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# Analysis of Evaluation Index System for Safety Resilience in Major Railway Projects Based on AISM

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**Abstract:** Major railway projects are large-scale infrastructure investments facing significant safety challenges due to complex geological conditions, extreme environments, and uncertain risks. This study integrates resilience theory into railway construction safety management, shifting from traditional risk management (Safety-I) to resilience-based management (Safety-II). A resilience evaluation framework was developed using the 4Rs (robustness, redundancy, resourcefulness, rapidity) and ARRA (absorptive, resistant, restorative, adaptive) capabilities. Adversarial Interpretative Structural Modeling (AISM) and systematic clustering analysis were applied to identify key safety resilience factors and construct an evaluation index system. The findings highlight that optimized personnel allocation, adaptive machinery, standardized material use, comprehensive emergency response, and a stable construction environment are crucial for enhancing safety resilience. The proposed framework provides practical insights for improving safety strategies, minimizing risks, and ensuring sustainable railway infrastructure development.

**Keywords:** major railway projects; construction safety; resilience management; influencing indicator system

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## 1. Introduction

Major railway projects generally refer to railway construction projects characterized by large investment [1], long construction periods, long spans, and complex technology [2]. Their construction aims to provide fast and reliable rail transport services, which are of great significance to the high-quality economic development, long-term social stability, optimal resource allocation, and cultural diversity exchanges of a country or region [3]. Compared to regular railway projects, these major projects are similar in construction content, typically including new construction, reconstruction, or expansion in areas such as tracks, subgrades, bridges, tunnels, stations, vehicle engineering, and signal engineering. In terms of construction features, besides having the characteristics of general railway construction, these projects have more difficulties [4]. In addition, some major railway projects also feature traversing complex and dangerous areas and deep uncertainties [5]. Complex and dangerous areas are typically characterized by harsh natural conditions and complex social situations [6]. In terms of natural conditions, these regions have complex geology with terrains such as plateaus, mountains, deserts, and grasslands; frequent natural disasters like avalanches, earthquakes, rock bursts, high ground temperatures [7], low temperatures, and low oxygen at high altitudes; and fragile ecological environments. In terms of social conditions, due to the long span of major railway projects involving different ethnic groups, their customs, languages, religions, and architecture may be impacted by

the construction [5]. Deep uncertainty is a specific type of uncertainty in major railway construction, referring to the early stages of decision-making and design where project decision-makers and designers cannot fully comprehend the situations faced during the mid-term construction phase [8], leading to an inability to accurately predict and assess potential emergencies that might occur, which can introduce more risk factors and incidents, impacting construction safety and potentially disrupting the progress of major railway projects according to the original plan, with effects that may persist into the operational maintenance phase.

Given the characteristics of major railway projects, construction safety is crucial during their development. However, recognized for its distinct characteristics, the construction sector ranks among the most high-risk industries globally [9,10]. Safety issues in construction engineering are influenced by various factors. Diverse natural environments, complex geological conditions, and extreme weather conditions pose significant challenges to construction personnel, machinery, materials, and management, severely impacting major railway construction projects.

Current research on construction safety in major railway projects mainly focuses on safety risk management, implementing the Safety-I philosophy, which emphasizes identifying "what went wrong" and then addressing the gaps [11]. The management of safety risks typically involves processes such as identification, assessment, control, and monitoring. By identifying risk factors and assessing the likelihood and potential losses from risk incidents, plans are made in advance to mitigate the impact of such incidents and reduce risk losses [12,13].

Compared to general railway projects, major railway projects not only feature immense scale, diversified objectives, numerous uncertainties, long implementation periods, and complex integration of new technologies but also possess unique attributes such as high innovation and strong industrial relevance [14,15], significantly impacting the social and economic aspects of their regions [8]. Therefore, beyond risk management, new management approaches and perspectives are needed to address the safety challenges faced by major railway construction projects. Unlike risk management theory, resilience theory not only focuses on how to resist and recover after accidents but also emphasizes reducing the likelihood of accidents and enhancing the capability to handle risks post-recovery. This approach allows for a more comprehensive study of safety in major railway projects [16] practicing the Safety-II philosophy, which focuses on "ensuring everything goes right" and stresses proactive development towards anticipated safety directions [12,13], better suited for complex and variable construction environments [17].

Consequently, organizations of major railway construction projects should become highly resilient in safety, utilizing the unique 4R attributes and ARRA capabilities of resilience management to reduce the likelihood of safety incidents, promptly resist accidents, investigate residual safety risks, and enhance adaptability to safety incidents [18]. The 4R attributes include robustness, redundancy, resourcefulness, and rapidity [19]. Robustness, also known as resilience, refers to the attribute of a system or organization to withstand disturbances and maintain continuous operation. Redundancy refers to the attribute of having additional necessary resources in a system or organization for a task, ensuring that these resources are replaceable. Resourcefulness is the attribute of accurately identifying problems, clarifying the order of operations, and adequately allocating resources when issues arise in the system or organization. Rapidity refers to the attribute of promptly responding to issues as they arise in the system or organization, controlling losses, and minimizing subsequent damage caused by the problems. Diagram of safety status changes in major railway engineering construction under the influence of safety resilience as shown in Figure 1.

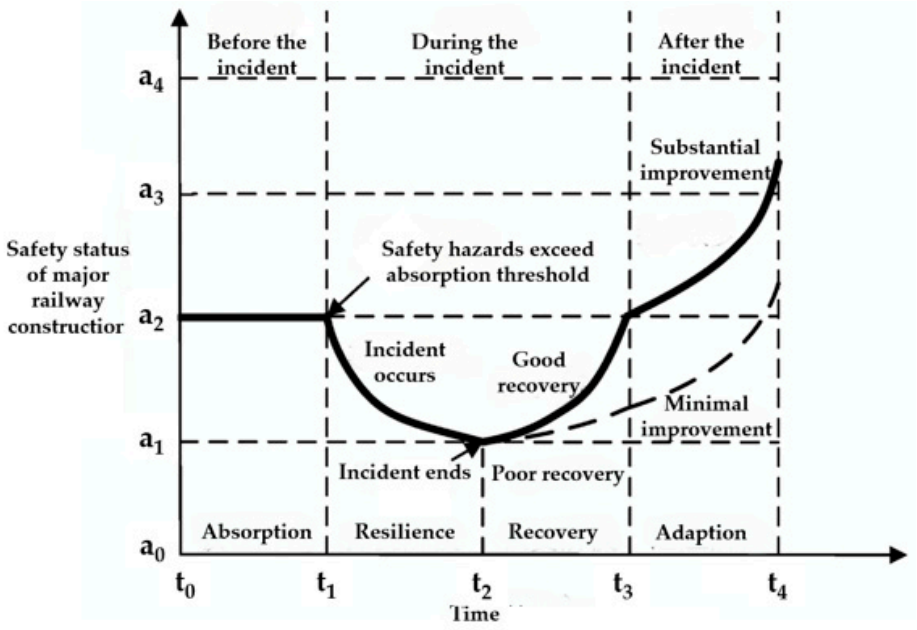



**Figure 1.** Diagram of safety status changes in major railway engineering construction under the influence of safety resilience.

ARRA capabilities include absorptive capacity, resilience, recovery, and adaptability [20,21]. Absorptive capacity is the ability to reduce safety hazards and lower the likelihood of safety incidents. Resilience is the ability to manage safety and reduce the impact of safety incidents, preventing the worsening of such incidents. Recovery is the ability to identify residual safety hazards and restore safe construction practices. Adaptability is the ability to summarize and learn from the experience of handling safety incidents, enhancing the project organization's efficiency in dealing with such accidents. Framework of safety resilience in major railway engineering construction as shown in Figure 2.

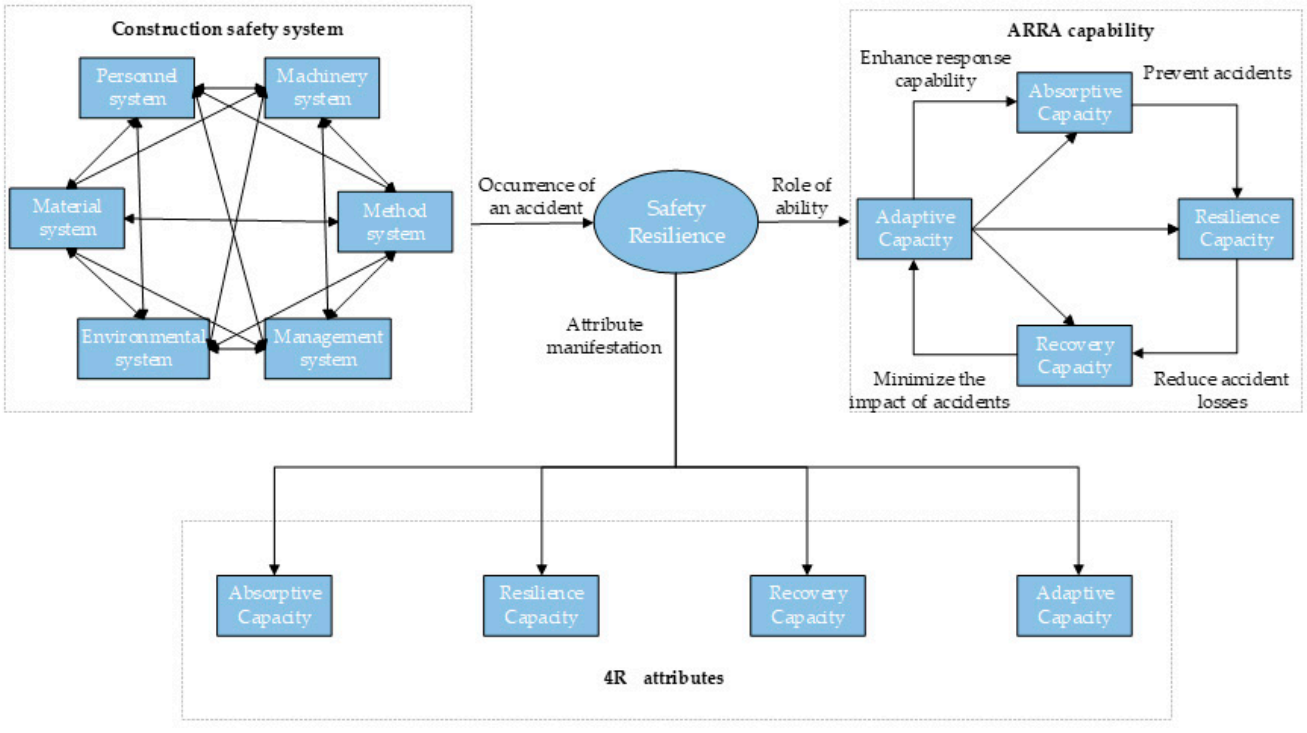



**Figure 2.** Framework of safety resilience in major railway engineering construction.

This paper will be organized according to the following logical structure. Section 2 reviews the relevant literature. Section 3 identifies and revises factors influencing the resilience of construction safety in major railway projects and develops a resilience evaluation indicator system for construction safety in major railway projects. Section 4 deconstructs and analyzes the meanings of the evaluation indicators. Section 5 presents conclusions and future outlooks.

