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Research on the Correlation of Safety Risk of Railway Bridge Construction Based on Meta-Analysis

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Abstract: China has emerged as a prominent global player in the field of railways, with numerous railway construction projects spanning across diverse locations. Railway bridges, as a crucial component of railway construction, warrant significant attention. Meta-analysis, a statistical method that systematically synthesizes research findings, has been utilized to summarize and compare the results of safety risk management studies pertaining to railway bridge construction in China. By integrating social network analysis and evidence-based assessment of the literature, this study explores the interrelationships among risk factors. Within a specific railway bridge construction project, various safety risk factors may originate from common sources, including environmental factors, material and equipment factors, technical factors, management factors, personnel factors, and bridge-specific factors. Notably, there exists coupling among these security risk factors, whereby the presence or occurrence of one factor can influence the probability or severity of consequences associated with other factors. The results reveal that safety risk factors in railway bridge construction accumulate and propagate, thereby impacting the efficacy of safety risk management. Moreover, these factors are significantly influenced by the complexities inherent in the geo-meteorological and social-technical systems. This finding provides valuable insights for innovations in security risk management practices and offers suggestions for future innovation pathways.

Keywords: railway bridge construction; safety risk; risk correlation; management path innovation

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1. Introduction

One evening in late 2001, a worker was carrying out construction activities on a pier situated in the middle of the Yangtze River. Alongside 26 other workers, he skillfully tied up the steel sheeting. Suddenly, strong winds swept across the river, resulting in the collapse of the bridge pier's steel bars, posing an immediate threat to the lives of all 14 construction workers present. Despite prompt action from the police, who swiftly organized water transport boats and speedboats for an active rescue operation, the incident claimed the lives of two workers, while the remaining individuals were promptly transported to the hospital. The following morning, construction activities on the affected pier were halted, and local law enforcement established a cordon along the river. This incident occurred at the Longxu railway bridge in Luzhou, which happens to be the first railway bridge in China spanning the Yangtze River. In the 21st century, dozens of safety accidents have occurred in the construction of railway bridges in China, resulting in many casualties. It is important to acknowledge that globally, it is impossible to completely eliminate the accident rate during the construction of railway bridges, and the focus should be on minimizing safety risks to the greatest extent possible. This is due to the interconnected and cumulative nature of risks, which gradually accumulate throughout various stages of construction, thereby increasing the overall probability of safety risks and resulting in a compounded effect. Such risks can also lead to secondary hazards, such as an increased risk of falling from heights due to adverse weather conditions or geological disasters caused by machinery failure, heavy objects falling, and injuries to personnel. The characteristics of the water magnified the risk of high-altitude operations, leading to this serious accident.

The identification of safety risk factors during railway bridge construction is a critical concern in railway construction. However, there is limited scientific research exploring the interrelationships among these risk factors and examining their pathways within the project system perspective.

2. Literature Review

In the 1980s, several large- and medium-sized enterprises in China began incorporating safety system engineering into their management departments and implementing various risk management methods. These methods included fuzzy analytic hierarchy process, Monte Carlo simulation, and grey theory, which were utilized to address risk identification and yielded some positive outcomes [1]. However, most of the studies focused on developing a project complexity framework based on a single variable dimension of the risk source. They aimed to assess the safety risk of large-scale construction projects [2] or conducted in-depth investigations into the characteristics of railway bridge safety risk management from a single case perspective [3]. Consequently, these studies identified safety risks in the railway bridge construction process based on individual risk sources or engineering cases, without elucidating the interaction mechanisms among safety risk factors. To address this gap, this paper explores the innovation of the security risk management approach from a systemic perspective, discussing the interaction mechanisms of safety risk factors. In recent years, technological advancements, including the Internet of Things, big data analysis, and artificial intelligence, have been increasingly implemented in traditional industry production safety risk management [4]. These technologies enable timely monitoring and prediction of potential safety risks, facilitating the implementation of appropriate intervention and management measures to minimize the occurrence of accidents.

Meta-analysis is a quantitative and comprehensive method used in conducting literature research. It enables the objective analysis of research findings from similar studies, reducing inconsistencies in conclusions and mitigating the impact of negative results. By overcoming the limitations of small individual samples, it enhances the accuracy of the literature research, providing a more comprehensive and reliable analysis. Through the utilization of meta-analysis, Marvier analyzes the findings of risk identification and summarizes various types of risks [5]. The paper introduces the risk matrix for quantitative evaluation into a meta-network analysis tool. From a network perspective, Messori examines the impact of risks on project objectives, the relationships between risks, and the influence of risk factors on risks [6]. Additionally, Marchetti qualitatively analyzes the impact of risk factors on the historical literature in order to identify key risk factors [7]. Furthermore, Noar employs risk data to construct an early warning model [8]. The use of the meta-analysis method facilitates the rational utilization of published literature data from multiple researchers. This enables the identification of major risks from a broader perspective and provides a theoretical foundation for safety risk management.

This paper conducts a meta-analysis of safety risk factors during the construction stage of railway bridges in China since the 21st century, utilizing various sources such as literature databases, case databases, official website data, and news reports. By integrating the intricate relationship between cases and safety risk factors from diverse perspectives, it explores the correlation of safety risks in railway bridge construction. Furthermore, it delves into theoretical advancements in the field of safety risk management and investigates the innovation path paradigm in traditional industries. This research holds reference value and practical significance for enhancing safety risk management capabilities in the production construction of the railway industry and other traditional industries.

3. Construction of Meta-Analysis Model

3.1. Search Strategy

To comprehensively identify the factors that influence railway bridge risk based on existing literature in China and ensure the integrity of data collection, a thorough search was conducted encompassing published Chinese journal articles, as well as master's and doctoral theses. This search involved exploring titles, keywords, and subject categories. The China National Knowledge Infrastructure was utilized as the retrieval database. The key search terms included railway bridge, construction risk, risk identification, risk management, risk, and their combinations. A total of 1244 Chinese articles were retrieved through this process.

3.2. Inclusion Criteria

To comprehensively identify the factors that influence the risk associated with railway bridges, an extensive search of the existing literature in China was conducted, ensuring the integrity of data collection. This search encompassed published Chinese journal articles as well as master's and doctoral theses, utilizing title, keyword, and subject searches. The China Knowledge Network database was employed for retrieval purposes. The key search terms included "railway bridge", "construction risk", "risk identification", "risk management", and their combinations. As a result, a total of 1244 Chinese articles were retrieved.

