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Integrated Weighting Analysis for Operational Risk Assessment Indicators in HS Chemical Company

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Abstract: Growing regulatory demands for industrial safety and environmental protection in the chemical sector necessitate robust operational risk assessment to enhance management efficacy. Here, the HS Chemical Company is evaluated through a multidimensional framework encompassing market dynamics, macroeconomic factors, financial stability, governance, supply chains, and production safety. By integrating the Analytic Hierarchy Process (AHP) with entropy weighting, a hybrid weighting model that mitigates the limitations of singular methods is established. The analysis of this study identifies financial risk (weight: 0.347) and production safety (weight: 0.298) as dominant risk drivers. These quantitative insights offer a basis for resource prioritization and targeted risk mitigation strategies in chemical enterprises.

Keywords: Chemical enterprises; Operational risk; Analytic hierarchy process (AHP); Entropy weighting method; Weighting analysis

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1. Introduction

The chemical industry serves as a critical pillar of the national economy, with its products essential to agriculture, industry, defense, and technological advancement. As a key player in chemical production and R&D, this sector remains indispensable for economic development.

HS Chemical Company, with over three decades of operation, specializes in four core segments: basic chemicals, fertilizers, advanced chemical materials, and new energy materials. The planned commissioning of new production facilities in 2024 is projected to drive sustained sales growth, with revenues expected to rise steadily in subsequent years. This expansion underscores the necessity for systematic operational risk assessment.

To address this need, a comprehensive risk evaluation index system is established, integrating the Analytic Hierarchy Process (AHP) and entropy weighting method. This hybrid approach enables scientifically robust risk identification, minimizing potential losses through data-driven decision-making.

The development of risk assessment frameworks for the chemical industry has been extensively investigated in academic research. Zhao established a tri-scale indicator system encompassing risk source strength, receptor vulnerability, and risk prevention capability [1]. Wang developed a universal hierarchical indicator system to identify risks arising from intrinsic process safety, operational management, as well as chemical storage and transportation [2]. Ding proposes an integrated risk assessment approach combining three key indicators: (1) loss of containment (LOC) potential at chemical facilities, (2) secondary fire incident probability, and (3) inter-unit proximity within chemical installations [3]. Aggregate risk scores were correlated with tank inventory availability to develop inventory management-based risk mitigation strategies for chemical loading operations.

Diverse methodological approaches have emerged in chemical industry risk assessment research. Yan developed a novel risk computation framework termed Risk Mesh (RM), enabling three-dimensional risk evaluation through field-theory-based modeling [4]. Concurrently, Gan established a modified cross-sectional risk assessment methodology for post-disaster scenarios, comprising five key components: (1) geolocation mapping of chemical facilities, (2) identification of flood-compromised or at-risk plants, (3) analysis of chemical hazard typology and frequency distributions, (4) population exposure assessment, and (5) spatial visualization of composite risk indicators [5]. Qi combined the bow tie model, the three-dimensional risk matrix and the Analysis Network Process (ANP) to construct a semi-quantitative comprehensive risk assessment model for fires in hazardous chemical laboratories [6]. Guo developed a multi-task learning framework, termed Robust Progressive Layer-wise Extraction (RPLE), for systematic prediction of accident risk categories, likelihood probabilities, and severity levels [7]. In parallel, He introduced a dynamic, multi-hazard assessment approach for generating chemical accident evacuation strategies [8]. This methodology employs cumulative individual risk as the primary optimization metric while dynamically accounting for multi-hazard characteristics and domino effects during evacuation scenarios.

2. Methods

Risk is formally defined as uncertainty associated with potential loss, characterized by two intrinsic properties: (1) its objective existence as a measurable phenomenon, and (2) uncertainty as its fundamental nature. Operationally, risk quantifies the impact of uncertainty on objectives, conventionally expressed through the composite function:

$$R = P \times C$$

where R denotes risk magnitude, P represents event probability ($0 \leq P \leq 1$), and C indicates consequence severity. This formulation reflects a non-linear integration of likelihood and impact rather than simple arithmetic multiplication.

To achieve scientifically robust weight determination for operational risk indicators in HS Chemical Company, a hybrid weighting model integrating the Analytic Hierarchy Process (AHP) with entropy weighting is established. This dual approach mitigates inherent biases of singular weighting methods through cross-validation, preserves expert judgment via AHP's pairwise comparison matrices, while leveraging entropy-based objective optimization from empirical data distributions.