## 2. Literature Review

### *2.1. Construction Safety Research*

The construction phase is the period in major railway projects that involves the most personnel and resource investment, where it is imperative to ensure the health and safety of personnel and the security of materials and property to the greatest extent. In tunnel construction safety research, Jianxiu Wang and Ansheng Cao [22] developed a risk evaluation indicator system for urban shallow-buried long-span dual-arch tunnel construction, considering aspects such as engineering geology, hydrogeology, surrounding construction environment, engineering design, construction technology, construction management, and data monitoring. Liang Ou and Yun Chen [23] developed a safety indicator system for urban rail transit tunnel construction, focusing on geological conditions, construction environment, planning and design, construction technology, management factors, and safety aspects. In bridge construction safety research, Li et al. [24] employed the cloud entropy weighting method to objectively weigh the safety risk indicators of bridge construction. They used the cloud model theory for risk assessment and directly determined the overall risk level of bridge construction and the levels of risk indicators through cloud model images. Shan et al. [25] utilized the N-K model to quantify the coupling relationships between safety risk factors in bridge construction, assessed the risk levels, and used social network analysis (SNA) to analyze the network of risk factors in bridge construction accidents, conducting a coupled analysis of the safety risks in bridge construction. In the research on safety in railway construction, Chunfang Lu and Chaoxun Cai [5] noted that the main safety risks during the construction of the Sichuan–Tibet Railway can be categorized into highland disasters, climatic disasters, geological disasters, and construction disasters. They proposed a comprehensive response framework integrating survey and design, construction and management, disaster monitoring, and emergency response. Shan Z and Liang YL [26] identified safety risks in Chinese railway bridge construction, including personnel, machinery, materials, method, environment, and management from the 5M1E perspective; they explored the interrelationships between risk factors through an integrated approach of social network analysis and evidence-based evaluation based on the literature.

### *2.2. Resilience Management Research*

Resilience, from the Latin "resilio" and originating from a physical concept, literally means "recovery strength, elasticity", referring to the ability of an object to return to its original state after being subjected to external forces. In the 1970s, ecologist Holling [27] first used resilience to describe the persistence of natural systems and their ability to absorb various changes and disturbances. Subsequently, research on resilience has been widespread in fields such as ecology, engineering, and positive psychology. The evaluation of system resilience, particularly in complex and large-scale systems, has garnered increasing attention from both the engineering and academic communities [28]. In the field of engineering management, the definition of resilience depends on whether the subject being analyzed is a community, an organization, a project, an engineering system, or something else. The core principle of engineering resilience is to ensure that key engineering or infrastructure systems can maintain their core functions when facing internal or external shocks

or conflicts [29,30]. Williams et al. [31] view resilience as a process in which businesses or groups strive to cope with adverse conditions in a challenging context, interacting with their capabilities and the environment to proactively adjust and maintain effective operation before, during, and after incidents. The key elements of engineering resilience include monitoring and warning capabilities, resistance to absorption, recovery and reconstruction capabilities, and adaptive learning in major projects [32]. In the field of safety science, Wears [33] first introduced resilience theory to safety science, defining resilience as the inherent ability of a system to adjust its functions to cope with disturbances. Costella [34] believes that resilience engineering is a new method of safety management for complex dynamic systems. Penaloza et al. [35] identified resilience engineering as the safety indicator that organizations should use to measure safety performance. Holing [27] views safety resilience as the capability of engineering systems to perceive risks, predict accidents, take emergency measures, and learn from accident experiences. Ranasinghe et al. [36] conducted a systematic evaluation of resilience engineering indicators and safety management.

### *2.3. Resilience Research in Major Railway Engineering*

Engineering safety resilience is manifested at all stages of an incident, with the engineering system having the capabilities to perceive, predict, respond, recover, and learn. It refers to the abilities of a complex construction system, composed of organization, personnel, materials, technology, and information, to perceive, predict, respond, recover, and learn before, during, and after an incident under external environmental disturbances. In terms of tunnel safety resilience, it is defined as the ability of the tunnel system to withstand disturbances from various risk factors during construction, maintaining safety and normal production without external assistance. For the safety resilience of high-altitude railway operations, it is defined as the process attributes of the railway in high-altitude areas to resist risks and prevent structural damage while maintaining normal operations, despite being disturbed by various factors. By combining process attributes such as adaptability, resistance, and recoverability of resilience's dynamic evolution, an evaluation indicator system is constructed from aspects of management, personnel, environment, and materials. This system is weighted using the Analytic Hierarchy Process and CRITIC method, with the resilience levels of safety systems ultimately determined by the Euclidean distance. Subsequently, Shiqun Li [37] introduced resilience theory into high-speed rail tunnel operation risk analysis, creating an existing high-speed railway tunnel safety resilience evaluation framework. Focusing on the characteristics of high-speed railway tunnels, protective measures, and emergency management, a resilience evaluation model for high-speed rail tunnels based on an improved TOPSIS fuzzy matter-element method was constructed, establishing classification standards for high-speed rail tunnel resilience. In the context of institutional resilience in major railway construction projects, Xi Zhao and Yuming Liu [38] defined the essence of institutional resilience through grounded theory, analyzed the mechanisms of institutional resilience formation using an interpretive structural modeling approach, and proposed strategies to enhance institutional resilience.

## 3. Construction of Evaluation Index System for Safety Resilience in Major Railway Engineering Construction

### *3.1. Identification and Correction of Influencing Factors of Construction Safety Resilience*

This section will identify and correct the influencing factors based on the concept of construction safety resilience in major railway engineering, analyzing these factors through the AISM method [39] (Adversarial Interpretive Structure Modeling) to identify the key influencing factors. Based on the identified influencing factors, a construction safety resilience evaluation indicator system for major railway engineering will be built through

cluster analysis, followed by an analysis of the meaning of each indicator. The influencing factors will be further analyzed through AISM to clarify the internal logical relationships between the factors and identify the key influencing factors. The systematic cluster analysis will be employed to reclassify the influencing factors identified from the six subsystems of 5M1E based on the four ARRA capabilities: absorptive capacity, resistance, recoverability, and adaptability. A construction safety resilience evaluation indicator system for major railway engineering will be established, with an analysis of the meaning of each indicator to support the management of construction safety in major railway engineering.

#### 3.1.1. Approach to Identifying Influencing Factors of Construction Safety Resilience

As shown in Figure 3, firstly, it should be clarified that construction safety resilience is a management practice based on resilience theory within construction safety management. Therefore, the factors included in the subsystems of personnel, machinery, materials, methods, environment, and management within construction safety management will also impact construction safety resilience. Secondly, factor identification should be conducted based on specific identification principles. Given the wide variety of influencing factors for construction safety resilience and the large volume of data from literature, technical specifications, and construction surveys, following rational identification principles will help improve the efficiency of the identification process. Finally, the initially selected factors should be verified and proofread. Expert opinions should be used to refine the initially identified influencing factors.