Subsequently, specific inclusion criteria were developed for the literature. Firstly, papers without a clearly defined object of study were excluded. Secondly, articles that solely provided qualitative analysis of railway bridge risk factors or presented incomplete examples without proper discussion were eliminated. Thirdly, the selected papers were required to explicitly describe the security risk factors relevant to this study or possess characteristics that could be transformed into security risk factors through analysis. Additionally, these papers needed to have a clear identification process; otherwise, they were rejected. Fourthly, literature with arbitrary risk classifications or vague definitions of risk factors was excluded.

Following this set of criteria, the full texts of the remaining articles were carefully reviewed. Ultimately, a total of 21 articles were determined to be suitable for inclusion in this research. These comprised six journal papers and 15 Master's theses, as depicted in Figure 1.

3.3. Identification Profile

In the process of risk identification, risk factors are typically classified based on their source. Each category of security risk factors consists of multiple sub-factors, referred to as primary security risk factors and secondary security risk factors.

By analyzing the data from 39 research samples, along with information from the literature and case surveys, the identified safety risk factors were summarized. Furthermore, the first-level security risk factors were analyzed, screened, and clustered based on 21 articles that provided their definitions. As a result, ten categories of first-level security risk factors were identified and are presented in Appendix A.

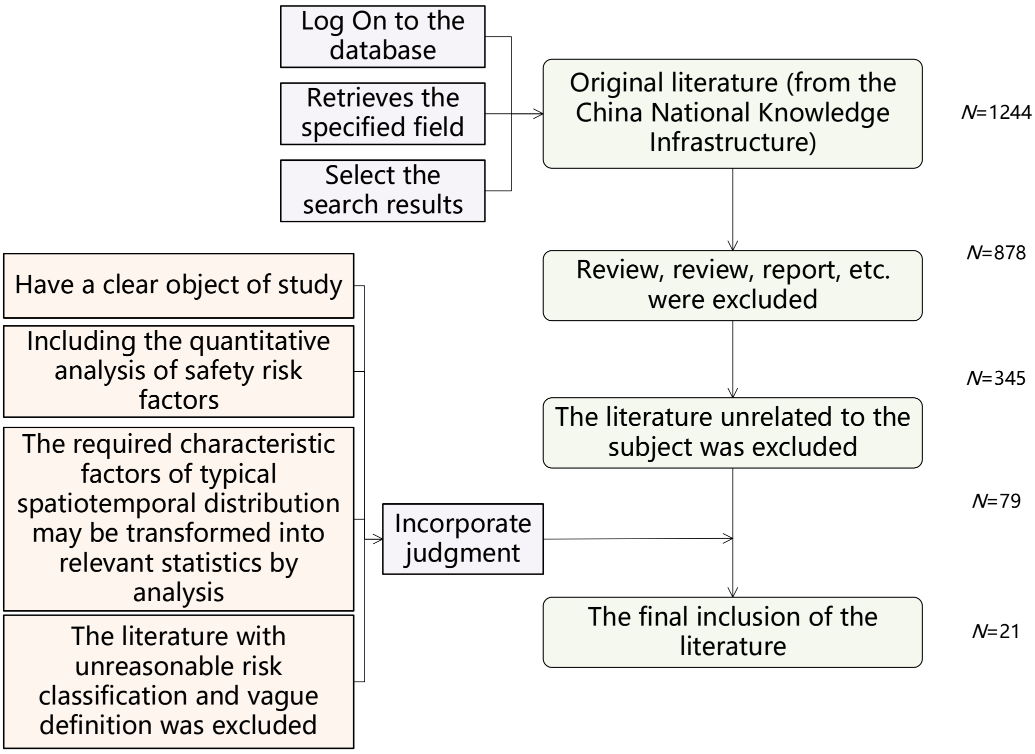

Figure 1. Data acquisition process.

To gain a better understanding of the common factors, the correlation between secondary and primary security risk factors was examined. The analysis revealed three distinct characteristics of second-level safety risk factors, which enable a more comprehensive evaluation of risk harm, potential, and the implementation of effective prevention and control measures. This, in turn, optimizes and enhances security risk management strategies, thereby improving the maturity and effectiveness of security risk management.

1. Diverse classification angles: Unlike primary security risk factors, which are generally classified based on the source of the risk, secondary security risk factors offer a more detailed and refined perspective. They are not solely categorized based on the source of the risk factors; instead, risks can be classified as functional, non-functional, or compliance-related, depending on the construction process or the nature of the risks.
2. Specific features: Secondary security risk factors encompass a broader range of specific risk factors. This precise characterization enables a more accurate description and definition of risks, facilitates the identification and assessment of their potential impacts, and even allows for the quantification of the probability of occurrence and the consequences of these risk factors.
3. Operational risk prevention and control: The specific and clear characteristics of secondary security risk factors facilitate the identification of potential risk points. This, in turn, enables the tailoring of risk management control objectives and monitoring indicators. It also allows for the monitoring and evaluation of the implementation of risk control measures, providing valuable lessons learned and feedback. This mechanism supports continuous improvement and learning in risk control practices.

4. Results

4.1. Frequency-Based Risk Grouping

The first-level security risk factors identified in the literature were clustered, excluding those with a frequency of 1, which were either classified as “Other” or excluded altogether. A total of 10 categories of Level 1 safety risk factors were screened, including environment, materials and equipment, technology, management, personnel, project itself, design, politics, other, and sub-projects. The results are presented in Table 1. The literature selected for analysis consisted of Chinese core and above journals, dissertations or research papers from "Double first-rate" disciplines or universities, and highly relevant sources. Only the literature that provided a clear definition or description of risk factors was considered, adhering to strict standards of frequency. As a result, six safety risk factors—environment, material equipment, technology, management, personnel, and project itself—were identified as occurring more than five times.

Box plots were employed to analyze the frequency of occurrence of secondary security risk factors across different categories. These plots depict the central location and dispersion extent of one or more groups of continuous quantitative data distributions, shedding light on data dispersion, outliers, and distribution differences. Figure 2 illustrates the low fluctuation in data for each security risk factor. Due to the limited sample size, individual data points may magnify the entire box, as depicted in the graph. However, this allows for a better identification of potential security risks and facilitates the analysis of the influence of different safety risks on railway bridge construction based on empirical evidence.

