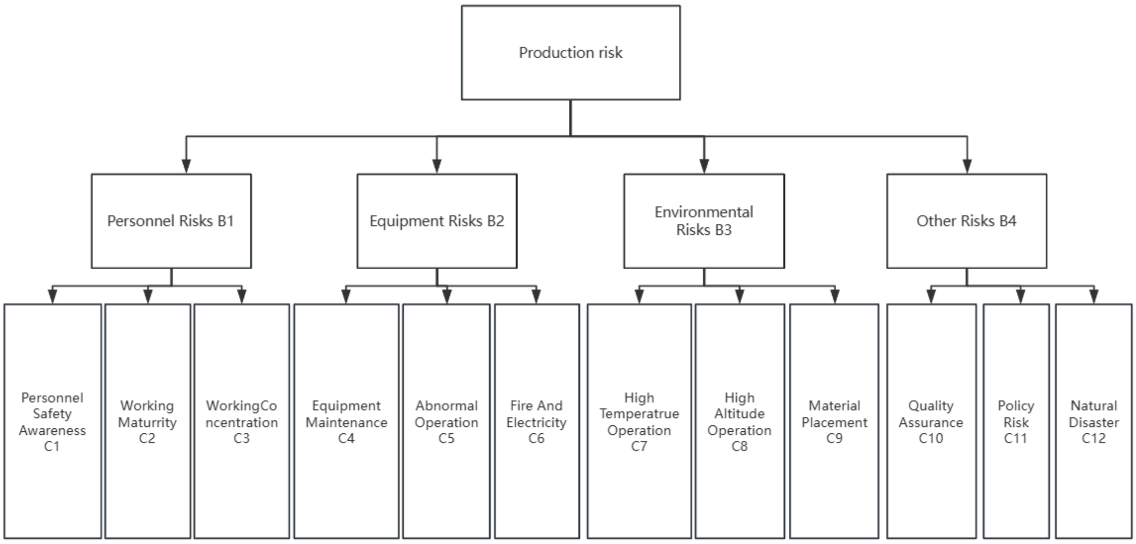

Figure 1. Production risk classification

The relative importance of production risks is evaluated using a pairwise comparison method. Risks are compared and scored according to the judgment scale in Table 5. This method can conveniently and effectively quantify the importance of risk factors, and the relative importance between risks can be clearly observed through scoring.

Table 5. Pairwise comparison method judgment scale

Meaning	Scale
Factor i is as important as factor j	1
Factor i is slightly more important than factor j	3
Factor i is more important than factor j	5
Factor i is significantly more important than factor j	7
Factor i is absolutely more important than factor j	9
The importance of factor i and factor j is between the above judgments	2, 4, 6, 8
Factor j is more important than factor i	1/3, 1/5, 1/7, 1/9

A primary judgment matrix is constructed based on the scoring results, as shown in Table 6.

Table 6. Primary judgment matrix

Risk	Personnel Risks	Equipment Risks	Environmental Risks	Other risks
Personnel Risks	1	1/2	3	5
Equipment Risks	2	1	5	7
Environmental Risks	1/3	1/5	1	2
Other risks	1/5	1/7	1/2	1

Similarly, the pairwise comparison method is used to score risk factors belonging to the personnel risk category. A secondary judgment matrix is constructed based on the scoring results, as shown in Table 7.

Table 7. Second-level judgment matrix B1

Personnel Risks	C1	C2	C3
C1	1	2	5
C2	1/2	1	2
C3	1/5	1/2	1

Similarly, the judgment matrix B2 for equipment risk is constructed, as shown in Table 8.

Table 8. Second-level judgment matrix B2

Equipment Risks	C4	C5	C6
C4	1	1/2	5
C5	2	1	7
C6	1/5	1/7	1

Next, the judgment matrix B3 for environmental risk is constructed, as shown in Table 9.

Table 9. Second-level judgment matrix B3

Environmental Risks	C7	C8	C9
C7	1	1/6	1/2
C8	6	1	5
C9	2	1/5	1

Finally, the judgment matrix for other risks is constructed, as shown in Table 10.