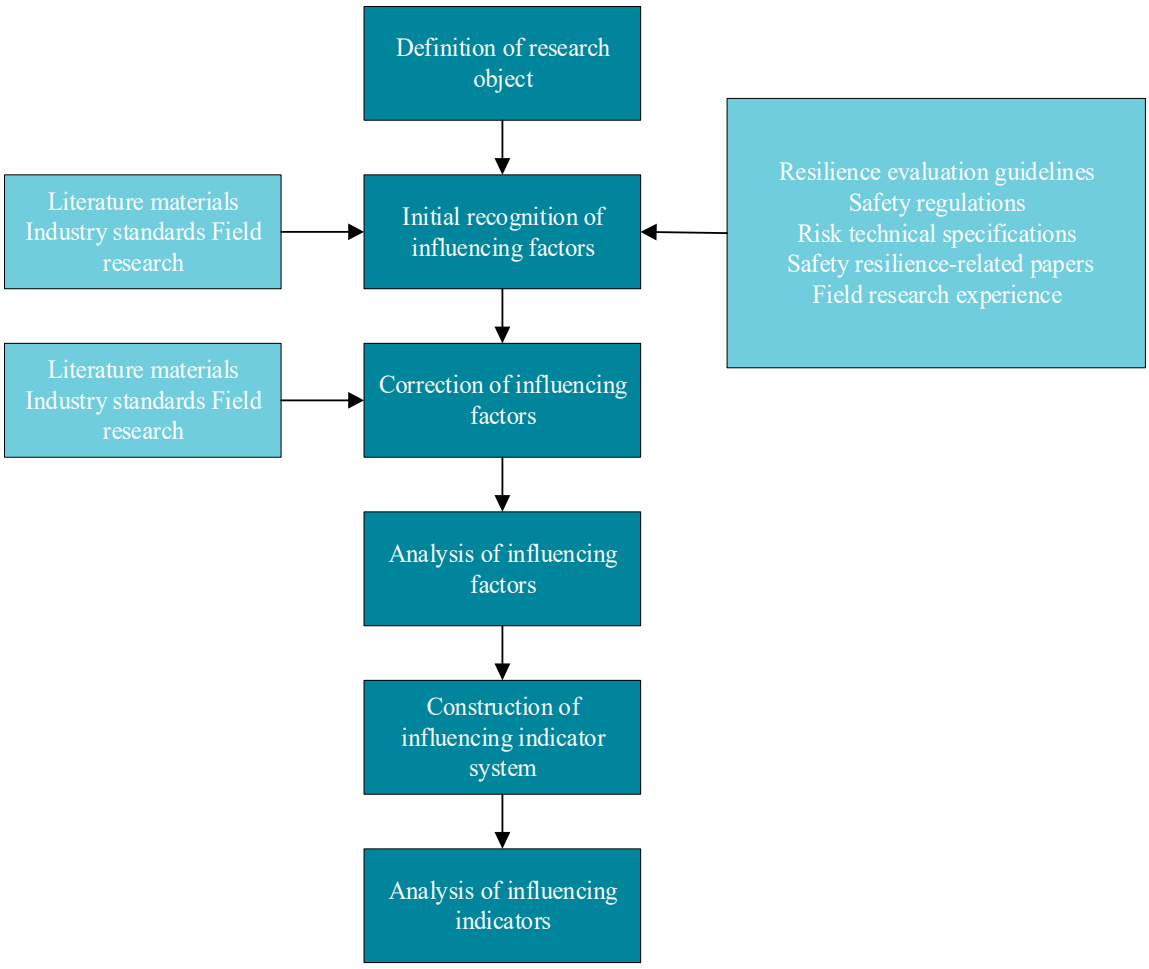



**Figure 3.** Approach to identifying influencing factors of safety resilience in major railway engineering construction.

In addition, the identification of influencing factors aims to identify the factors that reflect the 4R attributes of safety resilience within the six subsystems of construction safety and to analyze these factors, clarifying their interactions, relationships, and key influencing factors. Ultimately, the identified influencing factors will be reclassified according to the ARRA capabilities, and the safety resilience evaluation indicator system for major railway engineering will be established.

#### 3.1.2. Preliminary Identification of Influencing Factors of Construction Safety Resilience

Based on the definition of construction safety resilience in major railway engineering, and following the process determined by the identification approach, the identification of factors in this study will closely align with the previously defined basic concepts and the characteristics of the 4R attributes. The identification process draws from resilience-related evaluation guidelines, railway construction technical specifications, safety regulations, safety risk standards, safety resilience papers, and railway construction safety risk papers. A total of 44 influencing factors related to construction safety resilience in major railway engineering are initially identified from the six construction safety subsystems: personnel, machinery, materials, methods, environment, and management. The preliminary identification results of influencing factors are shown in Table 1.

**Table 1.** Preliminary identification results of influencing factors of construction safety resilience in major railway engineering.

| Subsystem | Influencing Factor | Attribute | Identification Basis |
|---|---|---|---|
| Personnel | Age Structure of Personnel | Robustness | References [9,26,40–45] |
| | Fatigue | Robustness | |
| | Risky Operations | Robustness | |
| | Number of Safety Personnel | Redundancy | |
| | Construction Personnel Skill Level | Redundancy | |
| | History of Occupational Diseases | Robustness | |
| | Health Status | Robustness | |
| | Psychological State | Robustness | |
| | Safety Awareness | Redundancy | |
| Mechanical | Protective Equipment Configuration | Redundancy | References [9,43,45–47] |
| | Testing Equipment Configuration | Redundancy | |
| | Compliance of Equipment Entry Acceptance | Robustness | |
| | Use of Advanced Construction Equipment | Robustness, Timeliness | |
| | Ease of Operation of Construction Equipment | Intelligence | |
| | Timely Maintenance of Equipment | Robustness, Timeliness | |
| Materials | Material Transportation Capacity | Redundancy, Timeliness | References [26,45,46,48,49] |
| | Transportation of Large Components | Redundancy | |
| | Transportation, Inspection, Storage, and Use of Flammable, Explosive, Toxic, and Harmful Materials | Robustness | |
| | Classification and Stacking of Materials | Redundancy, Intelligence | |
| Methods | Outdated Construction Techniques | Robustness, Timeliness | References [9,26,40,43,46,50–52] |
| | Inapplicable Construction Techniques | Robustness, Timeliness | |
| | Unreasonable Construction Plan | Robustness, Timeliness | |
| | Special Plans for Key Difficult Projects | Intelligence | |
| | Execution of Technical Disclosure | Intelligence | |
| | Risk Engineering Process Disclosure | Timeliness | |

**Table 1.** *Cont.*

| Subsystem | Influencing Factor | Attribute | Identification Basis |
|---|---|---|---|
| Environment | Uneven Construction Site | Robustness, Timeliness | References [26,47–49,53] |
| | Disorganized Stacking of Materials and Equipment | Robustness, Timeliness | |
| | Poor Lighting and Ventilation | Robustness, Timeliness | |
| | Impeded Roads and Drainage | Robustness, Timeliness | |
| | Heavy Rain, Freezing, Sandstorm, Severe Cold, Low Oxygen | Robustness, Timeliness | |
| | High Ground Temperature, Large Deformations, Earthquakes | Robustness, Timeliness | |
| | Passing Through Nature Reserves | Robustness, Timeliness | |
| | Passing Through Minority Ethnic Villages | Robustness, Timeliness | |
| Management | Low Effectiveness of Safety Management Organization | Intelligence, Timeliness | References [9,26,40,41,43,52–55] |
| | Imperfect Safety Management System | Redundancy, Intelligence, Timeliness | |
| | Unified Management Authority and Responsibility | Intelligence | |
| | Incomplete Emergency Plans | Redundancy, Intelligence | |
| | Insufficient Emergency Resources | Redundancy, Intelligence | |
| | Untimely Emergency Handling | Timeliness | |
| | Untimely Recovery | Timeliness | |
| | Low Frequency of Safety Training | Robustness, Intelligence | |
| | Unreasonable Safety Training Methods | Robustness, Intelligence | |
| | Education System Not Implemented | Robustness, Intelligence | |

#### 3.1.3. Modification of Influencing Factors of Construction Safety Resilience

A brief analysis of the preliminary identification results reveals that some of the identified influencing factors are similar and can be merged. Additionally, there is inconsistency in the expressions, with positive, negative, and neutral terms being used interchangeably. These can be modified and consolidated. Therefore, modifications and adjustments, such as rephrasing and merging, are made to the preliminary identification results of influencing factors. For example, fatigue and hazardous operations are merged into the category of personnel safety awareness; heavy rain, freezing, sandstorms, as well as high-altitude, low-oxygen, high-temperature, large deformation, and earthquakes, are merged into the stability of the natural environment; personnel health status and psychological state are consolidated into a single category of personnel health status; low frequency of safety training, inappropriate training methods, and failure to implement education are combined as safety education and training effectiveness. The revised results are shown in Table 2.

According to the preliminary adjustment results, the questionnaire for the modification of influencing factors is designed (see Appendix A). The questionnaire consists of three parts: basic information of the survey participants, factor modification scores, and other suggestions. The questionnaire is designed based on the 5M1E and the adjusted 28 factors. Survey participants are invited to score the importance of the influencing factors based on their work experience and the actual conditions of construction safety in major railway engineering. The results are divided according to a Likert five-point scale, where scores of 1, 2, 3, 4, and 5 represent “very unimportant”, “relatively unimportant”, “neutral”, “relatively important”, and “very important”, respectively. The survey participants mainly consist of personnel from construction units, design units, construction organizations, and relevant universities and research institutes involved in major railway engineering projects. A total of 100 questionnaires were distributed, and 87 were returned. Questionnaires with obvious extreme values, missing data, or highly similar responses were excluded. Ultimately, 71 valid questionnaires were returned, resulting in an effective response rate of 81.6%, which meets the relevant standards for survey validity.

**Table 2.** Adjustment results of construction safety resilience influencing factors.

| Factor Subsystem | Influencing Factor |
| --- | --- |
| Personnel | Safety Personnel Ratio<br>Adequate Personnel Number<br>Construction Personnel Skill Level<br>Construction Personnel Health Status<br>Safety Awareness |
| Mechanical | Safety Equipment Configuration<br>Advancement of Construction Machinery<br>Suitability of Construction Machinery<br>Compliance of Machinery Operation<br>Machinery Maintenance |
| Materials | Supply Assurance<br>Reliable Material Storage<br>Standardized Use of Materials<br>Maintaining Material Quality |
| Methods | Reasonableness of Construction Plan<br>Completeness of Emergency Plan<br>Targeted Approach of Special Plans<br>Specialized Technical Disclosure |
| Environment | Reasonableness of Construction Site Layout<br>Social Environmental Friendliness<br>Stability of Natural Environment<br>Frequency of Extreme Weather |
| Management | Establishment of Management Systems<br>Implementation of Management<br>Effectiveness of Safety Education and Training<br>Allocation of Rights and Responsibilities<br>Timeliness of Pre-Shift Education<br>Analysis and Summary of Accident Handling |

The collected questionnaire data are subjected to reliability and validity analysis, and the other suggestions collected are comprehensively analyzed. Reliability refers to the consistency, dependability, and stability of the data. Data with high reliability serves as the foundation for further analysis. In this study, Cronbach's $\alpha$ coefficient is used to test the reliability of the questionnaire data. Validity refers to the extent to which the data can accurately measure the research subject. In this study, the Kaiser–Meyer–Olkin (KMO) test and Bartlett's test are used to examine the validity of the questionnaire data. This study utilized the SPSSAU software to calculate Cronbach's alpha coefficient and perform the Kaiser–Meyer–Olkin (KMO) test. The Cronbach's $\alpha$ coefficient for the questionnaire data is 0.879, indicating excellent reliability, while the KMO value is 0.886, indicating excellent validity. In the comprehensive analysis, experts believe that mechanical operation compliance in the mechanical system is related to the skill level of construction personnel in the personnel system. Additionally, the preparation of special plans and the technical disclosure in the method system are interrelated. In the management system, factors such as timely pre-shift education and effective safety education are similar. Therefore, mechanical operation compliance is merged with the skill level of construction personnel, the preparation of special plans is merged with technical disclosure to form a more targeted special plan, and timely pre-shift education and effective safety education are merged into safety education effectiveness. After the adjustment of the influencing factors, the remaining data are analyzed after excluding the discarded factors from the questionnaire. The Cronbach's $\alpha$ coefficient of the modified influencing factors is 0.881, and the KMO

value is 0.893, both of which are excellent and higher than the values before the factor modification. The final result of the modification of the influencing factors of construction safety resilience in major railway engineering includes six subsystems and 25 indicators. The indicators are primarily expressed in neutral terms, with positive expressions as supplementary. The modified results are shown in Table 3.

