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A Study of Quality Management Risks in Construction Projects Based on Social Network Analysis

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Abstract: This research employs a two-dimensional perspective that integrates stakeholders and the entire project lifecycle. It utilizes social network analysis methods and Ucinet6 software to establish a network model of quality management risks in the context of Engineering Inherent Defects Insurance (IDI), Engineering Quality Liability Insurance, and Engineering Quality Assurance Insurance. The study calculates and analyzes the centrality, group density, and cohesive subgroups within the risk network. It identifies key influencing factors and, based on the analysis results, proposes strategies and recommendations. This research provides vital decision support for the future development of the construction industry. The study reveals that three key factors, namely, inadequate construction organization management, unclear construction scope definition, and improper maintenance of construction machinery, are closely related to quality management risk factors. These risks can be effectively mitigated through measures such as strengthening the training of management personnel, implementing relevant regulations, and regular maintenance of construction machinery.

Keywords: social network analysis, construction projects, quality management, risk

1. Introduction

In recent years, with the robust development of China's construction industry, concerns regarding the quality of construction have gained increasing attention. Among these concerns, quality management stands out as a critical factor influencing overall quality. The construction process involves complex interactions between human and machine elements, and while there has been substantial research on construction quality management risks, there remains an absence of a comprehensive risk management system, particularly concerning the management of quality risks during the building's use phase. To address this gap, China has introduced the concepts of Inherent Defects Insurance (IDI), Engineering Quality Liability Insurance, and Engineering Quality Assurance Insurance from international practices. However, these concepts are relatively new in China, and their implementation faces various challenges. In this context, the enhancement of the quality management risk system for construction projects becomes paramount.

Quality management risks often exhibit suddenness and high dynamics, making them difficult to predict and eliminate in advance. While existing research has provided basic summaries of quality management risk factors, the defined boundaries remain relatively broad, lacking comprehensive specificity. Many studies are founded on the assumption of the independent existence of risk factors,

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neglecting the interrelationships between them. In reality, during the construction and usage phases of buildings, quality management risk factors are correlated rather than completely independent, forming a complex network of management risks. Therefore, identifying key factors, distinguishing their relative importance, and establishing relevant quality management risk network models can effectively reduce the probability of quality issues in construction. This, in turn, enhances the efficiency of human-machine interactions in project management. For instance, as demonstrated by Fan Zhang and others [1], social network analysis methods were used to analyze and evaluate the selection of construction equipment types, providing meaningful suggestions for the optimal selection of various types of construction equipment, and proposing a practical case study to evaluate the selection of loaders. Similarly, W. S. Yip et al [2]. carefully considered stakeholders' concerns about the triple bottom line (TBL) and employed Social Network Analysis (SNA) to identify and investigate potential obstacles and their causal relationships related to stakeholders in sustainable manufacturing (SM). Targeted control strategies were proposed from the perspective of the survey results of SNA.

Based on these insights, this article will effectively identify construction project quality management risk factors from three perspectives: human, machine, and their interaction. It will utilize SNA to establish a research model for quality management risk networks, assess relevant network nodes, analyze their mutual influences, identify key quality management risk factors, and provide recommendations for risk mitigation. The aim is to offer new insights into the research on construction project quality management risks.

2. Social Network Analysis

2.1. Concept of Social Network Analysis

SNA originated in the 1930s and was initially used for quantitatively analyzing issues in sociology. As sociology evolved, researchers began to recognize that studying individual actions alone was no longer sufficient; rather, the focus shifted toward studying the structure of society and the relationships within it. By the 1990s, SNA had started to find extensive applications in various fields.

SNA is a comprehensive theoretical approach based on graph theory and mathematical models to analyze the structure of relationships between actors, the relationships between actors and their social networks, and the interactions between social networks. In this context, actors, referred to as "nodes," can be abstract or concrete, and the set of relationships among these actors constitutes the "social network."

2.2. Applications of Social Network Analysis

Conducting analyses through SNA is crucial for identifying key influencing factors and their intrinsic connections. Dr. Behzad Rouhanizadeh [3] used SNA to investigate the causal relationships between factors contributing to delays in the post-hurricane recovery process, pinpointing three factors responsible for the most significant delays. Sandeep K. Sood and others [4] proposed a new concept of Free Resource Fog (FRF) based on SNA, employing this concept to collect available free resources from all running jobs to help eliminate deadlocks. Sadegh Amani Beni [5] and colleagues proposed a comprehensive method for detecting market forces based on the concept of SNA centrality, revealing measures for formulating structural and behavioral market forces. They concluded that SNA can be used as an effective tool for monitoring future smart grid market forces, which have a large number of participants and complexity.