2.1. Analytic hierarchy process

The Analytic Hierarchy Process (AHP), developed by operations researcher Thomas L. Saaty in the 1970s, provides a systematic framework for quantifying qualitative decision-making in complex systems. This method decomposes problems into hierarchical structures (**Figure 1**), determines relative weights through pairwise comparison matrices, and synthesizes results for comprehensive evaluation.

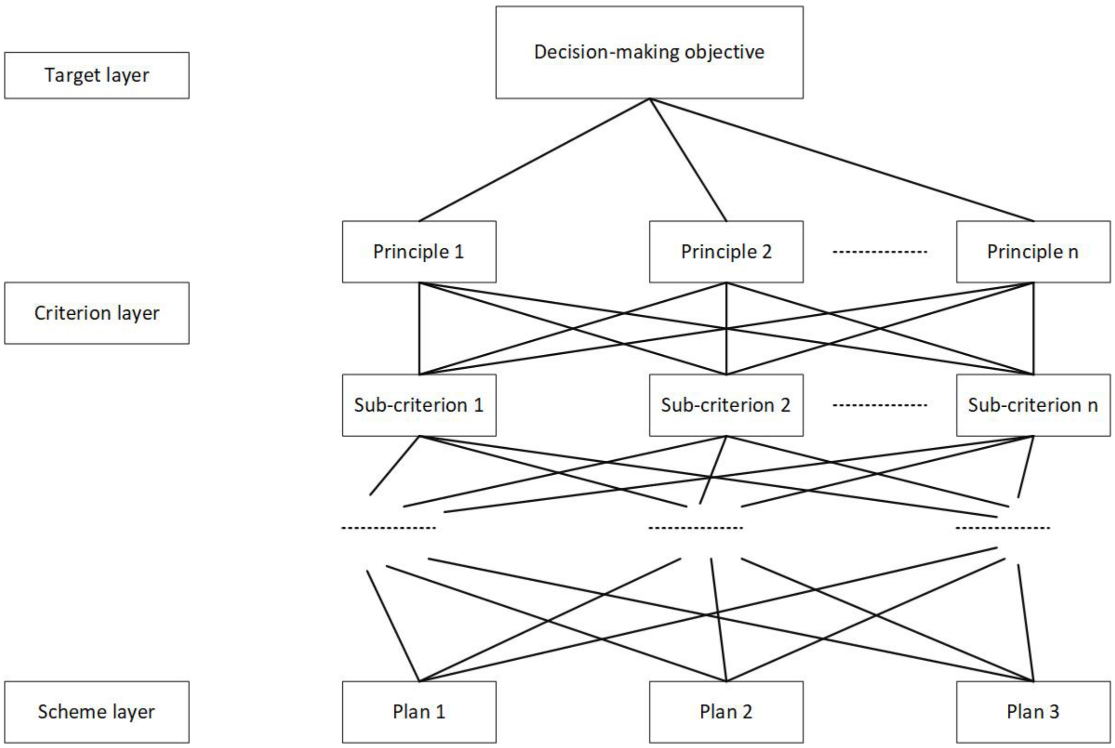

Figure 1. Hierarchical structure diagram

2.1.1. The calculation process of the Analytic Hierarchy Process

(1) The judgment matrix A was normalized to generate matrix D, followed by row-wise summation:

$$D_{ij} = \frac{r_{ij}}{\sum_{i=1}^{m} r_{ij}} \tag{1}$$

$$f_{ij} = \sum_{j=1}^{m} D_{ij} \tag{2}$$

(2) The vector F = ($f_1, f_2, f_3, \ldots f_n$) of matrix D was normalized to derive both the evaluation index weights W_i and the principal eigenvector W.

$$W_i^1 = f_i \sum_{j=1}^{m} f_j \tag{3}$$

$$W = \begin{bmatrix} W_1 \\ W_2 \\ \vdots \\ W_n \end{bmatrix} \tag{4}$$

(3) Calculate the principal eigenvalue λ_{max}

$$\lambda_{max} = \frac{1}{m} \sum_{i=1}^{m} \frac{(AW^1)i}{W^1} \tag{5}$$

(4) Consistency verification

Compute the consistency index CI.

$$CI = \frac{\lambda_{max} - m}{m - 1} \tag{6}$$

2.2. Entropy value method

2.2.1. Entropy weighting methodology

The entropy method is an objective weighting approach that determines indicator weights based on their variation degrees through information entropy theory. This technique applies subsequent weighting to yield more impartial evaluation outcomes.