Table 10. Second-level judgment matrix B4

Other risks	C10	C11	C12
C10	1	7	5
C11	1/7	1	1/3
C12	1/5	3	1

Step 1: Calculate the geometric mean Si of each row of each judgment matrix according to the scoring results:

$$Si = \sqrt[n]{\prod_{j=1}^{n} aij} \quad (1)$$

(1) Calculate Si of each row of the first-level judgment matrix:

$$S_I=(1*1/2*3*5)^{1/4}=1.655$$

$$S_{II}=(2*1*5*7)^{1/4}=2.893$$

$$S_{III}=(1/3*1/5*1*2)^{1/4}=0.604$$

$$S_{IV}=(1/5*1/7*1/2*1)^{1/4}=0.398$$

(2) Similarly, calculate Si of each row of the personnel risk judgment matrix:

$$S_1=(1*2*5)^{1/3}=2.154$$

$$S_2=(1/2*1*2)^{1/3}=1$$

$$S_3=(1/5*1/2*1)^{1/3}=0.464$$

(3) Similarly, calculate Si of each row of the equipment risk judgment matrix:

$$S_4=(1*1/2*5)^{1/3}=1.357$$

$$S_5=(2*1*7)^{1/3}=2.410$$

$$S_6=(1/5*1/7*1)^{1/3}=0.306$$

(4) Similarly, calculate Si of each row of the environmental risk judgment matrix:

$$S_7=(1*1/6*1/2)^{1/3}=0.437$$

$$S_8=(6*1*5)^{1/3}=3.107$$

$$S_9=(2*1/5*1)^{1/3}=0.737$$

(5) Similarly, calculate Si of each row of other risk judgment matrices:

$$S_{10}=(1*7*5)^{1/3}=3.271$$

$$S_{11}=(1/7*1*1/3)^{1/3}=0.362$$

$$S_{12}=(1/5*3*1)^{1/3}=0.843$$

Step 2: Calculate the weight of Si in each matrix as the weight of each risk factor:

$$Wi = Si/\sum_{i=1}^{n} Si \quad (2)$$

(1) Calculate the weights of each factor in the first-level judgment matrix:

$$\sum_{i=1}^{n} Si=1.655+2.893+0.604+0.398=5.55$$

$$W_I= S_I/ \sum_{i=1}^{n} Si=1.655/5.55=0.298$$

$$W_{II}=2.983/5.55=0.537$$

$$W_{III}=0.604/5.55=0.180$$

$$W_{IV}=0.398/5.55=0.072$$

$$W=[0.298,0.537,0.180,0.072]^T$$

(2) Similarly, calculate the weights of each factor in the personnel risk judgment matrix:

$$\sum_{i=1}^{n} Si=2.154+1+0.464=3.618$$

$$W_1= S_1/ \sum_{i=1}^{n} Si==2.154/3.618=0.595$$

$$W_2=1/3.618=0.276$$

$$W_3=0.464/3.618=0.128$$

$$W=[0.595,0.276,0.128]^T$$

(3) Similarly, calculate the weights of each factor in the equipment risk judgment matrix:

$$\sum_{i=1}^{n} Si=1.357+2.410+0.306=4.073$$

$$W_4= S_4/ \sum_{i=1}^{n} Si=1.357/4.073=0.333$$

$$W_5=2.410/4.073=0.592$$

$$W_6=0.306/4.073=0.075$$

$$W=[0.333,0.592,0.075]^T$$

(4) Similarly, calculate the weights of each factor in the environmental risk judgment matrix:

$$\sum_{i=1}^{n} Si=0.437+3.107+0.737=4.281$$

$$W_7= S_7/ \sum_{i=1}^{n} Si=0.437/4.281=0.102$$

$$W_8=3.107/4.281=0.726$$

$$W_9=0.737/4.281=0.172$$

$$W=[0.102,0.726,0.172]^T$$

(5) Similarly, calculate the weights of each factor in other risk judgment matrices:

$$\sum_{i=1}^{n} Si=3.271+0.362+0.843=4.476$$

$$W_{10}= S_{10}/ \sum_{i=1}^{n} Si=3.271/4.476=0.731$$

$$W_{11}=0.362/4.476=0.081$$

$$W_{12}=0.843/4.476=0.188$$

$$W=[0.731,0.081,0.188]^T$$

Step 3: Calculate the maximum eigenvalue:

$$\lambda max = \sum_{i=1}^{n} \frac{[AW]i}{nWi} \quad (3)$$

(1) Calculate the maximum eigenvalue in the first-level judgment matrix:

In this calculation process, AW $=\begin{bmatrix} 1 & 1/2 & 3 & 5 \\ 2 & 1 & 5 & 7 \\ 1/3 & 1/5 & 1 & 2 \\ 1/5 & 1/7 & 1/2 & 1 \end{bmatrix}[0.298,0.537,0.180,0.072]^T=\begin{bmatrix} 1.467 \\ 2.537 \\ 0.531 \\ 0.298 \end{bmatrix}$