**Table 3.** Results of the modification of influencing factors.

| Factor Subsystem | Influencing Factor |
| --- | --- |
| Personnel | Safety Personnel Ratio<br>Adequate Personnel Number<br>Construction Personnel Skill Level<br>Construction Personnel Health Status<br>Safety Awareness |
| Mechanical | Safety Equipment Configuration<br>Advancement of Construction Machinery<br>Suitability of Construction Machinery<br>Machinery Maintenance |
| Materials | Supply Assurance<br>Reliable Material Storage<br>Standardized Use of Materials<br>Maintaining Material Quality |
| Methods | Reasonableness of Construction Plan<br>Completeness of Emergency Plan<br>Targeted Approach of Special Plans |
| Environment | Reasonableness of Construction Site Layout<br>Social Environmental Friendliness<br>Stability of Natural Environment<br>Frequency of Extreme Weather |
| Management | Establishment of Management Systems<br>Implementation of Management<br>Effectiveness of Safety Education and Training<br>Allocation of Rights and Responsibilities<br>Analysis and Summary of Accident Handling |

### *3.2. Analysis of Factors Influencing Safety Resilience in Major Railway Engineering Construction*

This section will deconstruct the identified influencing factors based on the AISM theory calculation process, clarifying the internal hierarchical structure of the influencing factors and conducting a more in-depth analysis of the construction safety resilience factors. The Adversarial Interpretative Structural Modeling method is an improvement on the ISM method (Interpretative Structural Modeling) [56]. Compared to ISM, AISM introduces adversarial (game-theoretic) thinking into the ranking rules. In addition to sorting based on outcomes, it also sorts according to causes. Therefore, analyzing research objects using AISM may result in two different topological hierarchical diagrams: UP-type and DOWN-type.

#### 3.2.1. Calculation Process of AISM Theory

The specific calculation process of AISM is as follows:

(1) Establish the adjacency matrix

The adjacency matrix is the foundation of AISM. Based on the number of influencing factors $n$, an $n \times n$ matrix $A$ is constructed, where each cell $A_{ij}$ represents the influence

of the *i*-th influencing factor on the *j*-th influencing factor. The specific relationship is as follows:

$$A_{ij} = \begin{cases} 1, \text{ The } i-\text{th factor exerts influence on the } j-\text{th factor.} \\ 0, \text{The } i-\text{th factor exerts no influence on the } j-\text{th factor.} \end{cases} \quad (1)$$

(2) Establish the reachability matrix

The reachability matrix is built upon the adjacency matrix, using Boolean operations to investigate the extent to which influencing factors can be reached after a certain length of path. By adding the n-order identity matrix $I$ to the adjacency matrix $A$ and performing self-multiplication, when the result of the $k + 1$-th multiplication equals the result of the $k$-th multiplication, the $k$-th result is the reachability matrix, where $k$ represents the longest path and maximum transmission times of the adjacency matrix. The reachability matrix is calculated as follows:

$$(A + I)^{(k-1)} \neq (A + I)^k = (A + I)^{(k+1)} = M \quad (2)$$

The calculated result $M$ is the reachability matrix of the adjacency matrix $A$.

(3) Establish the general skeleton matrix

After obtaining the reachability matrix, the general skeleton matrix needs to be computed. First, node reduction is performed to adjust the entire system into a Directed Acyclic Graph (DAG), merging interacting influencing factors into a single factor, resulting in the reduced node matrix $M'$. Next, edge reduction is carried out to remove redundant edges from the system, resulting in the skeleton matrix $S'$. The calculation formula for the edge-reduced skeleton matrix $S'$ is as follows:

$$S' = M' - \left(M' - I'\right)^2 - I \quad (3)$$

Restore the factors merged due to node reduction back into $S'$, which results in the general skeleton matrix $S$.

(4) Hierarchical extraction

Based on the result of the skeleton matrix $S' + I$, the reachable set $R_e$, predecessor set $Q_e$, and common set $C_e$ of each influence factor are identified. The set of elements corresponding to a row value of 1 for each factor forms the reachable set, while the set of elements corresponding to a column value of 1 forms the predecessor set. The intersection of the reachable set Re and the predecessor set $Q_e$ forms the common set $C_e$ for each factor.

AISM has two hierarchical extraction rules: the result-first UP-type extraction rule and the cause-first DOWN-type extraction rule.

The result-first UP-type extraction rule uses $C_e = R_e$ as the standard. If the reachable set equals the common set, factors are extracted and arranged in a top-down order.

The cause-first DOWN-type extraction rule uses $C_e = Q_e$ as the standard. If the predecessor set equals the common set, factors are extracted and arranged in a bottom-up order.

(5) Draw a hierarchical topology diagram

Based on the UP-type and DOWN-type hierarchy, combined with the result of the general skeleton matrix $S$, the UP-type and DOWN-type hierarchical topology diagrams are drawn.

(6) Result analysis

The UP-type and DOWN-type hierarchical topology diagrams divide the factors into three levels: the root layer, middle layer, and direct layer, providing a basis for analyzing the relationships between the influencing factors.

#### 3.2.2. Analysis of Factors Influencing Safety Resilience Based on AISM

The revised results of the influencing factors are numbered in the order of personnel, machinery, materials, methods, environment, and management. The numbering starts from A for the safety personnel ratio and sufficient personnel number to Y for the allocation of responsibilities and accident handling analysis and summary. Based on the meaning of each influencing factor and their interrelationships, and in combination with the relevant literature and expert opinions (see Appendix B), the adjacency matrix of influencing factors for construction safety resilience in major railway projects is determined. The adjacency matrix is shown in Table 4.

**Table 4.** Adjacency matrix of influencing factors for construction safety resilience in major railway projects.

| | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** | **I** | **J** | **K** | **L** | **M** | **N** | **O** | **P** | **Q** | **R** | **S** | **T** | **U** | **V** | **W** | **X** | **Y** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| B | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| D | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| E | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| F | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| G | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| H | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| I | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| J | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| K | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| L | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| N | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| O | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| R | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| S | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| T | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| U | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| V | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| W | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| X | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Y | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |

SPSSAU (Statistical Product and Service Software Automatically) is an online data analysis software that enables rapid computation of reachability matrices from adjacency matrices using established formulas. This study employs SPSSAU for data analysis. Input the above matrix into SPSSAU software for calculation. The resulting accessibility matrix of influencing factors for construction safety resilience in major railway projects is shown in Table 5.

**Table 5.** Accessibility matrix of influencing factors for construction safety resilience in major railway projects.

| | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** | **I** | **J** | **K** | **L** | **M** | **N** | **O** | **P** | **Q** | **R** | **S** | **T** | **U** | **V** | **W** | **X** | **Y** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| B | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |

**Table 5.** *Cont.*

| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T | U | V | W | X | Y |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| D | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 |
| E | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| F | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| G | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 |
| H | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| I | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| J | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| K | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| L | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| M | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 |
| N | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| O | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| R | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| S | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 0 |
| T | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 |
| U | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| V | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| W | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| X | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| Y | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |

Based on the calculation results of the accessibility matrix, the reachable sets, predecessor sets, and common sets of each influencing factor are determined. These are shown in Table 6.

**Table 6.** Table of reachable sets, predecessor sets, and common sets of major railway engineering construction safety resilience influencing factors.

| | Reachable Sets $R_e$ | Predecessor Sets $Q_e$ | Common Sets $C_e$ |
|---|---|---|---|
| A | A, H, K, N, Q, V, Y | A | A |
| B | B, I, K, P, Q, U, V | B, D, M, S | B |
| C | C | C, D, F, G, M, R, S, T, X | C |
| D | B, C, D, F, I, K, O, P, Q, R, U, V, X | D, M, S | D |
| E | E, I, J, K, P, Q, U, V, W | E | E |
| F | C, F, K, X | D, F, M, S | F |
| G | C, G, H, K, N, O, Q, R, T, U, V, X, Y | G | G |
| H | H, K, N, Q, V, Y | A, G, H | H |
| I | I, K, P, Q, U, V | B, D, E, I, J, M, P, S, W | P, I |
| J | I, J, K, P, Q, U, V | E, J, W | J |
| K | K | A, B, D, E, F, G, H, I, J, K, L, M, N, O, P, R, S, T, U, V, W, X, Y | K |
| L | K, L, O, Q, U, V | L | L |
| M | B, C, D, F, I, K, M, O, P, Q, R, U, V, X | M | M |
| N | K, N, Q, V, Y | A, G, H, N | N |
| O | K, O, Q, U, V | D, G, L, M, O, S | O |
| P | I, K, P, Q, U, V | B, D, E, I, J, M, P, S, W | P, I |
| Q | Q | A, B, D, E, G, H, I, J, L, M, N, O, P, Q, S, T, U, V, W, Y | Q |
| R | C, K, R, X | D, G, M, R, S, T | R |

**Table 6.** *Cont.*

| | Reachable Sets $R_e$ | Predecessor Sets $Q_e$ | Common Sets $C_e$ |
|---|---|---|---|
| S | B, C, D, F, I, K, O, P, Q, R, S, U, V, X | S | S |
| T | C, K, Q, R, T, X | G, T | T |
| U | K, Q, U, V | B, D, E, G, I, J, L, M, O, P, S, U, W | U |
| V | K, Q, V | A, B, D, E, G, H, I, J, L, M, N, O, P, S, U, V, W, Y | V |
| W | I, J, K, P, Q, U, V, W | E, W | W |
| X | C, K, X | D, F, G, M, R, S, T, X | X |
| Y | K, Q, V, Y | A, G, H, N, Y | Y |

Based on the result-first UP-type extraction and cause-first DOWN-type extraction, the influencing factors are extracted, and the UP-type and DOWN-type hierarchical topological diagrams are drawn, as shown in Figures 4 and 5.

