Research on Coal Mine Safety Risk Identification and Governance Strategies Based on Accident Statistics and Expert Interviews

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Abstract. Coal, serving as the "stabilizer" for China's energy security, continues to face severe challenges in production safety, with a fatality rate per million tons remaining high compared to developed countries. To effectively curb coal mine accidents, this study systematically analyzes typical accident cases from 2023 to 2025, innovatively combining text mining technology with expert interviews to identify key safety risk factors across four dimensions: regulatory oversight, personnel management, equipment environment, and operational management. Addressing identified risk pain points, the study proposes a multi-dimensional comprehensive governance strategy: First, establishing an "Internet+" third-party participation model for supervision to resolve issues of incomplete regulatory systems and superficial compliance; Second, strengthening lifecycle management of personnel through innovative training programs and stringent reward-punishment mechanisms to curb violations of work safety regulations; Third, enhancing equipment infrastructure and environmental governance by implementing a full lifecycle management system with adequate safety investments; Fourth, improving emergency management systems to boost accident response efficiency. The research aims to provide theoretical support and practical pathways for enhancing intrinsic safety standards in China's coal mining industry through coordinated efforts in technological prevention, human prevention, and managerial prevention.

Keywords: Coal mine safety; Risk identification; Text mining; Expert interviews; Safety management.

1 Introduction Globally

1.1 Research Background

Coal mining remains a dangerous profession. Given the unique distribution of energy resources in China, coal is bound to become the core support of China's energy system [1]. Coal has made profound and lasting contributions to China's energy history. As the nation undergoes energy transformation, coal remains indispensable for providing basic energy guarantees. [2]. Coal serves as a ballast for China's energy

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security, with a wide variety of coal-associated resources, widespread distribution, abundant reserves, and high utilization value. However, according to incomplete statistics from public sources, including the Ministry of Emergency Management, national and provincial mine safety supervision bureaus, the Coal Mine Safety Network (and its official account), and major news reports, from 2021 to 2023, there were 349 accidents in China's coal mines, resulting in a total of 687 deaths [3]. The safety production situation of China's coal mines shows a fluctuating improvement trend of "some decreases and some increases". China's death rate per million tons still ranks high compared to other countries in the world. Taking 2022 as an example, China's death rate per million tons was 0.054, while the United States' was 0.022, and many developed countries such as Germany, Australia, and Canada had a death rate of zero [4].Therefore, conducting in-depth analysis of the root causes of coal mine accidents and establishing a scientific and precise risk prevention and control system have become urgent requirements for promoting high-quality development in the coal industry and strengthening national energy security defenses.

1.2 Research Meaning

Coal mine safety management is an important cornerstone of national energy security. As the main energy source in China's energy system, coal plays an irreplaceable strategic role in ensuring energy supply and maintaining energy security. Therefore, strengthening coal mine safety management to ensure stable coal supply is of vital significance for maintaining the smooth operation of the national economy and the overall harmony and stability of society. Therefore, coal mine safety management is vital. It determines not only the survival of enterprises but also the sustainable development of the industry, national energy security, and social stability. Its importance is self-evident.

2 Identification of Safety Risk Factors in Coal Mines at Present

Coal mine safety risk identification serves as the cornerstone of risk assessment and prevention efforts, playing a pivotal role in accident prevention. Effectively identifying safety risk factors and systematically mapping potential hazards in production processes are essential prerequisites for analyzing root causes and developing targeted countermeasures. Scholars have conducted extensive research on risk factor identification, primarily employing empirical, model-based, and data-driven approaches to evaluate coal mine safety risks.

The technical roadmap for identifying coal mine safety risk factors in this study is illustrated in Figure 1, which integrates text mining and expert interviews to achieve more accurate results. As a core discipline in natural language processing, text mining has been widely applied in accident analysis across multiple industries [5], enabling automated analysis of unstructured data such as accident reports and extraction of implicit knowledge from massive document repositories. By converting texts into

structured representations through algorithms, key terms can be systematically extracted and risk correlation patterns identified, revealing underlying patterns in safety risks. This methodology has been extensively implemented in accident analysis sectors including petroleum [6], transportation [7], railways [8], and healthcare [9], effectively addressing limitations of traditional approaches and providing technical support for discovering latent risk patterns from large-scale datasets. Furthermore, combining expert interviews allows direct acquisition of industry context, insider insights, and trend analysis, compensating for the limitations of purely data-driven methods. The complementary approach not only enhances the comprehensiveness and depth of results but also significantly improves the persuasiveness and industry applicability of risk identification conclusions, laying a solid foundation for developing targeted prevention measures.

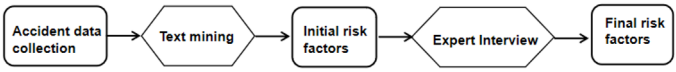

Fig. 1. Technical Roadmap

This study systematically analyzes coal mine accidents nationwide from 2023 to 2025 to establish a comprehensive safety risk factor inventory. The research comprehensively collects official reports, investigation documents, and case studies covering major accident types, including gas explosions, roof collapses, and water inrush incidents. The text mining process involves three key stages: First, Preprocessing, where raw accident reports are cleaned to remove stop words and punctuation, utilizing Jieba for word segmentation; Second, Algorithm & Extraction, where Latent Dirichlet Allocation (LDA) is employed to identify latent topics, combined with Term frequency-inverse document frequency (TF-IDF) to extract high-weight keywords (e.g., "gas explosion," "roof fall") from the unstructured text; Third, Coding, where two researchers independently code the extracted terms, with disagreements resolved through discussion to ensure inter-coder reliability. Through this case-by-case coding and content analysis of 68 valid samples, key risk elements such as direct causes, indirect causes, and management deficiencies were identified. To enhance accuracy, insights from interviews with 10 experts—selected via purposive sampling based on (a) a minimum of 10 years of experience in coal mine safety and (b) holding senior professional titles or managerial positions—are incorporated. During the Validation Process, a semi-structured interview guide is used, and experts are asked to rate the importance of the identified risk factors on a 5-point Likert scale. Factors with a consensus score below 3.5 are discarded. This protocol validates critical causative factors and identifies vulnerable areas. After cross-referencing statistical data with expert feedback and eliminating redundant variables, a consensus-based coal mine safety risk framework is developed (Table 1). This framework encompasses four dimensions: regulatory oversight, personnel management, equipment/environmental condi-

tions, and operational practices, providing a scientific foundation for subsequent risk prevention strategies.