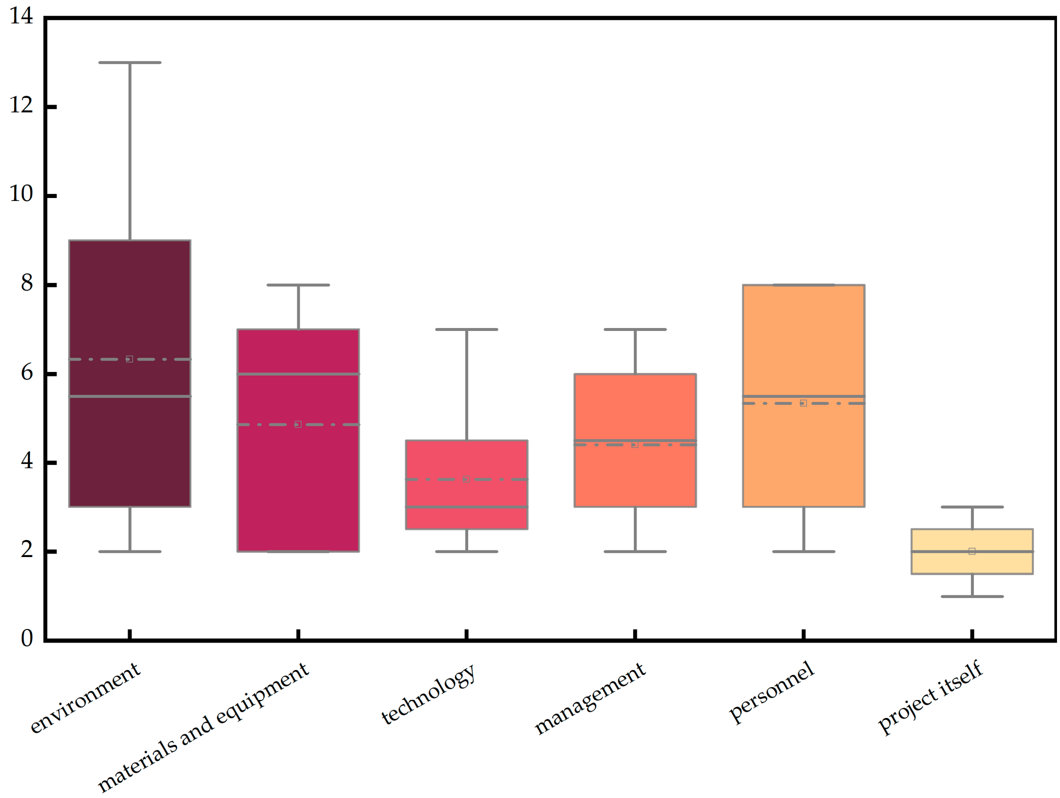

Figure 2. Box plot of frequency of safety risk factors.

Table 1. Table of effective frequency of primary security risk factors.

Primary Safety Risk Factors	Code	Frequency	Effective Frequency
environment	E	17	15
materials and equipment	ME	14	11
technology	T	14	10
management	M	13	11
personnel	P	10	9
project itself	PI	6	5
design	D	3	2
politics	PO	3	3
other	O	2	1
sub-projects	S	2	2

4.1.1. Environment Risks

The secondary security risk factors related to the environment encompass not only the natural environment but also the working environment and the cultural soft environment of both the enterprise and society. During the clustering process, similar risk factors such as "Climate environment" and "Climate change" were merged, while more specific risk factors like "Karst", "Landslide and debris flow", "Strong earthquake", and "Avalanche" were classified accordingly. This resulted in the identification of six secondary security risk factors: climatic conditions, hydrogeology, natural disasters, working environment, landforms, and the social soft environment of enterprises, as depicted in Table 2. The numbers in the table indicate the frequency of recognition for each category. Various natural risk factors significantly influence the operational environment, while risks associated with the cultural soft environment of enterprises and the political environment exhibit a certain level of consistency.

Table 2. Classification of safety risk factors for railway bridge construction.

Primary Safety Risk Factors	Secondary Safety Risk Factors	Code	Description	Frequency
Environment Risks	Climatic conditions	E1	Strong winds, heavy rain, etc.	13
	Hydrogeology	E2	Ground water, stress, etc.	9
	Natural disaster	E3	Earthquake, landslide, etc.	6
	Operating environment	E4	Room temperature, etc.	5
	Topography	E5	Mountain, plain, etc.	3
	Corporate social soft environment	E6	Corporate HSE culture, etc.	2
Materials and Equipment Risks	Material mass	ME1	Incoming inspection; material characteristics, etc.	8
	Maintenance	ME2	Level of maintenance, timeliness, etc.	7
	Safety protection	ME3	Personal protective measures, early warning information, etc.	6
	The use of materials	ME4	Material transportation, material storage, etc.	6
	Equipment quality	ME5	Equipment specification, quality inspection level, etc.	3
	Personnel experience level	ME6	Operation compliance, equipment adaptability, etc.	2
	Invasion limit	ME7	Invasion of falling objects, remnants, etc.	2
Technology Risks	Scheme design	T1	Special construction scheme design, safety scheme design, etc.	7
	Technological maturity	T2	New technology, new process maturity, etc.	5
	Technical applicability	T3		4
	Construction organization design	T4	Rationality, applicability, etc.	3
	Personnel experience level	T5	Personnel operations, personnel awareness, etc.	3
	Material and equipment	T6	Project compatibility, limit violation, etc.	3
	Construction difficulty	T7	The length and span of a bridge	2
	Technical disclosure integrity	T8		2
Management Risks	Monitoring	M1		7
	Institutional soundness	M2		6
	Construction organization design	M3	Rationality, applicability, etc.	6
	Responsibility for implementing	M4	Job Arrangement, division of labor, etc.	5
	Communication and cooperation	M5	Information feedback, trouble shooting, etc.	5
	Site layout	M6		4
	Personnel experience Level	M7		3
	Design	M8	Special construction scheme design, safety scheme design, etc.	3
	Work safety education	M9	Training, assessment, etc.	3
	Technical disclosure integrity	M10		2

Table 2. *Cont.*

Primary Safety Risk Factors	Secondary Safety Risk Factors	Code	Description	Frequency
Personnel Risks	Personnel experience level	P1	Operator	8
	Compliance operation	P2		8
	Safety training	P3	Safety awareness, reasonable protection, etc.	7
	Work attitude	P4		4
	Design management level	P5	Other participants	3
	Staffing	P6	Division of Labor, implementation of responsibilities, etc.	2
Project Itself Risks	Bridge position characteristic	PI1	Traffic grade, overpass, etc.	3
	Structure complexity	PI2	Structure selection, etc.	2
	Project requirements	PI3	Time Limit, quality, environmental protection, etc.	2
	New technology and new process application	PI4	Strong winds, heavy rain, etc.	1

4.1.2. Materials and Equipment Risks

Numerous studies have emphasized the significant influence of materials and equipment on safety risk. Their quality, usage, and operation directly impact the safety of workers and the construction site. From a sub-category perspective, material and equipment factors encompass various aspects such as function, characteristics, usage links, and operational levels. This includes factors like material quality, maintenance, safety protection, material usage, equipment quality, personnel operations, limits on foreign object invasion, and seven other secondary security risk factors, as depicted in Table 2.