2.2.2. Theoretical foundation

Information entropy, a core concept in information theory, quantifies data uncertainty. Key properties include:

(1) High entropy: Indicates greater disorder and lower information utility

(2) Low entropy: Reflects ordered patterns and higher informational value

2.2.3. Weighting principle

The method operates on the premise that: Indicators with smaller entropy demonstrate larger value fluctuations, containing more discriminative information. The calculation process of the entropy method are as follows:

(1) The index data is standardized. This paper studies the risk assessment related to enterprises. Therefore, all the indicators are negatively correlated indicators, that is, the smaller the risk level, the more beneficial it is.

$$x_{ij}^{'} = \frac{max(x_j) - x_{ij}}{max(x_j) - min(x_j)} \tag{7}$$

(2) Calculate the proportion of each indicator in each sample

$$P_{ij} == \frac{x_{ij}^{'}}{\sum_{i=1}^{n} x_{ij}^{'}} \tag{8}$$

(3) Determine the entropy values of each evaluation index

$$E_j = -k \sum_{j=1}^{n} q_{ij} \ln q_{ij} \tag{9}$$

$k = \frac{1}{\ln n}$ and $k > 0$

(4) Calculate the weights of the indicators

$$W_j = \frac{1 - e_j}{\sum_{j=1}^{m} 1 - e_j} \tag{10}$$

3. Hybrid AHP-Entropy Weighting Model

3.1. Determination of evaluation indicators

The construction of the risk assessment index system follows the principles of comprehensiveness, systematic operation, science, and rationality. Qualitative analysis is combined with quantitative analysis, combined with reality, and adapted to local conditions. Through the observation of the company by experts and literature research, the risk indicators existing in the operation were collected and sorted out, and experts were invited to discuss the selected first-level risk indicators. Finally, six first-level indicators, namely market risk, macro-environmental risk, financial risk, management risk, supply chain risk, and work safety risk, and 21 second-level indicators were determined, as shown in **Table 1**.

Table 1. Index system of risks

Criterion layer	Symbol	Indicator layer	Symbol
Market risk	U_1	Market competition risk	U_{11}
		Market demand risk	U_{12}
		Market sales risk	U_{13}
Macro environmental risk	U_2	Policy and legal risks	U_{21}
		Environmental protection risk	U_{22}
		Risk of public emergencies	U_{23}
Financial risk	U_3	Debt risk	U_{31}
		Risk of capital flow	U_{32}
		Raw material price risk	U_{33}
		Profit risk	U_{34}
		Investment risk	U_{35}
Manage risks	U_4	Talent risk	U_{41}
		Internal control risk	U_{42}
		Decision-making risk	U_{43}
Supply chain risk	U	Risk of supply disruption	U_{51}
		Procurement quality risk	U_{52}
		Inventory management risk	U_{53}
		Risk of supply timeliness	U_{54}
Production safety risks	U_6	Risk of natural disasters	U_{61}
		Fire safety risk	U_{62}
		Operational risk	U_{63}

3.2. The Analytic Hierarchy Process (AHP) determines the subjective weights

The importance of each indicator was scored by distributing questionnaires online to 20 experts. The first-level indicator (criterion layer) was scored as a whole first, and then the second-level indicator (indicator layer) was scored. Based on the above calculations, the set of weight values of the operation risk indicators of HS Chemical Company based on the AHP method can be sorted out, as shown in **Table 2**.

Table 2. Weights of the analytic hierarchy process

First-level indicator	Weight	Secondary indicators	Weight
Market risk	0.128	Market competition risk	0.637
		Market demand risk	0.105
		Market sales risk	0.258
Macro environmental risk	0.068	Policy and legal risks	0.258
		Environmental protection risk	0.108
		Risk of public emergencies	0.637
Financial risk	0.488	Debt risk Risk of capital flow	0.501 0.246
		Raw material price risk	0.129
		Profit risk	0.070
		Investment risk	0.054
Manage risks	0.022	Talent risk	0.108
		Internal control risk	0.258
		Decision-making risk	0.637
Supply chain risk	0.038	Risk of supply disruption	0.545
		Procurement quality risk	0.233
		Inventory management risk	0.084
		Risk of supply timeliness	0.139
Production safety risks	0.256	Risk of natural disasters	0.105
		Fire safety risk	0.258
		Operational risk	0.637

3.3. The entropy weight method determines the objective weights

The importance of each indicator was scored by distributing questionnaires online to 20 experts. The first-level indicator (criterion layer) was scored as a whole first, and then the second-level indicator (indicator layer) was scored. Finally, the objective weights of the indicators are determined to establish the evaluation set of the evaluated targets, as shown in **Table 3**.