Table 1. Coal Mine Safety Risk Checklist

Primary risk factors	Secondary risk factors	
Supervision Risk Factor (SRF)	1. Imperfect safety supervision system	2. Perfunctory supervision and inspection
	3. Lax approval and inspection of technical measures	4. Insufficient supervision on hidden danger investigation and rectification
	5. Inadequate implementation of acceptance standards for resumption of production	6. Insufficient professional competence of supervision personnel
Personnel Risk Factor (PRF)	1. Illegal command and operation	2. Weak ability to identify safety risks
	3. Inadequate safety education and training	4. Insufficient emergency response skills
Equipment & Environment Risk Factor (EERF)	1. Incomplete configuration of safety protection facilities	2. Unstable operation of monitoring and control system
	3. Substandard safety conditions of the operating environment	4. Equipment overservice or overloaded operation
	5. Inadequate equipment maintenance	6. Complex geological structure and insufficient detection
Management Risk Factor (MRF)	1. Imperfect work safety responsibility system	2. Insufficient guarantee for safety investment
	3. Ineffective implementation of safety management systems	4. Non-implementation of risk classification control measures
	5. Imperfect emergency management system	6. Illegal organization of production and operation

3 Safety Management Countermeasures for Coal Mines

3.1 Innovating Regulatory Models to Strengthen "Internet +" Third-Party Collaboration

To address regulatory inadequacies, superficial inspections, and competence gaps, we must innovate oversight via an "Internet+" third-party participation model grounded in multi-stakeholder game theory [10]. The proposed "Internet+" model directly addresses the "Imperfect safety supervision system" (SRF-1) and "Perfunctory supervision" (SRF-2) identified in our analysis (Table 1). By introducing third-party oversight, the model reduces the reliance on internal regulatory inspections, thereby mitigating the risk of oversight gaps. The game theory equilibrium ensures that the cost of non-compliance for enterprises exceeds the cost of safety investment, which is a di-

rect response to the "Illegal organization of production" (MRF-6) factor found prevalent in 23% of our case samples.

3.2 Strengthen Personnel Management to Consolidate the Foundation of Safety

To mitigate personnel risks, safety education must be innovated to ensure full participation and mandatory certification for key roles, enhancing awareness and skills. Strict enforcement is crucial: implement violation point systems and a "one-vote veto" mechanism, maintaining zero tolerance for command and operational breaches. Optimizing recruitment, elimination, and incentive frameworks will address competency disparities and foster self-discipline, preventing unsafe behaviors at the source. Furthermore, strengthening competency management through innovative training improves risk identification and emergency response. Rigorous crackdowns on the "three violations," mandatory personal protective equipment usage, and point-based evaluations with elimination mechanisms are essential to counter weak accountability. This comprehensive personnel management framework ensures practical implementation of control measures, laying a solid talent foundation for safe coal mine production.

3.3 Strengthen Equipment Foundation and Optimize Working Environment

To address equipment and environmental risks, adopt an "equipment-centric" philosophy with increased safety investments and a comprehensive lifecycle management system. Enforce rigorous maintenance to eliminate hazards, prevent using outdated equipment, and ensure stable monitoring. Enhance geological exploration and environmental remediation to improve working conditions. Prioritize talent development to strengthen operation and emergency capabilities. Implement a dual safeguard of technical prevention and human vigilance. Crucially, establish financial oversight for protective facilities, strictly prohibit operating faulty or expired equipment, and continuously upgrade hardware environments. This approach eliminates risks at the source, providing solid material support for safe production.

3.4 Improve the Emergency Response System and Enhance Crisis Management Capabilities

Adhering to "prevention first," we establish a comprehensive emergency management system. Scientifically developed plans, integrating expert insights and frontline experience, ensure practical applicability. We strengthen infrastructure by allocating adequate rescue equipment and cultivating professional teams. Regular live drills enhance multi-stakeholder coordination, enabling rapid, efficient collaboration. The proposed closed-loop emergency system targets the "Inadequate emergency response skills" (PRF-3) and "Imperfect emergency management system" (MRF-5) factors. By integrating expert insights on drill frequency (validated in interviews), the model aims

to reduce the average emergency response time. This is expected to mitigate the severity of accidents, particularly for high-frequency events like gas explosions identified in our dataset.

4 Conclusion and Prospects

Through integrating text mining and expert interviews, this study systematically developed a coal mine safety risk identification framework encompassing regulatory oversight, personnel management, equipment maintenance, and operational governance. Addressing identified critical challenges, comprehensive strategies were proposed including "Internet+" third-party collaborative governance, end-to-end personnel lifecycle management, enhanced intrinsic safety of equipment, and optimized emergency response systems. By integrating technical safeguards, human factor controls, and managerial interventions, the study establishes a multi-stakeholder collaborative governance model to mitigate accident risks and ensure coal mine safety.

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