4.1.3. Technology Risks

Compared to other types of safety risk factors, the labor-intensive nature of traditional industries establishes a close relationship between technical risk and personnel risk. This relationship encompasses eight aspects, including scheme design, technology maturity, technical applicability, construction organization design, personnel experience level, material and equipment considerations, construction difficulty, and technical integrity, as illustrated in Table 2. Technical risk itself focuses on three main aspects: technology renewal, hidden technological issues, and technological instability. Addressing these aspects requires timely adjustments in industry practices, attention to the enhancement of technological capabilities, enterprise competitiveness, and risk mitigation.

4.1.4. Management Risks

Management risk, in essence, refers to decision-making risk taken by managers or a series of violations stemming from the management system in place [9]. A robust management system establishes clear work norms and safety requirements for employees, along with appropriate training and support measures to ensure a safe working environment and reliable equipment. Effective communication and coordination mechanisms facilitate information flow and team cooperation, enabling the timely detection and correction of violations, and preventing potential risks and accidents. The ten aspects of management risk include monitoring and testing, system integrity, construction organization and design, responsibility implementation, communication and cooperation, site layout, personnel experience awareness, program design, safety education, and technical integrity. The specific relationships among these aspects are depicted in Table 2.

4.1.5. Personnel Risks

In many accident-causing theories, human factors are identified as the primary cause, and human risk is closely related to material and equipment risk, technology risk, and management risk. Personnel risks involve various participants such as workers, supervisors, suppliers, contractors, ESH managers, and government supervision and approval. The experience level, compliance work, safety training, work attitude, design management level, and staffing are factors that influence personnel risk. Education, training, attitudes, awareness, and other factors are particularly relevant to human risk, as shown in Table 2.

4.1.6. Project Itself Risks

The risk associated with the railway project itself primarily pertains to the construction difficulties inherent in the project. This includes factors such as the characteristics of the bridge location, the complexity of the structure, the adoption of new technologies and techniques, and the project's construction period, quality, and environmental protection requirements. The relationship between these factors is presented in Table 2. The risk arising from the bridge location is fundamentally determined by local natural environmental factors. To a certain extent, the project site selection should consider the balance between economic and social benefits, which renders traditional industries more reliant on location factors.

The lower frequency of secondary safety risk factors in the literature does not imply a low probability of risk. Instead, it may be a result of negligence or underestimation during the identification process, thereby posing a more serious threat to security. While different classification methods are reasonable, specific construction projects may require the combination of different classification methods to avoid misjudgment or omissions in risk identification.

4.2. Visualization of Risk Correlations

Drawing upon accident chain theory and system theory, the occurrence of safety risk accidents is attributed to the effect and feedback of various risks within the system. Safety accidents are prevalent in traditional industries not only due to the inherent potential and universality of safety risks but also because these risks interweave and interact with one another, gradually accumulating at different stages of production. This correlation increases the probability of overall security risk and leads to a cumulative effect. Additionally, internal cause-and-effect relationships between risks can give rise to large-scale chain effects and secondary risks. For instance, the failure of lifting machinery and subsequent heavy falling can cause geological disasters, resulting in injuries to individuals and posing serious environmental and safety risks to enterprises, society, and the environment. To comprehensively study risk management strategies, it is imperative to adopt a systematic and dynamic perspective.

To analyze the correlations between security risk factors, social network analysis was employed. This involved transforming the correlations into a co-occurrence matrix, where a value of 0 or 1 was used to indicate the presence or absence of correlation. UCIENT and Netdraw tools were then utilized to visualize the relationships between secondary risk factors, as depicted in Figure 3. The K-cores algorithm, commonly used to identify closely related sub-graph structures within a graph, was applied to the social network graph. In this algorithm, each vertex must have a minimum degree of K, and all vertices are connected to at least K other nodes in the subgraph. By analyzing the K-cores of the social network graph, relationship sub-graphs with more pronounced correlations to other secondary security risk factors were identified as red and black. This indicates that these two categories of security risk factors exert a significant and extensive influence on other factors. However, it is important to note that the correlation between different safety risk factors is solely based on the frequency of references and qualitative descriptions. It does not directly reflect the quantitative results pertaining to safety risk probability and consequence.

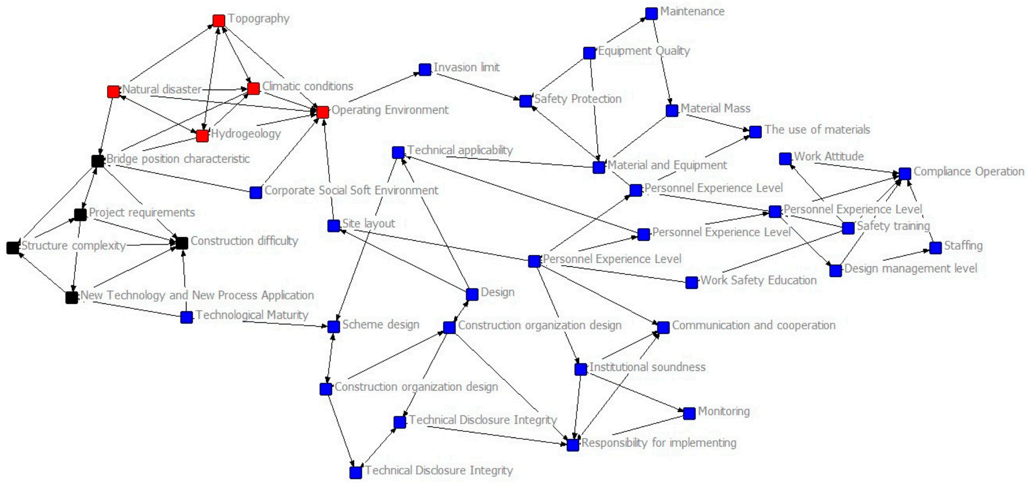

Figure 3. Relation diagram of secondary safety risk factors in railway bridge construction.