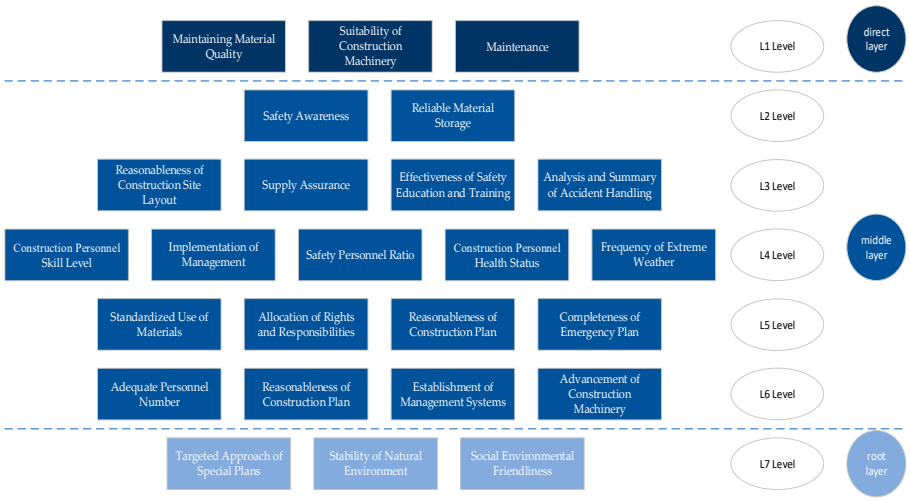



**Figure 4.** UP-type hierarchical topological diagram of major railway engineering construction safety resilience influencing factors.

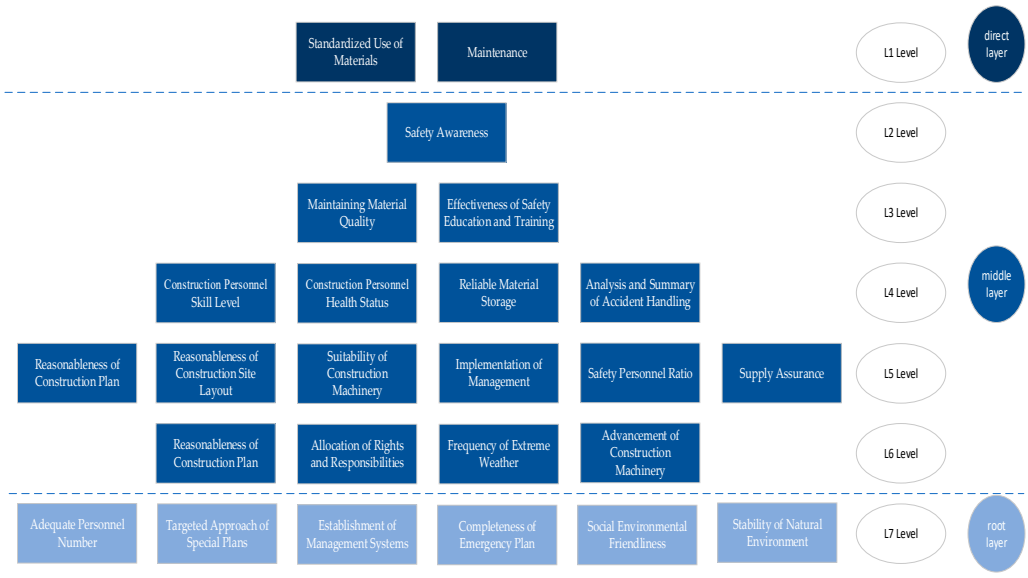



**Figure 5.** DOWN-type hierarchical topological diagram of major railway engineering construction safety resilience influencing factors.

3.2.3. Analysis of AISM Results for Safety Resilience in Major Railway Engineering Construction

Based on the AISM calculation results, a hierarchical analysis of the safety resilience is conducted. Through the UP-type and DOWN-type extraction rules, the identified influencing factors are categorized from six systems into three major levels: root, indirect, and direct layers, as well as seven sub-layers. The UP-type extraction rule extracts factors in a result-oriented manner. Therefore, the direct layer factors in the UP-type hierarchical topology are more numerous compared to those in the DOWN-type topology, focusing on the factors that are influenced among the many influencing factors. The DOWN-type extraction rule extracts factors in a cause-oriented manner. As a result, the root factors in the DOWN-type hierarchical topology are more numerous compared to the UP-type topology, focusing on the factors that influence other factors among the many influencing factors.

The factors in the direct layer can directly impact the safety resilience, influenced by the factors in the indirect and root layers, reflecting the result of the interaction and mutual influence of the influencing factors. The factors in the indirect layer indirectly influence the safety resilience by transmitting the influence of the root layer factors to the direct layer, reflecting the propagation of the interaction and mutual influence of the influencing factors. The factors in the root layer influence the safety resilience by passing their influence through the indirect layer to the direct layer, reflecting the cause and driving force of the interaction and mutual influence of the influencing factors.

1. Analysis of UP-Type Hierarchical Topology Structure

In this hierarchical topology, material quality maintenance, construction machinery applicability, and machinery maintenance are in the direct layer, while the specificity of the special plan, stability of the natural environment, and the friendliness of the social environment are in the root layer, with the remaining influencing factors in the indirect layer. Analyzing the safety resilience influencing factors from the perspective of this hierarchical topology, it can be seen that the factors in the mechanical subsystem and material subsystem are influenced by the other subsystems. Materials and machinery need to be used by personnel to participate in the construction. Whether the material quality can be maintained at a high level and whether the machinery meets construction requirements and receives timely maintenance directly impact the safety resilience of the construction. Factors from the methods and environment subsystems will affect the other factors. The effectiveness of the special plans for key challenging projects made during the early stages of the construction and the stability of the natural environment and social environment during construction will ultimately influence the direct layer factors by impacting the other factors, thereby affecting the safety resilience of the major railway construction.

2. Analysis of DOWN-Type Hierarchical Topology Structure

In this hierarchical topology, material usage standards and machinery maintenance are in the direct layer, while adequate personnel numbers, the specificity of the special plan, the formulation of management systems, the completeness of emergency plans, the stability of the natural environment, and the friendliness of the social environment are in the root layer, with the remaining influencing factors in the indirect layer. Analyzing the safety resilience influencing factors of major railway construction from the perspective of this hierarchical topology, it can be seen that the factors in the mechanical subsystem and material subsystem are influenced by the other subsystems. Materials and machinery need to be used by personnel to participate in the construction. Whether the material quality can be maintained at a high level and whether the machinery receives timely maintenance directly impacts the safety and resilience of the construction. Factors from the personnel, methods, environment, and management subsystems will affect the other factors. In the construction of major railway projects, the number of personnel at different

levels in the project organization, the effectiveness of special plans for key challenging projects, the completeness of emergency plans for unforeseen events, the stability of the natural environment, the harmony of the social environment, and the reasonableness of the management system will ultimately influence the direct layer factors by affecting the other factors, thus impacting the safety resilience of the construction.

## 3. Comprehensive Analysis

The UP-type hierarchical topology is result-oriented, so in this structure, factors in the direct layer, such as material quality maintenance, construction machinery suitability, and machinery maintenance, should receive more attention. The DOWN-type hierarchical topology is cause-oriented, so in this structure, factors in the root layer such as adequate personnel numbers, the specificity of special plans, the establishment of management systems, the completeness of emergency plans, the stability of the natural environment, and the friendliness of the social environment should be given more attention.

### *3.3. Construction of Influencing Index System for Safety Resilience of Major Railway Projects*

Compared with the 4R attributes, ARRA reflects resilience across different stages before and after an accident. Therefore, this section will build upon the results of the analysis of safety resilience factors in major railway construction projects, incorporating ARRA capabilities, by collecting data and conducting a systematic cluster analysis on the identified factors from the six subsystems of 5M1E. The resilience factors of major railway construction safety will then be reclassified according to absorption capability, resistance capability, recovery capability, and adaptability. The safety resilience of major railway projects will be used as a primary indicator, with absorption capability, resistance capability, recovery capability, and adaptability as secondary indicators and the safety resilience influencing factors as tertiary indicators. This will form an evaluation index system for safety resilience, with detailed analysis and clarification of the meaning of each evaluation indicator under these capabilities.

Construction of the Safety Resilience Influencing Index System for Major Railway Projects

The safety resilience influencing factors identified in this paper were derived from six subsystems of construction safety management—personnel, machinery, materials, methods, environment, and management—based on the meaning of safety resilience and the 4R attributes of safety resilience. These factors do not directly reflect the safety resilience of the project organizational system, and compared to ARRA capabilities, the 4R attributes cannot accurately reflect the role of safety resilience before and after an accident. A questionnaire (see Appendix C) is used to conduct a systematic cluster analysis of the identified safety resilience factors in major railway projects using SPSS 20.0 software. The influencing factors are numbered from 1 to 25, ranging from safety personnel ratio and personnel sufficiency to responsibility distribution and accident analysis summary. The clustering method selected is the inter-group linkage, with squared Euclidean distance as the measure for interval clustering. The analysis results are shown in Figure 6 below.

According to the system cluster dendrogram of safety resilience influencing factors for major railway projects, through system clustering analysis, the 25 influencing factors are classified into four categories: absorption capacity, resistance capacity, recovery capacity, and adaptability, containing 8, 6, 7, and 4 factors, respectively. Based on this result, the matrix of safety resilience influencing factors for major railway projects based on ARRA capabilities is constructed, as shown in Table 7.