λmax=1.467/4*0.298+2.537/4*0.537+0.531/4*0.180+0.298/4*0.072

=1.231+1.181+0.738+1.025=4.185

(2) Similarly, calculate the maximum eigenvalue in the personnel risk judgment matrix:

In this calculation process, AW $=\begin{bmatrix} 1 & 2 & 5 \\ 1/2 & 1 & 2 \\ 1/5 & 1/2 & 1 \end{bmatrix}[0.595,0.276,0.128]^T=\begin{bmatrix} 1.787 \\ 0.830 \\ 0.385 \end{bmatrix}$

λmax=1.787/3*0.595+0.839/3*0.276+0.385/3*0.128

=1.001+1.013+1.003=3.0171

(3) Similarly, calculate the maximum eigenvalue in the equipment risk judgment matrix:

In this calculation process, AW $=\begin{bmatrix} 1 & 1/2 & 5 \\ 2 & 1 & 7 \\ 1/5 & 1/7 & 1 \end{bmatrix}[0.333,0.592,0.075]^T=\begin{bmatrix} 1.004 \\ 1.783 \\ 0.226 \end{bmatrix}$

λmax=1.004/3*0.333+1.783/3*0.592+0.226/3*0.075

=1.005+1.004+1.004=3.013

(4) Similarly, calculate the maximum eigenvalue in the environmental risk judgment matrix:

In this calculation process, AW $=\begin{bmatrix} 1 & 1/6 & 1/2 \\ 6 & 1 & 5 \\ 2 & 1/5 & 1 \end{bmatrix}[0.102,0.726,0.172]^T=\begin{bmatrix} 0.309 \\ 2.198 \\ 0.521 \end{bmatrix}$

λmax=0.309/3*0.102+2.198/3*0.726+0.521/3*0.172

=1.010+1.009+1.010=3.029

(5) Similarly, calculate the maximum eigenvalue in other risk judgment matrices:

In this calculation process, AW $=\begin{bmatrix} 1 & 7 & 5 \\ 1/7 & 1 & 1/3 \\ 1/5 & 3 & 1 \end{bmatrix}[0.731,0.081,0.188]^T=\begin{bmatrix} 2.238 \\ 0.248 \\ 0.577 \end{bmatrix}$

λmax=2.238/3*0.731+0.248/3*0.081+0.577/3*0.188

=1.021+1.021+1.023=3.065

Step 4: Verify consistency:

$$CI = \frac{\lambda max - n}{n-1} \quad (4)$$

$$CR = CI/RI \quad (5)$$

(1) Consistency test of the first-level judgment matrix:

$$CI = \frac{4.185-4}{4-1} = 0.062$$

CR=CI/RI(RI=0.9)=0.062/0.9=0.069

Because CR = 0.069 < 0.1, the above calculation can be considered to satisfy the consistency test. Therefore, the relative degree of each production risk category is: equipment risk (0.537) > personnel risk (0.298) > environmental risk (0.180) > other risks (0.072).

After understanding the relative importance of the four categories of risks, we continue to use fuzzy hierarchical analysis to analyze the interrelationships and relative importance of risks with similar attributes in each category.

(2) Similarly, we conduct a consistency test on the personnel risk judgment matrix:

$$CI = \frac{3.017-3}{3-1} = 0.009$$

CR=CI/RI(RI=0.58)=0.016

Calculations show CR < 0.1, indicating that the analysis results of personnel risks meet the consistency test. The relative importance of each risk factor is: personnel safety awareness (0.595) > work proficiency (0.276) > work focus (0.128).

(3) Similarly, we conduct a consistency test on the equipment risk judgment matrix:

$$CI = \frac{3.013-3}{3-1} = 0.007$$

CR=CI/RI(RI=0.58)=0.012

Since CR = 0.012 < 0.1, the calculation process related to equipment risks meets the consistency test. Therefore, the relative importance of each risk factor is determined to be: operational abnormality (0.592) > equipment maintenance (0.333) > fire and electricity use (0.075).

(4) Similarly, we conduct a consistency test on the environmental risk judgment matrix:

$$CI = \frac{3.029-3}{3-1} = 0.015$$

CR=CI/RI(RI=0.58)=0.026

Because CR = 0.026 < 0.1, the calculation of environmental risks meets the consistency test. The relative importance of each risk factor is determined to be: material placement (0.726) > high-altitude operation (0.172) > high-temperature operation (0.102).