The chord diagram utilizes distinct color blocks to represent different factors, with the length of each block determined by the sum of correlation coefficients corresponding to the secondary factors associated with that factor. If a factor exhibits a high correlation coefficient with other factors, its color block will be longer. The connection between color blocks is depicted by bands, which represent the correlation between two factors. The width of the band corresponds to the absolute value of the correlation, indicating a wider band for higher correlation coefficients. The scale of the band connecting to the color blocks represents the absolute value of the corresponding correlation coefficient, thus indicating a larger correlation coefficient for wider bands. Proportional chords employ proportional layouts to demonstrate the similarity or dissimilarity between datasets.

Using the method of social network analysis, the frequency of occurrence of each secondary security risk factor in the literature is employed to examine the correlations between different factors within the first level of security risk factors. This approach provides a more intuitive depiction of the relationships between these factors, as depicted in Figure 4. The proportional chord diagram clearly illustrates the interconnectedness and interdependence of the various factors, showing how they are related to one another. Notably, among all the first-level safety risk factors, the environmental factor is the most frequently mentioned, exerting a significant influence on the safety risk factors associated with the bridge itself. Additionally, there is a certain degree of correlation between technical factors and management factors, as well as material and equipment factors. Furthermore, some secondary risk factors repeatedly appear within these types of risks, indicating a lack of clear classification. However, personnel experience level emerges as a fundamental cause of many risks, which is further explored in the analysis of security risk factors at other levels.

4.3. Robustness Test

Using subgroup analysis, a statistical method commonly employed in medical research and clinical trials, the overall sample was divided into several subgroups. Each subgroup was then independently analyzed to investigate potential differences among them. The safety risk factors associated with railway bridge construction were classified into primary and secondary categories. Subgroup analysis was conducted to aid construction personnel and other risk management participants in categorizing risks based on the source of the risk factors and assessing accidents that may arise due to safety risk factors. By examining the correlations among various safety risk factors, valuable insights can be gained regarding how potential risks can lead to other risks and even safety accidents.

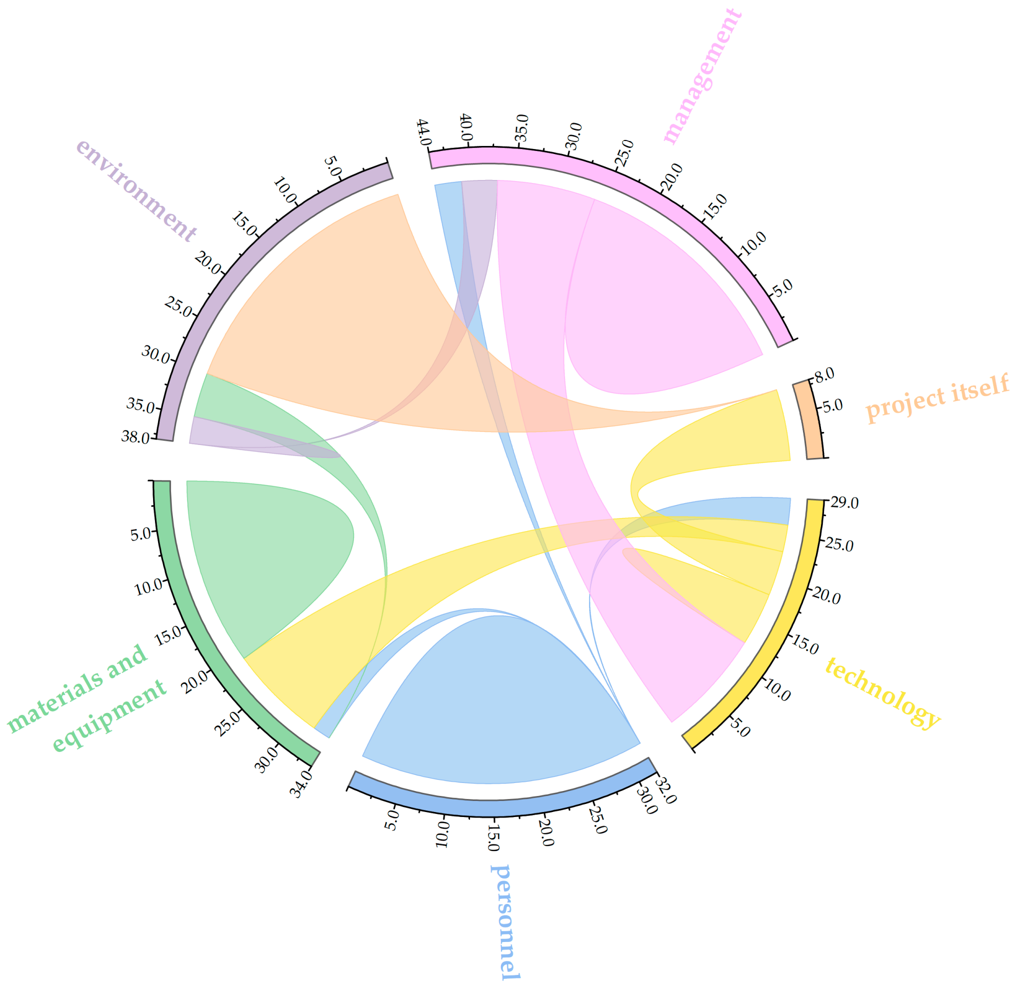

Figure 4. Proportional chord diagram based on correlation of secondary risk factors.

For studies weighted according to the PRISMA process and assessed based on the literature screening criteria and literature level, robustness was tested using STATA18. Subgroup analysis was performed after eliminating one study at a time [10]. The frequency of valid risk factors was standardized using Z-scores, and the resulting risk factor measurement scores followed a normal distribution. The results indicate that the impact of risk factors, as observed in the remaining studies after excluding one study, remained stable and reliable within a 95% confidence interval, as shown in Table 3.

Table 3. A robustness test for risk data using the leave-one-out method.