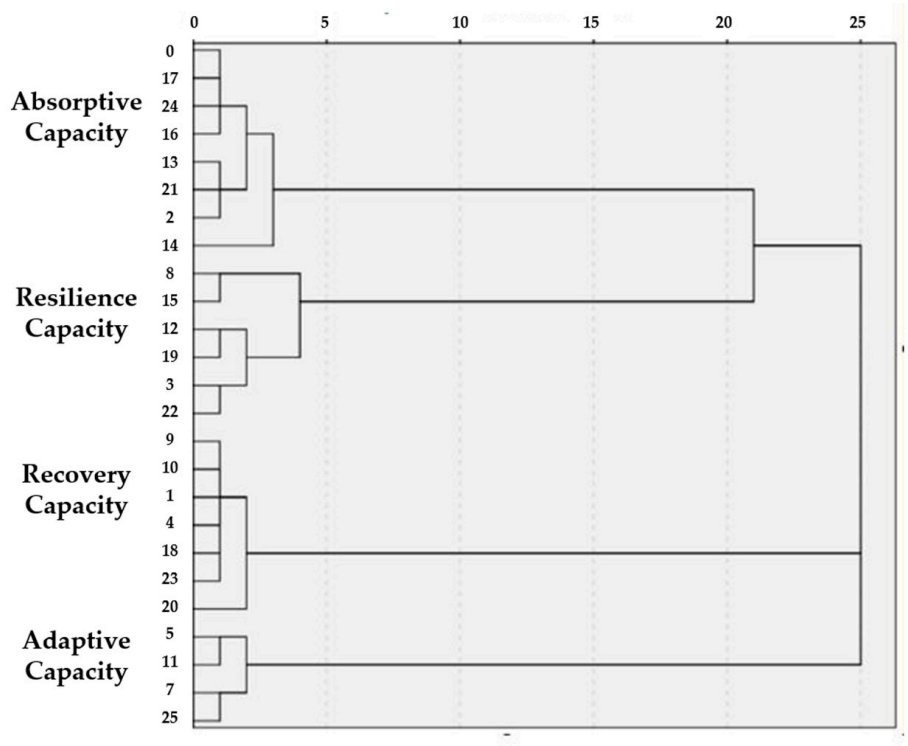



**Figure 6.** System cluster dendrogram of safety resilience influencing factors for major railway projects.

**Table 7.** Matrix of safety resilience influencing factors for major railway projects based on ARRA capabilities.

| | **Personnel Factors** | **Mechanical Factors** | **Material Factors** | **Method Factors** | **Environmental Factors** | **Management Factors** |
|---|---|---|---|---|---|---|
| Absorptive Capacity | Adequate Personnel Number | Safety Equipment Configuration | Maintaining Material Quality | Reasonableness of Construction Plan Targeted Approach of Special Plans | Reasonableness of Construction Site Layout | Establishment of Management Systems Allocation of Rights and Responsibilities |
| Resilience Capacity | Construction Personnel Skill Level | Suitability of Construction Machinery | Standardized Use of Materials | Completeness of Emergency Plan | Stability of Natural Environment | Implementation of Management Systems |
| Recovery Capacity | Safety Personnel Ratio Construction Personnel Health Status | Machinery Maintenance | Supply Assurance | / | Social Environmental Friendliness Frequency of Extreme Weather | Effectiveness of Safety Education and Training |
| Adaptability Capacity | Construction Personnel Safety Awareness | Advancement of Construction Machinery | Reliable Material Storage | / | / | Analysis and Summary of Accident Handling |

Based on the matrix of safety resilience influencing factors according to ARRA capabilities, a safety resilience evaluation index system for major railway engineering projects is constructed, consisting of three levels: 1 primary index, 4 secondary indices, and 25 tertiary indices, as shown in Table 8.

**Table 8.** Evaluation index system for the construction safety resilience of major railway engineering projects.

| Primary Indicator | Secondary Indicator | Tertiary Indicator |
|---|---|---|
| Safety Resilience in Major Railway Construction R | Absorption Capacity $R_1$ | Adequate Personnel Number R11<br>Safety Equipment Configuration R12<br>Maintaining Material Quality R13<br>Reasonableness of Construction Plan R14<br>Targeted Approach of Special Plans R15<br>Reasonableness of Construction Site Layout R16<br>Establishment of Management Systems R17<br>Allocation of Rights and Responsibilities R18 |
| | Resilience Capacity R2 | Construction Personnel Skill Level R21<br>Suitability of Construction Machinery R22<br>Standardized Use of Materials R23<br>Completeness of Emergency Plan R24<br>Stability of Natural Environment R25<br>Implementation of Management Systems R26 |
| | Recovery Capacity R3 | Safety Personnel Ratio R31<br>Construction Personnel Health Status R32<br>Machinery Maintenance R33<br>Supply Assurance R34<br>Social Environmental Friendliness R35<br>Frequency of Extreme Weather R36<br>Effectiveness of Safety Education and Training R37 |
| | Adaptability Capacity R4 | Construction Personnel Safety Awareness R41<br>Advancement of Construction Machinery R42<br>Reliability of Storage R43<br>Analysis and Summary of Accident Handling R44 |

## 4. Influencing Index System Analysis

### *4.1. Absorption Capacity Evaluation Index Analysis*

Absorption capacity is reflected before a safety incident occurs. It is a fundamental ability of construction safety resilience in major railway projects. By organizing the 5M1E subsystems of construction safety management, the project organization system can absorb certain safety hazards. Safety accidents occur only when safety hazards accumulate to a certain extent, exceeding the range that the absorption capacity can withstand. For example, small safety issues left unresolved may combine with other factors (e.g., human error, poor conditions) to create a situation where an accident becomes unavoidable.

In this study, the assessment of absorption capacity is evaluated using indicators such as adequate personnel numbers, safety equipment configuration, material quality maintenance, the rationality of construction plans, the rationality of site layout, management system formulation, and the division of responsibilities.

(1) Adequate Number of Personnel

Adequate personnel refers to arranging a sufficient number of staff in the project management office, safety management department, other management departments, and specialized engineering teams during the construction of major railway projects.

(2) Safety Equipment Configuration

Safety equipment configuration refers to the provision of sufficient, advanced, and reliable safety protection and testing equipment for on-site construction workers, in addition to the essential production machinery required for the construction of major railway projects.

(3) Maintenance of Material Quality

The maintenance of material quality refers to ensuring that the materials used in major railway construction projects meet qualified standards. Major railway projects differ from general construction projects; the environmental conditions along the route, especially through complex and hazardous areas, can affect material quality. Besides construction materials such as wood, concrete, and stone, explosives and large-scale components are also used, all of which may be affected by environmental conditions during transportation and storage, leading to potential quality degradation. Before using the materials, a re-inspection of their quality must be carried out to ensure that material quality issues do not affect the construction process, reducing safety hazards.

(4) Reasonableness of the Construction Plan

The reasonableness of the construction plan refers to a reliable plan to guide the construction work of major railway projects. When preparing the construction plan, a thorough survey of the terrain, geology, and other conditions along the route is required, along with a clear outline of the project overview, the establishment of a reasonable construction organization structure, and the rational arrangement and planning of construction tasks. In addition, the reasonable setting of construction goals and the selection of suitable construction techniques and methods for the project are important.

(5) Targeted Approach of Special Plans

The specificity of the specialized plan refers to the project organization setting up specialized plans to guide the construction of key and difficult projects during the construction. Key and difficult projects are the core of major railway construction, and their completion directly affects the overall construction. Additionally, special instructions should be provided for technical disclosures and risk control disclosures for key and difficult projects to reduce safety hazards that may arise during their construction.

(6) Reasonableness of Construction Site Layout

The rational layout of the construction site means that during the construction of major railway projects, the site should be properly arranged to reduce existing safety hazards and lower the probability of safety risk events. A properly located construction site should have good leveling, soil quality, and geological conditions. Different functional areas, such as construction, offices, material storage, and equipment placement, should be reasonably planned to ensure that all work proceeds in an orderly manner.

(7) Establishment of Management Systems

The establishment of management systems means that during the construction, management regulations should be established based on the actual situation of the construction, tailored to local conditions, ensuring the systems are effective and reasonable, regulating construction work, improving work efficiency, and reducing safety hazards. Management departments should be set up according to the needs of the construction site, with clear responsibilities for each department.

(8) Allocation of Rights and Responsibilities

During the construction of major railway projects, appropriate rights should be granted alongside the responsibilities of each position. In cases where management personnel from safety and other business management departments encounter emergencies during the evaluation and supervision of railway construction, the responsible managers should be granted the authority within their duties to directly handle such emergencies. This approach avoids situations where issues can only be addressed after approval, ensuring

timely handling of safety risks and minimizing the accumulation of risks that could lead to safety incidents.

### 4.2. Resilience Capacity Evaluation Index Analysis

Resilience capacity is the primary capability in responding to the impact of safety incidents. By adjusting various factors of the 5M1E subsystems, the occurrence of safety incidents is addressed promptly to reduce the losses caused and prevent further incidents, ensuring the safety status of the project organization remains as stable as possible. In this study, the assessment of resilience capacity is based on evaluation indicators such as the skill level of construction personnel, the suitability of construction machinery, material usage standards, the completeness of emergency plans, the frequency of extreme weather events, and the level of management implementation.

(1) Construction Personnel Skill Level

The skill level of construction personnel refers to their ability to accurately, properly, and safely complete construction tasks. High-level construction workers on-site can effectively reduce the impact of safety incidents. Personnel from different specialties must have a thorough understanding of the construction stages and processes in their respective fields of railway engineering. They should be proficient in operating the required machinery, using protective safety equipment properly, and making decisions to ensure their own safety and minimize property loss in the event of an accident.

(2) Suitability of Construction Machinery

The suitability of construction machinery refers to the ability of the machinery provided by the project organization in major railway engineering projects to maintain normal operation even after a safety incident occurs without causing further safety accidents or additional losses due to machinery being unsuitable. The construction machinery selected for major railway engineering projects must meet the project's requirements, including the size of the project, performance requirements, and safety requirements.