Table 3. Weights of the entropy weight method

First-level indicator	Weight	Secondary indicators	Weight
Market risk	0.172	Market competition risk	0.406
		Market demand risk	0.183
		Market sales risk	0.411
Macro environmental risk	0.159	Policy and legal risks	0.262
		Environmental protection risk	0.439
		Risk of public emergencies	0.299

Table 3 (Continued)

First-level indicator	Weight	Secondary indicators	Weight
Financial risk	0.234	Debt risk	0.221
		Risk of capital flow	0.377
		Raw material price risk	0.134
		Profit risk	0.113
		Investment risk	0.154
Manage risks	0.103	Talent risk	0.305
		Internal control risk	0.255
		Decision-making risk	0.440
Supply chain risk	0.104	Risk of supply disruption	0.276
		Procurement quality risk	0.359
		Inventory management risk	0.188
		Risk of supply timeliness	0.176
Production safety risks	0.228	Risk of natural disasters	0.400
		Fire safety risk	0.182
		Operational risk	0.418

3.4. Determine the final comprehensive weight

When determining the weights of the operational risk indicators of HS Chemical Company, the Analytic Hierarchy Process (AHP) and the entropy weight method were respectively adopted to obtain the subjective weights and objective weights of the risk indicators. The comprehensive weights obtained then not only conform to the actual situation of the company, but also are more accurate and intuitive. The formula for combining the weights using the combined weighting method is as follows: $\omega = \frac{A_i \times B_i}{\sum_{i=1}^{n} A_i \times B_i}$. Finally, the comprehensive weights of risk factors within each criterion layer are obtained. The results are shown in **Table 4**.

Table 4. Comprehensive weights

First-level indicator	Weight	Secondary indicators	Weight
Market risk	0.128	Market competition risk	0.674
		Market demand risk	0.050
		Market sales risk	0.276
Macro environmental risk	0.106	Policy and legal risks	0.221
		Environmental protection risk	0.155
		Risk of public emergencies	0.624
Financial risk	0.347	Debt risk	0.467
		Risk of capital flow	0.391
		Raw material price risk	0.073
		Profit risk	0.033
		Investment risk	0.035

Table 4 (Continued)

First-level indicator	Weight	Secondary indicators	Weight
Manage risks	0.057	Talent risk	0.087
		Internal control risk	0.174
		Decision-making risk	0.740
Supply chain risk	0.065	Risk of supply disruption	0.548
		Procurement quality risk	0.305
		Inventory management risk	0.058
		Risk of supply timeliness	0.089
Production safety risks	0.298	Risk of natural disasters	0.118
		Fire safety risk	0.132
		Operational risk	0.750

4. Conclusion

Based on the calculations described above, the ranking of the six risk factors in the operations of HS Chemical Company is as follows: financial risk > production safety risk > market risk > macro-environmental risk > supply chain risk > management risk. The results indicate that production safety risk and financial risk have a relatively greater impact on the company's operations. The production processes of chemical enterprises involve various hazardous chemicals and complex procedures. In the event of safety accidents such as explosions or leaks, substantial direct economic losses can occur. Financial risk is an inescapable factor for every manufacturing enterprise. Chemical enterprises often undertake large-scale, long-term investment projects. Mistakes in investment decisions may lead to the idling or loss of significant amounts of corporate funds. Moreover, the prices of chemical products are highly influenced by market supply and demand relationships and fluctuations in raw material prices. If a company fails to accurately predict market changes and formulate reasonable pricing strategies, it may result in product overstocking or reduced profits. Although the other risks have lower scores, their impact on corporate operations should not be overlooked. Poor management, supply disruptions, and policy changes can all directly or indirectly affect the development of the enterprise.

Disclosure statement

The author declares no conflict of interest.

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