Primary Safety Risk Factors	Effective Value	Effective Value Interval after Excluding Single Study	Fluctuation Range
environment	1.7473	[1.6570,1.8983]	[−0.0903, 0.1510]
materials and equipment	0.8844	[0.7448, 1.0327]	[−0.1397, 0.1483]
technology	0.6687	[0.5221, 0.8238]	[−0.1467, 0.1551]
management	0.8844	[0.7816, 1.0655]	[−0.1028, 0.1810]
personnel	0.4530	[0.2758, 0.6160]	[−0.1772, 0.1630]
project itself	−0.4099	[−0.5695, −0.3208]	[−0.1597, 0.0890]
design	−1.0570	[−1.2092, −0.9878]	[−0.1522, 0.0692]
politics	−0.8413	[−1.0100, −0.7529]	[−0.1687, 0.0884]
other	−1.2727	[−1.4667, −1.2092]	[−0.1940, 0.0635]
sub-projects	−1.0570	[−1.2095, −0.9811]	[−0.1525, 0.0759]

4.4. Innovative Suggestions for Risk Management Paths

To address emerging risk patterns and complex security challenges, it is crucial to adopt traditional industry-based security risk management process paradigms. These paradigms encompass target setting, risk identification, risk analysis, risk response, risk monitoring, information communication and reporting, risk management assessment and evaluation, process optimization, and institutional innovation. Implementing these processes enhances management efficiency, improves risk response capabilities, and enables adaptation to the rapidly changing risk environment. This paper proposes five main innovation paths for safety risk management based on the correlation between production safety risks, as depicted in Figure 5. The Arrows in the figure indicate the main impact direction. These paths include technology-management empowerment, reinforcement of human factors, introduction of cross-departmental cooperation and coordination mechanisms, flexible establishment of monitoring and feedback mechanisms, and targeted management innovation.

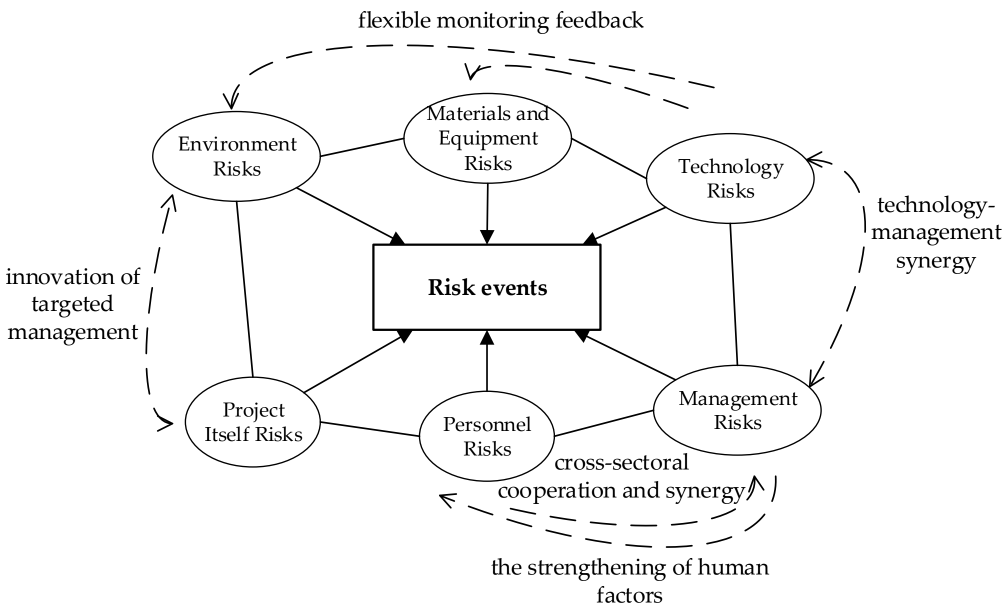

Figure 5. Security risk management innovation path diagram.

4.4.1. Technology-Management Enabling Pathways

This path combines advanced technology innovation with effective management innovation to enhance the effectiveness of safety risk management. The introduction of automation and intelligent technology enables real-time monitoring and control of environmental conditions, materials and equipment, personnel, and management factors. Concurrently, collaborative management and information sharing are strengthened, leading to a technology-management collaborative model that improves risk management responsiveness and decision-making efficiency. For instance, leveraging big data analysis and forecasting models enables accurate identification of potential risk factors across environmental, material and equipment, personnel, management, technology, and project-specific aspects. Data-driven risk management facilitates the proactive implementation of measures to control and prevent risks.

4.4.2. Strengthening Human Factors

Adhering to the concept of human factors engineering, this approach focuses on systems, products, or processes involving human participation. Safety risk management is prioritized with a human-centered approach, establishing a positive and robust safety culture that emphasizes safety values and behavioral norms. Attention is given to staff training, enhancing safety awareness, and behavior through regular training and educational activities. This fosters employees' ability to identify and respond to risks effectively.

4.4.3. Introduction of Cross-Sectoral Cooperation and Synergy Mechanisms

This path involves the implementation of cross-sectoral cooperation and coordination mechanisms, emphasizing prevention and proactive management. Traditional security risk management processes are often unidirectional and isolated by sector. Innovative management practices facilitate cooperation and information sharing among departments, ensuring comprehensive and efficient management. To ensure the successful implementation of safety management, leadership at all levels demonstrates and motivates attention to safety. This approach stimulates the involvement and participation of departments and employees, promoting synergy among various factors.

4.4.4. Establishment of Flexible Monitoring Feedback Mechanisms

By implementing real-time monitoring and early warning systems, this path enables the timely detection of risk changes and evolution, providing feedback on unsafe behavior of personnel or objects during the production process. Appropriate measures can then be taken to adjust and respond. Monitoring involves intelligent monitoring utilizing new technologies and equipment, as well as human–object–human interaction monitoring.

4.4.5. Innovation Path of Targeted Management

This path focuses on characteristic risk management innovation according to specific project risks. By employing flexible and innovative project management organizations and institutions, risk management strategies and measures are tailored to minimize the occurrence and impact of safety risk accidents based on the characteristics and requirements of different projects.

5. Conclusions

The objective of this study is to conduct a comprehensive literature review on the safety risks associated with railway bridge construction in China since the 21st century. By analyzing the correlation between word frequency in documents and descriptive statements, the effectiveness of risk management can be assessed. Taking a systematic perspective, the multiple interactions among various security risk factors highlight the complexity of the geo-meteorological system and the socio-technical system. These interactions also demonstrate the transfer of risks across different system levels, resulting in an overall increase in vulnerability for railway bridge projects. It can be inferred that faults and vulnerabilities in the construction process directly contribute to safety risks and can independently lead to risk-top events in any given project. When combined with other risk factors, the probability of such risks occurring becomes even greater.