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2.3. Quantitative Metrics in Social Network Analysis

SNA treats numerous individuals as network nodes while simultaneously examining node attributes and overall system structural characteristics, showcasing the strengths of social network analysis methods.

From the perspective of social networks, various centrality metrics are analyzed to quantify the power of individual actors, aiding in determining the importance of various factors. Therefore, this article will elucidate the following centrality metrics:

(1) Degree Centrality: This reflects the concentration of node connections. In simple terms, it measures the power of a node by the number of points directly related to it, known as degree centrality. In other words, a node's degree centrality is the sum of the lines directly connected to that node, also known as node degree. Degree centrality can be divided into node Outdegree and node Indegree. Analyzing node outdegree and indegree can reveal which risk factors in the risk network are most likely to influence other risks and which risks are most susceptible to the influence of other risks. It can be considered one of the simplest and most intuitive indicators.

$$\text{Node Indegree } C_D(n_i) = \frac{\sum_1^i dI(ni)}{v_{i\,max}(N-1)} \quad (1)$$

$$\text{Node Outdegree } C_D(n_i) = \frac{\sum_1^i do(ni)}{v_{i\,max}(N-1)} \quad (2)$$

Where $\mathrm{dI(ni)}$ is the Indegree value of node i, $\mathrm{do(ni)}$ is the outdegree value of node i, and n is the network size.

(2) Betweenness Centrality: This reflects the extent to which a node acts as a "broker." It is the ratio of the number of paths passing through node i to the total number of paths between two points. Betweenness centrality indicates the likelihood of a node in the network acting as a mediator between other nodes and the impact it has on nodes passing through it. It measures the degree of control a node has over the network and its influence on nodes passing through it.

$$C_B = \frac{\sum_{j<k} g_{jk}(n_i)/g_{jk}}{[(N-1)(N-2)]} \quad (3)$$

Where $g_{jk}(n_i)$ is the number of paths passing through node i between points j and k, and g_{jk} is the total number of paths between points j and k in the network.

(3) Closeness Centrality: This reflects the closeness between nodes. It is defined as the sum of the shortest distances between a node and all other nodes in the graph. Nodes with higher closeness centrality are more central and can exert influence on other nodes more rapidly than those with lower closeness centrality. Unlike degree centrality, closeness centrality considers indirect relationships.

$$C_C = (n-1)\left[\sum_{j=1}^{n} d(n_i, n_j)\right]^{-1} \quad (4)$$

Where $d(n_i, n_j)$ represents the number of paths between node i and node j, and n is the network size.

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3. Model Development

3.1. Factor Identification

In this study, we start by utilizing the concepts of Inherent Defects Insurance (IDI), Engineering Quality Liability Insurance, and Engineering Quality Assurance Insurance. We adopt a two-dimensional perspective, focusing on stakeholders and the entire engineering construction process, to identify specific risk factors. We categorize these risk factors into three levels, as shown in Table 1.

Table 1: Identification and Classification of Quality Management Risk Factors in Construction Projects.

Risk Code	Risk Factor	Category	Stakeholder
R1	Inadequate quality management control system	Human	Construction
R2	Inexperienced and underqualified construction personnel		Construction
R3	Incomplete completion acceptance management system		Supervision
R4	Improper completion acceptance inspection		Supervision
R5	Lack of operational management experience		Contractor
R6	Inadequate operational management system		Contractor
R7	Unclear responsibility for quality issues		Construction
R8	Unreasonable construction organization management		Construction
R9	Unclear definition of construction scope		Construction
R10	Inadequate performance of quality and safety responsibilities		Supervision
R11	Improper management of construction machinery arrangements	Machine	Construction
R12	Improper maintenance of construction machinery		Construction
R13	Improper use and operation of construction machinery		Construction
R14	Excessive wear and tear of machinery due to prolonged use		Construction
R15	Adverse construction climate conditions	Environ ment	Construction
R16	Rare extreme weather changes during construction		Construction
R17	Complex and variable construction conditions		Construction

3.2. Obtaining the Adjacency Matrix

In this study, we employed a questionnaire survey method to determine the interrelationships between quality management risk factors. Additionally, interviews were conducted with professionals who

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possess a deep understanding of the project specifics. A “0-1” scoring system was utilized to assess the degree of association between each factor. A score of “0” indicates that factor Ri does not influence factor Rj, while a score of “1” indicates that factor Ri influences factor Rj. The resulting adjacency matrix, where the “rows” represent factors that directly influence other factors and the “columns” represent factors that are directly influenced by other factors, is presented in Table 2.