(3) Standardized Use of Materials

Material usage regulations refer to the requirement that all materials needed for construction in major railway engineering projects must be used according to relevant regulations, especially after a safety incident, to avoid further impacts and greater losses due to the improper use of construction materials.

(4) Completeness of Emergency Plan

The completeness of the emergency plan refers to the comprehensive emergency procedures developed by the project organization system to respond to safety incidents, ensuring timely handling to minimize the impact of such incidents. The emergency plan should provide effective guidance for handling safety incidents within the project organization, including detailed contingency plans that clarify how to respond to incidents, assign responsibilities, and supply emergency resources. It ensures that the project organization system can respond swiftly and appropriately to an emergency incident.

(5) Stability of Natural Environment

The stability of the natural environment refers to the surrounding natural environment of the project organization system being stable during construction, especially ensuring that the impact of a safety incident does not worsen due to environmental instability.

(6) Implementation of Management Systems

The degree of management implementation refers to the ability of the management system and measures established by the project organization to be effectively applied to the

safety management, ensuring management effectiveness and reducing the losses caused by safety incidents. In addition to managing specific construction tasks and personnel, the project organization should also establish an independent supervisory body to evaluate the management work of personnel and assess whether management measures are effectively implemented in front-line safety management.

### *4.3. Recovery Capacity Evaluation Index Analysis*

Recovery capability is the core ability to restore the construction safety state after the impact of a safety incident no longer expands. It involves conducting checks on the 5M1E subsystems and deeply investigating any remaining safety factors in the project system after the safety incident has been handled. This process aims to eliminate construction safety hazards, improve construction safety levels, and restore the safety state to a higher level. In this study, the evaluation of recovery capability is based on indicators such as safety personnel ratio, construction personnel health status, machinery maintenance, material supply assurance, targeted special plans, social environmental friendliness, frequency of extreme weather, and effectiveness of safety education and training.

(1) Safety Personnel Ratio

The allocation of safety personnel refers to adjusting the distribution of personnel based on changes in the actual conditions of the construction site, increasing the number of required personnel types. After handling a safety incident, the overall safety status of the project system is at its lowest point but no longer decreasing. At this stage, the demand for safety management personnel and safety education training staff increases.

(2) Construction Personnel Health Status

The health status of construction workers refers to the condition where, after handling a safety incident, the workers remain in good health to continue their construction work. Major railway construction projects often pass through complex and hazardous areas, and workers who are employed in such regions for extended periods are vulnerable to both physical and psychological health issues. After handling a safety incident, when the safety status of the project organization is still low, special attention should be paid to the physical and psychological health of the workers. This is to prevent harm to their health during the safety hazard investigation and recovery process, thereby assisting in the restoration of the project's safety status.

(3) Machinery Maintenance

Machinery maintenance refers to the timely repair and maintenance of mechanical equipment during the residual safety hazard inspection phase after handling a safety incident. During the residual safety hazard inspection phase, timely cleaning, lubrication, tightening, and the adjustment of various mechanical equipment should be carried out. Additionally, maintenance records should be established to track the condition of the equipment.

(4) Supply Assurance

Material supply assurance refers to ensuring the timely provision of materials needed during the restoration of construction safety. After handling a safety incident, the timely supply of required materials during the restoration of the project's safety status must be ensured, so that the usage of daily construction and safety materials will not be impacted and tasks affected by the incident can resume promptly.

(5) Social Environmental Friendliness

Social environment friendliness refers to the surrounding social environment being supportive and not hindering the restoration of the construction safety status during the

recovery phase. The occurrence of a safety incident impacts the entire project system, requiring the project organization to allocate additional resources to restore safety to its normal state. If the social environment is not friendly, protests, demonstrations, or even conflicts may arise, which could affect the identification of safety hazards and hinder the recovery of construction safety status.

(6) Frequency of Extreme Weather

The frequency of extreme weather refers to the number of times extreme weather events occur in the environment of the project organization during the restoration of the construction safety status. Major railway projects often traverse complex and hazardous areas, where extreme weather such as strong winds, heavy rain, and snowstorms are common. The occurrence of extreme weather can severely impact the project organization, which is in a lower safety state, and hinder the identification of remaining safety hazards.

(7) Effectiveness of Safety Education and Training

The effectiveness of safety education and training refers to the training conducted after handling safety accidents. This training should improve the management personnel's ability to handle safety incidents. It should also enhance the construction workers' ability to respond to accidents.

### *4.4. Adaptability Capacity Evaluation Index Analysis*

Adaptability is the key ability to improve a project organization's capacity to handle safety accidents. It is achieved by collaborating with various subsystems of 5M1E after the remaining safety hazards are identified. Adaptability has two dimensions. The first category involves adapting to the occurrence of similar safety incidents, enhancing the absorption capacity for analogous risks, thereby reducing the likelihood of their recurrence. The second category pertains to adapting to diverse safety incidents, improving resistance and recovery capabilities to address different types of safety events. This strengthens the project organizational system's resilience against impacts caused by similar safety incidents and further decreases the probability of such incidents occurring. In this study, adaptability is evaluated through indicators such as construction workers' safety awareness, the advanced nature of construction machinery, reliable material storage, and accident handling analysis and summary.

(1) Construction Personnel Safety Awareness

The safety awareness of construction workers refers to the improvement of their safety consciousness after the remaining safety hazards are identified and the safety state is restored, allowing them to better adapt to the occurrence of safety accidents. Construction workers are on the front lines of railway engineering projects. Unsafe behavior by workers is a significant factor contributing to accidents, and their safety awareness is crucial in determining the overall safety status of the project organization.

(2) Advancement of Construction Machinery

The advancement of construction machinery refers to the selection of machinery with sufficient technological advancement in major railway projects. It should be adaptable to the occurrence of safety accidents and capable of adjusting its safety settings based on previous incidents. Due to the long duration and high complexity of major railway projects, construction machinery must work in coordination with workers to complete the construction tasks effectively. Therefore, machinery with advanced technology is essential.

(3) Reliable Material Storage

Reliable material storage refers to the proper storage of necessary materials during major railway construction projects aimed at addressing safety incidents and enhancing

the project organization's ability to respond to such incidents. Clearly define the categories and quantities of materials needed throughout the construction period. Plan, classify, label, stack, and store the materials required for construction and safety recovery, with additional reserves to ensure that material shortages do not affect construction safety, thereby enhancing the project organization's ability to respond to safety incidents.

(4) Analysis and Summary of Accident Handling

Accident handling analyses and summaries involve conducting a thorough analysis of the causes, process, handling, and recovery of a safety incident after the safety issues have been addressed in a major railway construction project. Analyzing and summarizing safety incidents is a crucial step in improving the project organization's ability to absorb and resist incidents and recover from their impact.

## 5. Conclusions

The construction of major railway projects, with their large scale, long durations, and technical complexity, presents significant safety challenges due to diverse environmental, geological, and socio-cultural factors. This study has demonstrated that traditional risk management approaches, which focus primarily on post-incident analysis and mitigation, may not be sufficient to address the complex safety issues inherent in these projects.

Therefore, this study is carried out from the following aspects:

(1) By incorporating resilience theory into the safety management framework, this research proposes a shift towards resilience-based management (Safety-II), which emphasizes proactive safety measures and the system's capacity to recover and adapt to unforeseen risks.

(2) The development of a safety resilience evaluation framework, incorporating the 4R attributes (robustness, redundancy, resourcefulness, and rapidity) and ARRA capabilities (absorptive, resistant, restorative, and adaptive), provides a comprehensive tool for assessing and improving safety management throughout the project lifecycle.

(3) Through AISM and systematic clustering analysis, key safety resilience factors were identified and integrated into an actionable evaluation system, ensuring a more holistic approach to managing safety.

Ultimately, this research offers a practical and systematic approach to enhance safety resilience in major railway projects, contributing to safer, more efficient construction practices and sustainable infrastructure development, with implications for future research and practical applications in construction safety management.

## 6. Future Research Discussion

The next step of the research will be based on the evaluation index system for the construction safety resilience of major railway projects. It will compare common weighting methods and evaluation models to select the most suitable ones. The appropriate weighting method will be applied, and the evaluation model will be used to construct the safety resilience evaluation model for major railway construction projects. Evaluation level characteristics will be proposed, and specific cases will be selected for empirical analysis. Based on the evaluation results, the key areas for improving construction safety resilience in major railway projects will be identified, and improvement measures will be proposed.

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## Appendix A. Survey on the Modified Factors Affecting the Construction Safety Resilience of Major Railway Projects

*Appendix A.1*

Dear Expert.

Thank you very much for taking the time out of your busy schedule to fill out this questionnaire! In order to complete the modification of factors affecting the construction safety resilience of major railway projects, this study has gathered relevant factors through literature, industry standards, and field surveys, and made adjustments. This questionnaire is designed to modify the factors affecting the six subsystems—personnel, machinery, materials, methods, environment, and management—based on the adjusted factors. We sincerely invite you to participate. The questionnaire is anonymous, and all information will be used solely for academic research purposes. Your personal information and responses will not be disclosed to any third party.

Part One: Basic Information

Please mark "√" in the option you deem appropriate (there are no right or wrong answers; this is for research data reference only).

1. What type of organization do you work for? [Choice question]:
   - ○ Owner
   - ○ Construction Unit
   - ○ Design Unit
   - ○ Research Institute
   - ○ Government Department
   - ○ Other
2. The years of your professional experience. [Choice question]:
   - ○ Less than 3 years
   - ○ 3–5 years
   - ○ 5–10 years
   - ○ More than 10 years
3. How well do you understand the safety of major railway construction projects? [Choice question]:
   - ○ Not familiar
   - ○ Somewhat familiar
   - ○ Familiar
   - ○ Expert

*Appendix A.2*

Part Two: Revision of Factors Affecting Safety Resilience in Major Railway Construction Projects

This study identifies 28 factors across 6 subsystems. Please rate the importance of each factor based on your work experience and the actual safety situation in railway construction. The scale is as follows: 1 = Very Unimportant, 2 = Slightly Unimportant, 3 = Neutral, 4 = Slightly Important, 5 = Very Important.