Throughout the reviewed literature and cases, the relationship between safety risks and the natural environment, as well as project characteristics, is notably prominent. These factors play a crucial and continuous causal role. Environmental risks, material and equipment risks, technical risks, management risks, and social and personal factors all stem from interactions between these elements. The findings of this study may not be surprising to readers well-versed in the causal mechanisms of accidents, as most safety risks are rooted in systemic issues associated with project implementation and construction personnel. However, the correlation between factors often becomes obscured by other concerns. Consequently, potential risks in the identification of risk factors may be more prevalent than expected, and their adverse effects can surpass initial estimations, leading to safety risk accidents. In future railway construction projects, such as the safety risk management of railway bridges, railway tunnels, and other railway infrastructure, it is crucial to prioritize a holistic approach that considers the interrelatedness of these factors, rather than addressing them in isolation. This comprehensive approach emphasizes the formulation of emergency plans for safety accidents and the implementation of safety risk control measures. Whether addressing unsafe human behavior or unstable conditions, effective control measures should be implemented from both human and technological perspectives.

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Appendix A. Research Literature Risk Identification Basic Information Table

Number	Author	Title	Year of Publication	Identify Risks	Number of Primary Risk Factors
1	Song Gang [11]	Study on the Construction Control and Risk Assessment of T-Shaped Rigid Frame Bridge under Level Rotation	2011	construction technology, construction management risk; material, equipment risk; natural disaster; personnel, design risk; other risks	7
2	Guo Dongchen [12]	Studies of the Steel-Concrete Composite Continuous Beam Bridge Risk Assessment on Construction Phase	2012	construction scale; geological conditions; climate environment; landform; bridge location characteristics; construction technology maturity	3
3	Xu Zhishun [13]	Research on Risk Management of Gui-Guang High-Speed Railway During Construction Stage	2013	politics, technology, progress, quality, nature, management	5
4	Du Juan [14]	Research on Construction Risk of Railway Bridge in Collapsible Loess Area	2013	technology; management; environment; political, legal and other risks; economy (not related to security)	4
5	Ma Xiaotong [15]	Research on the Model of HSE Assessment of High-speed Railway Bridge Construction	2015	operators, equipment, working environment, management	4
6	Chen Chengjun [16]	Controlthe Risk Management and of Construction Project in XP	2016	safety uncertainty caused by technology, construction, and equipment	2

Number	Author	Title	Year of Publication	Identify Risks	Number of Primary Risk Factors
7	Lu Xiaonan [17]	Study on Construction Risk assessment of Newly-Built Railway under Bridges With Existing Highspeed Railways	2018	natural environment; construction technology; material and equipment; organization and management	4
8	Liu Yibao [18]	Research on Dynamic Risk Assessment System of the Construction Period in Bridge Engineering Based on BIM Technology	2019	cast-in-place pile, cap, pier cap, cantilever cast-in-place prestressed concrete, precast slab and beam erection	2
9	Li Yanhe [19]	Construction risk quantification and evaluation based on fuzzy theory	2019	construction organizational risk, human material and equipment risk, construction environmental risk, construction technical risk and special risk	5
10	Wang Feiqiu et al. [20]	Risk assessment of construction safety of high-speed railway bridge across existing lines based on bp neural network	2019	material and equipment risk; construction management risk personnel risk; environmental risk; construction technology risk;	5
11	Liu Xiaobing [21]	Study on Safety Risk Management in Construction of A Railway Project close to the Operating Line	2019	roadbed damaged, track damaged, signal equipment damaged, power system damaged, personnel into the line of business, mechanical set each trespass limit, falling objects, remnants trespass limit	3
12	Zhang Guoxi [22]	Study on Construction Safety Risk of Bridges Spanning Existing Railway Lines Based on Cloud Theory	2019	people, equipment, materials, construction environment, organization, and management	4
13	Zhang Jin, Xu Junxiang [23]	Safety Risk Assessment of Bridge and Tunnel Construction on Sichuan-Tibet Railway	2020	construction environment, construction personnel, materials and equipment, safety management	4
14	Yuan Guangjie [24]	Risk Analysis and Countermeasure Studyon Construction Process of Super High PierT Frame Bridge under Complicated Environment	2020	environmental risk factors; structure risk factors; material risk factors; design risk factors; construction technology risk factors; monitoring risk factors; management risk factors	6
15	Song Xianchang [25]	The Research on Security Risk Management of Bridge Construction Project of Lunan Railway	2020	environmental conditions; construction technology; materials and equipment; organization and management	4

Number	Author	Title	Year of Publication	Identify Risks	Number of Primary Risk Factors
16	Cao Genghao [26]	Study on Construction Risk Control of Fangjiamiao Double Track Grand Bridge of Zhengzhou-Wanzhou High-speed Railway	2021	political policy risk; financial risk; natural condition risk; construction process risk; staff risk	4
17	Ji Feng [27]	Study on Construction Risk Assessment of Highway Railway Suspension Bridge	2021	north anchor caisson; south anchor extended foundation; pile foundation and cap structure; north–south anchor; main/sling saddle; catwalk; main cable; main beam	1
18	Li Haowen, Bao Xueying [28]	Risk assessment of Sichuan-Tibet railway bridge construction based on dynamic weight—2-D cloud model	2021	bridge risk; natural and geological risk; material and equipment risk; construction personnel risk; construction technology risk	5
19	Xu Xianghui [29]	Research on Construction Risk Assessment and Control of Steel Box Girder Bridges Based on Hydraulic-walking Incremental Launching Technology	2021	design, construction environment, construction process risk, construction equipment risk, personnel risk, material risk	5
20	Huang Jixiang et al. [30]	Safety Risk Analysis of Railway Bridge Construction in Plateau Area	2021	personnel quality; mechanical equipment and construction materials; management; environment	4
21	Liu Peng [31]	Research on Safety Risk Management and Control of Deep Foundation Pit Construction Adjacent to Existing High-Speed Railway Bridges	2022	excavation depth of foundation pit, hydrogeological condition, construction scheme, construction technology level and condition, construction management level, distance between bridge and foundation pit, foundation depth, bridge structure status quo, pile-soil relative stiffness, superstructure form	4