Table 2: Adjacency Matrix of Quality Management Risk Factors in Construction Projects.

Code	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
R1	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0
R2	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
R3	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
R4	1	0	1	0	0	0	1	0	0	1	0	0	0	0	1	0	0
R5	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
R6	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0
R7	1	0	1	0	0	1	0	1	1	0	0	0	0	0	0	0	0
R8	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0
R9	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
R10	1	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0
R11	0	1	0	0	1	1	0	1	0	0	0	0	0	0	0	1	0
R12	0	1	0	0	1	1	0	1	0	1	1	0	0	0	1	1	1
R13	0	1	0	0	0	0	0	0	1	1	0	0	0	1	1	1	1
R14	0	1	0	0	0	0	0	1	0	0	1	1	1	0	0	0	0
R15	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	0
R16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R17	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0

3.3. Construction of Risk Social Network

This section presents a detailed overview of the steps involved in constructing the risk network. It primarily encompasses the following five steps: data import, social network visualization, centrality analysis, cohesive subgroup analysis, and network density. As illustrated in Figure 1.

3.3.1. Data Import

First, we access the Matrix spreadsheet function in Ucinet6 and import the data from Excel, which includes the data presented in Table 2. The data is copied and pasted, and then saved in Ucinet format as either “##h” or “##d.”

3.3.2. Social Network Visualization

Next, we use the NetDraw function within Visualize. We open the processed data by selecting File → Open → Ucinet dataset → Network, which allows us to generate a visual representation of the social network.

3.3.3. Centrality Analysis

We then access the Network function and, through Centrality → Multiple Measures, open the processed data to obtain results for three different centrality measures.

3.3.4. Cohesive Subgroup Analysis

Within the Network function, we use Subgroups → Cliques to open the processed data. This step provides both textual data for subgroup analysis and a visual tree diagram.

3.3.5. Network Density

Finally, we access the Network function again, this time using Cohesion → Density → (new) Density Overall to open the processed data. This step allows us to generate results for network density analysis.