(5) Similarly, we conduct a consistency test on the other risk judgment matrices:

$$CI = \frac{3.065-3}{3-1} = 0.033$$

CR=CI/RI(RI=0.58)=0.057

CR=0.057<0.1, it can be considered that the calculation process of other risk-related factors meets the consistency test, and the relative importance level of each risk factor is determined as quality assurance (0.731)>natural disaster (0.188)>policy risk (0.081).

The above steps calculated the primary indicators, namely the relative importance index of each risk category, as the primary weight coefficient, and compared the relative importance weight coefficients of each risk in a single category as secondary weights. In order to more clearly and scientifically compare different categories of risk factors horizontally, the next step is to calculate the product of the primary weights and secondary weights as the comprehensive evaluation index weight of each important risk factor, denoted as w_i(i=1, 2, 3…12).

$w_1=W_I*W_1$=0.298*0.595=0.177

w_2=0.298*0.276=0.082

w_3=0.298*0.128=0.038

w_4=0.537*0.333=0.179

w_5=0.537*0.592=0.318

w_6=0.537*0.075=0.040

w_7=0.180*0.102=0.018

w_8=0.180*0.726=0.131

w_9=0.180*0.172=0.031

w_{10}=0.072*0.731=0.053

w_{11}=0.072*0.081=0.006

w_{12}=0.072*0.188=0.014

The calculation results are organized to form an evaluation table of the importance of enterprise production risk factors, and sorted according to the comprehensive evaluation weight values, as shown in Table 11.

Table 11. Evaluation table of the importance of enterprise production risk factors

Risk Category	Primary Weight	Production Risk	Secondary Indicators	Comprehensive Evaluation Weight	Weight Ranking
Personnel Risks	0.298	Personnel safety awareness	0.595	0.177	3
		Work Proficiency	0.276	0.082	5
		Work Focus	0.128	0.038	8
Equipment Risks	0.537	Equipment Maintenance	0.333	0.179	2
		Operational Abnormalities	0.592	0.318	1
		Use of fire and electricity	0.075	0.040	7
Environmental Risks	0.180	High-temperature operation	0.102	0.018	10
		Material placement	0.726	0.131	4
		High-altitude operations	0.172	0.031	9
Other risks	0.072	Quality Assurance	0.731	0.053	6
		Policy Risks	0.081	0.006	12
		Natural disasters	0.188	0.014	11

By applying the pairwise comparison method under the background of fuzzy evaluation, and fully considering the opinions of experts, the production risk factors were compared hierarchically. By comparing the weights corresponding to the risk factors, it can be determined that the relative importance of each risk is: equipment risk is higher than personnel risk, personnel risk is higher than environmental risk, and environmental risk is higher than other risks. At the same time, by comprehensively considering the primary and secondary weights, the comprehensive evaluation weight of each risk factor was determined. The top five risk factors in the comprehensive evaluation weight ranking were identified as key risk factors: abnormal equipment operation, equipment maintenance risk, personnel safety awareness, material placement risk, and work proficiency.

3.4. Determine the Risk Control Plan

Step 1: Analyze the factors affecting the evaluation of the risk control plan.

(1) Determine the risk control scheme. Three alternative production risk control schemes are proposed for Company A, namely R1, R2 and R3.

(2) Determine the set of key risk indicators that have a greater impact on the risk control plan. Analyzing the criterion layer in Figure 2, it can be concluded that the target layer and the criterion layer affect the selection of the plan. The plan's avoidance and response capabilities for each risk factor in the criterion layer are the most direct methods to evaluate whether the plan is effective. The top five risk factors were selected as key risk factors by the comprehensive weight ranking obtained from the previous fuzzy comprehensive evaluation method, which are the key evaluation indicators of the weighted scoring method. Factor set F={F1 equipment operation abnormality, F2 equipment maintenance risk, F3 personnel safety awareness, F4 material placement risk, F5 work proficiency}.