References

1. Stewart, M.G. Reliability-Based Assessment of Ageing Bridges Using Risk Ranking and Life Cycle Cost Decision Analyses. *Reliab. Eng. Syst. Saf.* **2001**, *74*, 263–273. [CrossRef]
2. He, Q.; Luo, L.; Hu, Y.; Chan, A.P.C. Measuring the Complexity of Mega Construction Projects in China—A Fuzzy Analytic Network Process Analysis. *Int. J. Proj. Manag.* **2015**, *33*, 549–563. [CrossRef]
3. Lee, Y.-J.; Kim, R.; Suh, W.; Park, K. Probabilistic Fatigue Life Updating for Railway Bridges Based on Local Inspection and Repair. *Sensors* **2017**, *17*, 936. [CrossRef]
4. Arbuthnott, A.; Eriksson, J.; Wincent, J. When a New Industry Meets Traditional and Declining Ones: An Integrative Approach towards Dialectics and Social Movement Theory in a Model of Regional Industry Emergence Processes. *Scand. J. Manag.* **2010**, *26*, 290–308. [CrossRef]
5. Marvier, M. Using Meta-Analysis to Inform Risk Assessment and Risk Management. *J. Verbr. Lebensm.* **2011**, *6* (Suppl. S1), 113–118. [CrossRef]

6. Messori, A.; Maratea, D.; Fadda, V.; Trippoli, S. Using Risk Difference as Opposed to Odds-Ratio in Meta-Analysis. *Int. J. Cardiol.* **2013**, *164*, 127. [CrossRef] [PubMed]
7. Marchetti, D.; Wanke, P.F. Efficiency in Rail Transport: Evaluation of the Main Drivers through Meta-Analysis with Resampling. *Transp. Res. Part A Policy Pract.* **2019**, *120*, 83–100. [CrossRef]
8. Noar, S.M.; Rohde, J.A.; Barker, J.O.; Hall, M.G.; Brewer, N.T. Pictorial Cigarette Pack Warnings Increase Some Risk Appraisals But Not Risk Beliefs: A Meta-Analysis. *Hum. Commun. Res.* **2020**, *46*, 250–272. [CrossRef]
9. Cong, H.; Zou, D.; Wu, F. Influence Mechanism of Multi-Network Embeddedness to Enterprises Innovation Performance Based on Knowledge Management Perspective. *Clust. Comput.* **2017**, *20*, 93–108. [CrossRef]
10. Siontis, K.C.; Hernandez-Boussard, T.; Ioannidis, J.P.A. Overlapping Meta-Analyses on the Same Topic: Survey of Published Studies. *BMJ* **2013**, *347*, f4501. [CrossRef] [PubMed]
11. Song, L. Study on the Construction Control and Risk Assessment of T-Shaped Rigid Frame Bridge under Level Rotation. Master's Thesis, Chang'an University, Xi'an, China, 2011.
12. Guo, D. Studies of the Steel-Concrete Composite Continuous Beam Bridge Risk Assessment on Construction Phase. Master's Thesis, Beijing Jiaotong University, Beijing, China, 2012.
13. Xu, Z.S. Research on Risk Management of Gui-Guang High-Speed Railway during Construction Stage. Master's Thesis, Lanzhou Jiaotong University, Lanzhou, China, 2013.
14. Du, J. Research on Construction Risk of Railway Bridge in Collapsible Loess Area. Master's Thesis, Lanzhou Jiaotong University, Lanzhou, China, 2013.
15. Ma, X.T. Research on the Model of HSE Assessment of High-Speed Railway Bridge Construction. Master's Thesis, Lanzhou Jiaotong University, Lanzhou, China, 2015.
16. Chen, C.J. Control the Risk Management and of Construction Project in XP. Master's Thesis, Southwest Jiaotong University, Chengdu, China, 2016.
17. Lv, X.N. Study on Construction Risk Assessment of Newly-Built Railway under Bridges with Existing Highspeed Railways. Master's Thesis, Southwest Jiaotong University, Chengdu, China, 2018.
18. Liu, Y.B. Research on Dynamic Risk Assessment System of the Construction Period in Bridge Engineering Based on BIM Technology. Master's Thesis, Fuzhou University, Fuzhou, China, 2019.
19. Li, Y.H. Construction risk quantification and evaluation based on fuzzy theory. *Value Eng.* **2019**, *38*, 36–38.
20. Wang, F.Q.; Huang, J.L.; Fu, J.; Yan, Y.B.; Chen, H.H. Risk assessment of construction safety of high-speed railway bridge across existing lines based on bp neural network. *J. Railw. Sci. Eng.* **2019**, *16*, 1129–1136. [CrossRef]
21. Liu, X.B. Study on Safety Risk Management in Construction of A Railway Project close to the Operating Line. Master's Thesis, Beijing Jiaotong University, Beijing, China, 2019.
22. Zhang, G.X. Study on Construction Safety Risk of Bridges Spanning Existing Railway Lines Based on Cloud Theory. *Sci. Technol. Innov.* **2019**, *24*, 90–91.
23. Zhang, J.; Xu, J.X. Safety Risk Assessment of Bridge and Tunnel Construction on Sichuan-Tibet Railway. *J. Saf. Environ.* **2020**.
24. Yuan, G.J. Risk Analysis and Countermeasure Study on Construction Process of Super High PierT Frame Bridge under Complicated Environment. Master's Thesis, Chongqing Jiaotong University, Chongqing, China, 2020.
25. Song, X.C. The Research on Security Risk Management of Bridge Construction Project of Lunan Railway. Master's Thesis, Southwest Jiaotong University, Chengdu, China, 2020.
26. Cao, G.H. Study on Construction Risk Control of Fangjiamiao Double Track Grand Bridge of Zhengzhou-Wanzhou High-Speed Railway. Master's Thesis, Changsha University of Science & Technology, Changsha, China, 2021.
27. Ji, F. Study on Construction Risk Assessment of Highway Railway Suspension Bridge. Master's Thesis, Southwest Jiaotong University, Chengdu, China, 2021.
28. Li, H.W.; Bao, X.Y. Risk assessment of Sichuan-Tibet railway bridge construction based on dynamic weight-2-D cloud model. *J. Railw. Sci. Eng.* **2021**, *18*, 1650–1660.
29. Song, X.C. Research on Construction Risk Assessment and Control of Steel Box Girder Bridges Based on Hydraulic-walking Incremental Launching Technology. Master's Thesis, Southeast University, Nanjing, China, 2021.
30. Huang, J.X.; Kong, E.L.; Liu, Z.Q.; Wang, G.; Kong, J.D. Safety Risk Analysis of Railway Bridge Construction in Plateau Area. *Jiangxi Build. Mater.* **2021**, *12*, 68–72.
31. Liu, P. Research on Safety Risk Management and Control of Deep Foundation Pit Construction Adjacent to Existing High-Speed Railway Bridges. Master's Thesis, Chongqing Jiaotong University, Chongqing, China, 2022.