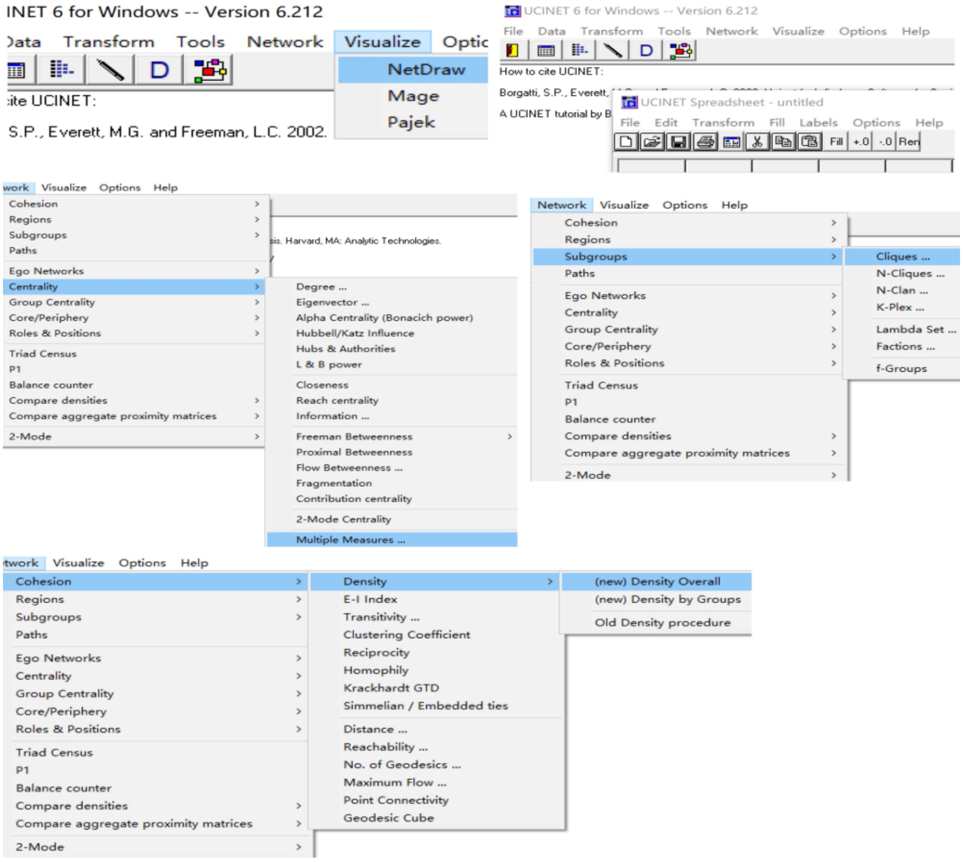

Figure 1: Operational Flow for Constructing the Risk Social Network.

4. Model Analysis

4.1. Network Characteristic Analysis

4.1.1. Visualization

As previously mentioned, we utilized the NetDraw function in Ucinet6 software to visualize the relationship network among risk factors in construction project quality management. The risk relationship matrix has been visualized, as shown in Figure 2.

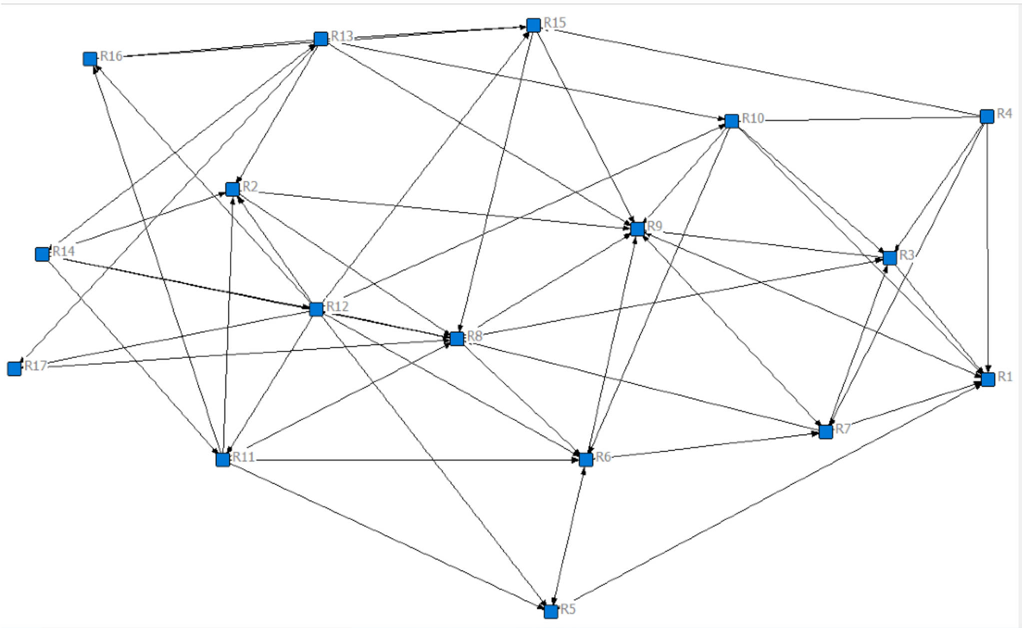

Figure 2: Social Network Diagram of Construction Project Quality Management Risks.

4.1.2. Centrality Analysis

Through the relationship network, it is evident that there are connections among the 17 influencing factors. The identification of key factors and their interplay requires an analysis of centrality, specifically, degree centrality, betweenness centrality, and closeness centrality.

(1) Degree Centrality Analysis

Degree centrality measures the number of nodes directly connected to each node. A higher value indicates that the node is more likely to be in a central position. As shown in Table 3, it is evident that “Incomplete Operation Management System (R6),” “Unreasonable Construction Organization Management (R8),” “Unclear Construction Scope Definition (R9),” “Failure of the Quality and Safety Responsibility Subject to Strictly Perform Duties (R10),” “Inadequate Management of Construction Machinery Arrangement (R11),” “Inadequate Maintenance of Construction Machinery (R12),” and “Improper Operation of Construction Machinery (R13)” have degree centrality values greater than the average, signifying that these factors occupy central positions and are crucial in influencing quality management. However, degree centrality only indicates the importance of the factors themselves and does not describe the relationships between them. Therefore, an analysis of betweenness centrality and closeness centrality is also required.