**Table A1.** Scoring table for the revision of factors affecting safety resilience in major railway construction projects.

| Factor Subsystem | Influencing Factor | Importance Level |
|---|---|---|
| Personnel | Safety Personnel Ratio<br>Adequate Personnel Number<br>Construction Personnel Skill Level<br>Construction Personnel Health Status<br>Safety Awareness | |
| Mechanical | Safety Equipment Configuration<br>Advancement of Construction Machinery<br>Suitability of Construction Machinery<br>Compliance of Machinery Operation<br>Machinery Maintenance | |
| Materials | Supply Assurance<br>Reliable Material Storage<br>Standardized Use of Materials<br>Maintaining Material Quality | |
| Methods | Reasonableness of Construction Plan<br>Completeness of Emergency Plan<br>Targeted Approach of Special Plans<br>Specialized Technical Disclosure | |
| Environment | Reasonableness of Construction Site Layout<br>Social Environmental Friendliness<br>Stability of Natural Environment<br>Frequency of Extreme Weather | |
| Management | Establishment of Management Systems<br>Implementation of Management<br>Effectiveness of Safety Education and Training<br>Allocation of Rights and Responsibilities<br>Timeliness of Pre-Shift Education<br>Analysis and Summary of Accident Handling | |

*Appendix A.3*

Part Three: Additional Suggestions

If you have any further suggestions or modifications regarding the factors influencing the construction safety resilience of major railway projects, you can provide them in this section. This research will give thorough consideration to your input. Thank you for your support.

**Table A2.** Additional suggestions for modifications to the factors influencing the construction safety resilience of major railway projects.

| Type of Suggestion | Specific Suggestion |
|---|---|
| | |

## Appendix B. AISM Adjacency Matrix Survey on Factors Affecting the Safety Resilience of Major Railway Engineering Construction

*Appendix B.1*

Dear Expert.

Thank you very much for taking the time out of your busy schedule to fill out this questionnaire! In order to complete the AISM analysis of factors affecting the safety resilience of major railway engineering construction, this questionnaire aims to gather your opinions on the interrelationships of these factors and is designed to construct the adjacency matrix. We sincerely invite you to participate. The questionnaire is anonymous, and all information will be used solely for academic research purposes. Your personal information and responses will not be disclosed to any third party.

Part One: Basic Information

Please mark "√" in the option you deem appropriate (there are no right or wrong answers; this is for research data reference only).

1. What type of organization do you work for? [Choice question]:
   - ○ Owner
   - ○ Construction Unit
   - ○ Design Unit
   - ○ Research Institute
   - ○ Government Department
   - ○ Other
2. The years of your professional experience. [Choice question]:
   - ○ Less than 3 years
   - ○ 3–5 years
   - ○ 5–10 years
   - ○ More than 10 years
3. How well do you understand the safety of major railway construction projects? [Choice question]:
   - ○ Not familiar
   - ○ Somewhat familiar
   - ○ Familiar
   - ○ Expert

*Appendix B.2*

Part Two: Determining the Relationships of Factors Affecting the Safety Resilience of Major Railway Engineering Construction

If you believe that the column factors have an effect on the row factors, please mark "1" in the corresponding space.

**Table A3.** Impact relationship table of factors affecting the safety resilience of major railway engineering construction.

| | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** | **I** | **J** | **K** | **L** | **M** | **N** | **O** | **P** | **Q** | **R** | **S** | **T** | **U** | **V** | **W** | **X** | **Y** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | | | | | | | | | | | | | | | | | | | | | | | | | |
| B | | | | | | | | | | | | | | | | | | | | | | | | | |
| C | | | | | | | | | | | | | | | | | | | | | | | | | |
| D | | | | | | | | | | | | | | | | | | | | | | | | | |
| E | | | | | | | | | | | | | | | | | | | | | | | | | |
| F | | | | | | | | | | | | | | | | | | | | | | | | | |
| G | | | | | | | | | | | | | | | | | | | | | | | | | |
| H | | | | | | | | | | | | | | | | | | | | | | | | | |
| I | | | | | | | | | | | | | | | | | | | | | | | | | |
| J | | | | | | | | | | | | | | | | | | | | | | | | | |
| K | | | | | | | | | | | | | | | | | | | | | | | | | |
| L | | | | | | | | | | | | | | | | | | | | | | | | | |
| M | | | | | | | | | | | | | | | | | | | | | | | | | |
| N | | | | | | | | | | | | | | | | | | | | | | | | | |
| O | | | | | | | | | | | | | | | | | | | | | | | | | |
| P | | | | | | | | | | | | | | | | | | | | | | | | | |
| Q | | | | | | | | | | | | | | | | | | | | | | | | | |
| R | | | | | | | | | | | | | | | | | | | | | | | | | |
| S | | | | | | | | | | | | | | | | | | | | | | | | | |
| T | | | | | | | | | | | | | | | | | | | | | | | | | |
| U | | | | | | | | | | | | | | | | | | | | | | | | | |
| V | | | | | | | | | | | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | |
| X | | | | | | | | | | | | | | | | | | | | | | | | | |
| Y | | | | | | | | | | | | | | | | | | | | | | | | | |

**Table A4.** Corresponding factors table (A–Y).

| Type of Suggestion | Specific Suggestion |
|---|---|
| A | Adequate Personnel Number |
| B | Safety Equipment Configuration |
| C | Maintaining Material Quality |
| D | Reasonableness of Construction Plan |
| E | Targeted Approach of Special Plans |
| F | Reasonableness of Construction Site Layout |
| G | Establishment of Management Systems |
| H | Allocation of Rights and Responsibilities |
| I | Construction Personnel Skill Level |
| J | Suitability of Construction Machinery |
| K | Standardized Use of Materials |
| L | Completeness of Emergency Plan |
| M | Stability of Natural Environment |
| N | Implementation of Management |
| O | Safety Personnel Ratio |
| P | Construction Personnel Health Status |
| Q | Machinery Maintenance |
| R | Supply Assurance |
| S | Social Environmental Friendliness |
| T | Frequency of Extreme Weather |
| U | Effectiveness of Safety Education and Training |
| V | Safety Awareness |
| W | Advancement of Construction Machinery |
| X | Reliable Material Storage |
| Y | Analysis and Summary of Accident Handling |

## Appendix C. System Clustering Survey of Major Railway Engineering Construction Safety Resilience Factors

Dear Expert.

Thank you very much for taking the time out of your busy schedule to fill out this questionnaire! In order to complete the system clustering analysis of major railway engineering construction safety resilience factors, this questionnaire aims to solicit your opinions on the clustering analysis of these factors. The factors will be fully categorized and grouped under the four capabilities of ARRA. We sincerely invite you to participate. We sincerely invite you to participate. The questionnaire is anonymous, and all information will be used solely for academic research purposes. Your personal information and responses will not be disclosed to any third party.

Part One: Basic Information

Please mark "√" in the option you deem appropriate (there are no right or wrong answers; this is for research data reference only).

1. What type of organization do you work for? [Choice question]:

- ○ Owner
- ○ Construction Unit
- ○ Design Unit
- ○ Research Institute
- ○ Government Department
- ○ Other

2. The years of your professional experience. [Choice question]:
   - ○ Less than 3 years
   - ○ 3–5 years
   - ○ 5–10 years
   - ○ More than 10 years
3. How well do you understand the safety of major railway construction projects? [Choice question]:
   - ○ Not familiar
   - ○ Somewhat familiar
   - ○ Familiar
   - ○ Expert

Part Two: Survey on the Characteristics of Major Railway Engineering Construction Safety Resilience Factors

Please score each factor based on how similar you believe it is to the characteristics of the corresponding capability. The score range is from 1 to 9. 1 means "strongly disagree", 2 means "disagree to a considerable extent", 3 means "slightly disagree", 4 means "somewhat disagree", 5 means "unclear", 6 means "somewhat agree", 7 means "slightly agree", 8 means "agree to a considerable extent", and 9 means "strongly agree".

**Table A5.** Scoring table for the characteristics of major railway engineering construction safety resilience factors.

| | **Absorption Capacity** | **Resilience Capacity** | **Recovery Capacity·** | **Adaptability Capacity** |
|---|---|---|---|---|
| Safety Personnel Ratio | | | | |
| Adequate Personnel Number | | | | |
| Construction Personnel Skill Level | | | | |
| Construction Personnel Health Status | | | | |
| Safety Awareness | | | | |
| Advancement of Construction Machinery | | | | |
| Suitability of Construction Machinery | | | | |
| Machinery Maintenance | | | | |
| Supply Assurance | | | | |
| Reliable Material Storage | | | | |
| Standardized Use of Materials | | | | |
| Maintaining Material Quality | | | | |
| Reasonableness of Construction Plan | | | | |
| Completeness of Emergency Plan | | | | |
| Targeted Approach of Special Plans | | | | |
| Reasonableness of Construction Site Layout | | | | |

**Table A5.** *Cont.*

| | Absorption Capacity | Resilience Capacity | Recovery Capacity· | Adaptability Capacity |
|---|---|---|---|---|
| Social Environmental Friendliness | | | | |
| Stability of Natural Environment | | | | |
| Frequency of Extreme Weather | | | | |
| Establishment of Management Systems | | | | |
| Implementation of Management | | | | |
| Effectiveness of Safety Education and Training | | | | |
| Allocation of Rights and Responsibilities | | | | |
| Analysis and Summary of Accident Handling | | | | |

**Note:**

| ARRA Capabilities | Meaning |
|---|---|
| Absorption | Reduce safety hazards and decrease the likelihood of safety incidents. |
| Resistance | Implement safety management to reduce the impact of safety incidents and prevent further escalation. |
| Recovery | Identify remaining safety hazards and restore safe construction. |
| Adaptation | Summarize and learn to improve incident response capabilities. |

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