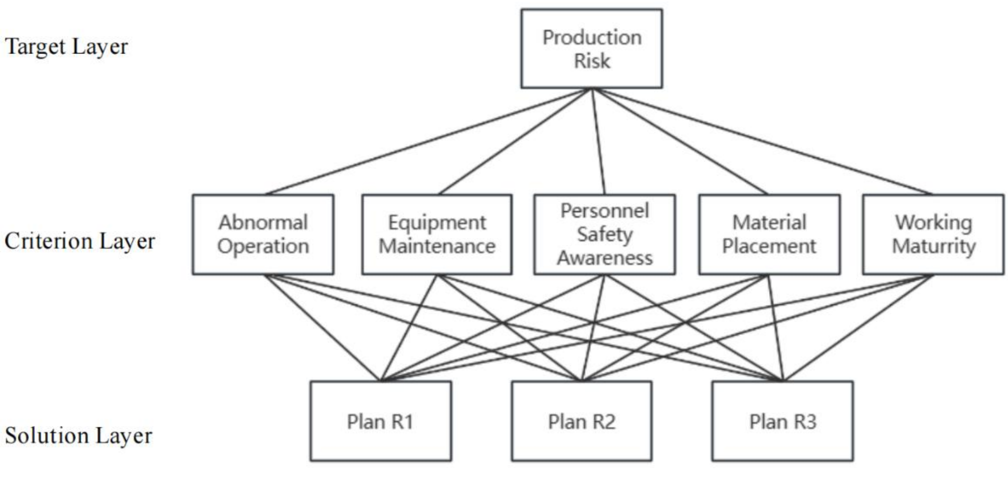

Figure 2. Hierarchical Analysis Diagram of Enterprise Production Risk Control Solution Selection

Step 2: Determine the weights of the influencing factors of the risk control solution.

Determine the weight set W. The calculation of the comprehensive evaluation index weight, denoted as wi, has already determined the relative relationship of the five index factors. Now, considering only the weights of these five factors, that is, converting the comprehensive evaluation index weights, we can obtain the factor weights as W={0.36,0.20,0.20,0.15,0.09}

$$\sum wi = w_5 + w_4 + w_1 + w_8 + w_2$$

$$= 0.318+0.179+0.177+0.131+0.082=0.887$$

$$W1 = w_5/\sum wi = 0.318/0.887 = 0.36$$

$$W2 = w_4/\sum wi = 0.179/0.887 = 0.20$$

$$W3 = w_1/\sum wi = 0.177/0.887 = 0.20$$

$$W4 = w_8/\sum wi = 0.131/0.887 = 0.15$$

$$W5 = w_2/\sum wi = 0.082/0.887 = 0.09$$

Step 3: Evaluate the risk control solution and make the optimal selection.

Let S represent the degree to which the control plan meets each key indicator. S is determined by the enterprise decision-makers scoring the plan on its satisfaction with each evaluation indicator. A value between 0 and 5 is used to represent the degree of satisfaction with the indicators. The higher the value, the higher the degree of satisfaction, and the more effective the plan is considered.

Table 12. Solution Scoring Table

Evaluation Indicators / Proposed Solution	F1 (0.36)	F2 (0.20)	F3 (0.20)	F4 (0.15)	F5 (0.09)
R1	4	5	2	3	4
R2	3	3	4	4	4
R3	4	2	3	5	3

Calculate the weighted score of each solution based on the scoring results:

$$RSi = \sum_{i=1}^{n} Sij \times Mi \tag{6}$$

RS_1=4*0.36+5*0.20+2*0.20+3*0.15+4*0.09=3.65

RS_2=3*0.36+3*0.20+4*0.20+4*0.15+4*0.09=3.44

RS_3=4*0.36+2*0.20+3*0.20+5*0.15+3*0.09=3.46

Obviously, S(R_1> S(R_3)>S(R_2), therefore, plan R_1can be judged as the optimal plan.

4. Conclusion

With the continuous development and progress of society, enterprise production processes are becoming increasingly complex, and more risks may arise in various aspects during the production process. In order to avoid safety accidents during the production process, increase unnecessary production costs, and achieve the enterprise's expected output value indicators, enterprises must pay full attention to the risk factors lurking everywhere in the production site and actively promote the construction of the enterprise's internal risk control management system.

(1) In order to cope with the interference of many uncertain factors in the production process, this paper proposes a control scheme evaluation method based on fuzzy comprehensive evaluation method and weighted scoring method. This method can scientifically and effectively quantify uncertain and fuzzy information, compare relevant risks through judgment matrix, and then use the weights of relevant factors to comprehensively analyze and obtain the most effective control scheme.

(2) In order to verify the feasibility of the proposed method, this paper applies it to the actual situation of the production process of Company A and conducts a series of studies. The study concluded that the most significant factors affecting safe production at Company A are equipment risk and personnel risk. It can be reasonably inferred that human-machine collaborative production activities are the primary scenario for safety accidents at Company A. Therefore, controlling these risks must focus on improving human-machine coordination and raising personnel safety awareness and operational skills. Only in this way can these risks be mitigated at their source while simultaneously improving personnel competence, thus ensuring more efficient development for the company.

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