(2) Betweenness Centrality Analysis

Betweenness centrality measures the control between nodes. A higher value indicates that a node is more likely to act as an intermediary, thus exerting more control over other nodes. As shown in Table 3, it is evident that “Unreasonable Construction Organization Management (R8),” “Unclear Construction Scope Definition (R9),” “Failure of the Quality and Safety Responsibility Subject to Strictly Perform Duties (R10),” “Inadequate Maintenance of Construction Machinery (R12),” “Improper Operation of Construction Machinery (R13),” and “Adverse Construction Climate Conditions (R15)” have betweenness centrality values higher than the average, signifying that these factors exert control over other factors. Higher betweenness centrality values indicate that these factors have both direct and indirect effects on quality management.

(3) Closeness Centrality Analysis

Closeness centrality measures the proximity between nodes. A higher value indicates that the total distance between nodes is shorter, implying better control and being controlled by others. As shown in Table 3, the average closeness centrality in this relationship network diagram is 60.339, indicating a strong controlling factor presence. Among these, "Incomplete Operation Management System (R6)," "Unreasonable Construction Organization Management (R8)," "Unclear Construction Scope Definition (R9)," "Failure of the Quality and Safety Responsibility Subject to Strictly Perform Duties (R10)," "Inadequate Management of Construction Machinery Arrangement (R11)," "Inadequate Maintenance of Construction Machinery (R12)," "Improper Operation of Construction Machinery (R13)," and "Adverse Construction Climate Conditions (R15)" are eight factors with high closeness centrality. Factors with high closeness centrality are more influenced by related factors and can effectively control other factors. Improving the effectiveness of these factors is crucial for enhancing the quality management of construction projects.

Table 3: Centrality Analysis Results of Quality Management Risk Factors.

Dimensionality	Degree	Closeness	Betweenness	Eigenvector
R1	37.500	55.172	3.401	28.033
R2	37.500	59.259	1.526	35.310
R3	37.500	59.259	1.778	31.722
R4	31.250	51.613	1.675	23.433
R5	25.000	55.172	2.093	21.964
R6	43.750	64.000	3.980	39.516
R7	37.500	59.259	2.329	32.136
R8	62.500	72.727	13.808	50.923
R9	56.250	69.565	8.785	46.488
R10	43.750	64.000	6.154	36.263
R11	43.750	61.538	3.980	35.864
R12	62.500	72.727	12.957	47.025
R13	43.750	61.538	6.728	32.165
R14	31.250	55.172	0.712	29.387
R15	37.500	61.538	5.475	32.346
R16	25.000	51.613	0.915	21.520
R17	18.750	51.613	0.370	18.996
Mean	39.706	60.339	4.510	33.123

4.1.3. Group Density Analysis

Table 4: Overall Analysis Indicators for Risk Network.

Indicator	Value
Number of Network Nodes	17
Number of Network Connections	60
Network Density	0.2206

As can be seen from Table 4, it is evident that through the use of Ucinet6.0 software, a total of 67 mutual influence relationships were calculated within this risk social network diagram. The overall network density is 0.2206, which indicates a relatively low level. The complexity of risks throughout the entire project is moderate, and the overall risk level that project managers need to contend with is on the lower side of moderate.

4.1.4. Cohesive Subgroup Analysis

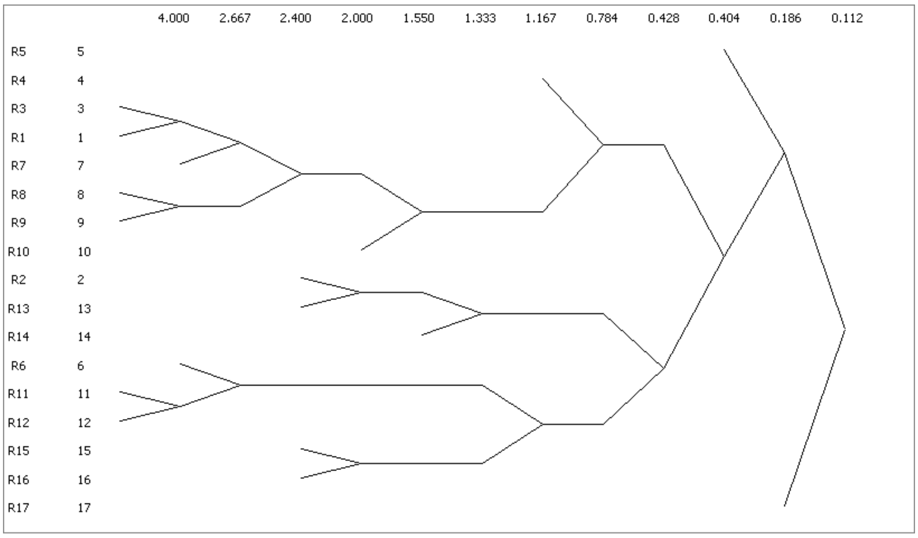

Figure 3: Tree Diagram of Cohesive Subgroups.

Figure 3 represents the tree diagram of cohesive subgroups for quality management risk factors.

4.2. Determination of Key Factors

After the above analysis, the construction project quality management risk factors with higher centrality were organized. “Unreasonable Construction Organization Management (R8),” “Unclear Construction Scope Definition (R9),” and “Inadequate Maintenance of Construction Machinery (R12)” appeared frequently in the analysis of the importance of influencing factors in quality management. These factors also exhibited strong relationships with other factors, making them crucial factors influencing the quality management risk in construction projects.

5. Discussion

Based on the analysis results above, the following risk control recommendations are proposed for quality management in construction projects, focusing on the key factors:

(1) Addressing Inadequate Construction Organization Management (R8): Emphasis should be placed on developing the organizational management capabilities of all participating units in the project and refining management details. Strengthen control over the experience levels of management personnel, particularly enhancing the knowledge of construction project management details among management personnel from participating units, as well as control over the professional skills of construction workers and compliance with construction standards. Pay attention to the reasonableness of management personnel’s organizational management, including whether there are issues such as out-of-sequence construction and unreasonable rush work, or whether the pursuit of aesthetic appearance has led to negligence in the feasibility of management. Enhance the awareness of management personnel regarding documentation, ensuring that research reports, construction logs, and other records are complete, flawless, and accurate.

(2) Addressing Unclear Definition of Construction Scope (R9): It is essential to focus on critical milestones throughout the project’s lifecycle and enhance the detailed definition of the construction scope. Relevant departments should divide the construction scope for the entire lifecycle of the construction project by formulating and publishing regulations and standards. Ensure that each part has responsible personnel and that issues can be addressed promptly. During the construction phase,

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participating units should strengthen inspections of the construction scope at various stages of the project, particularly focusing on critical milestones in the project schedule, and enhance on-site quality inspections of high-risk areas.

(3) Addressing Improper Maintenance of Construction Machinery (R12): Regular maintenance and upkeep of machinery equipment are required. In the construction phase, quality inspections of machinery equipment should be strengthened. Construction units should organize professionals to inspect various types of equipment, conduct random checks, and maintain records. They should also track the usage of machinery during the construction process to ensure accuracy. Monitoring should include inquiring with nearby residents or reviewing relevant maintenance records to address mechanical quality issues and determine whether maintenance and repairs are timely. Construction units should regularly inspect and maintain machinery equipment for potential quality issues. Additionally, there should be stricter requirements for the transportation and storage of equipment, with a focus on areas prone to mechanical wear and tear.

6. Conclusion

This study has focused on the aspect of quality management in construction projects. By utilizing the Social Network Analysis (SNA) method and considering three dimensions: stakeholders, machine, and environment, a comprehensive construction project quality management risk network model spanning the entire project lifecycle was constructed. Three critical influencing factors were identified. This study has provided a novel research approach for analyzing engineering quality management risks and has offered targeted risk control strategies.

However, there are certain limitations to this study. It primarily focused on stakeholders' analysis, relied on a relatively limited data source, and lacked real-world case studies. The inclusion of actual case studies could have made the research more comprehensive and specific.

In future research, a more in-depth analysis could be conducted involving all parties involved in construction projects, including the design and survey phases. Dynamic changes between different project stages could be closely monitored and supported by real-world examples. Regarding research methodology, optimization of the binary method could be considered, assigning values to the impact relationships between factors, with a particular focus on analyzing the interrelationships among risk factors. Alternatively, other quantitative methods or additional indicators could be introduced to construct risk network models from different perspectives.

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