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Research Article

Toward a Stakeholder Perspective on Safety Risk Factors of Metro Construction: A Social Network Analysis

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The rapid development of the metro has greatly relieved the traffic pressure on the urban ground system, but the frequency of metro construction accidents is also increasing year by year. Due to the complex construction process of the metro, once an accident occurs, casualties and property damage are extremely serious. The safety risk factors triggered by different stakeholders were the primary cause of accidents during the metro construction phase. This paper builts a social analysis network of safety risk factors in metro construction from a stakeholder's perspective. Based on 42 accident cases and related literature, 6 stakeholders and 25 safety risk factors were identified and the relationships between stakeholders and safety risk factors were also determined. Through the application of social network analysis, a social network of safety risk factors in metro construction was constructed, and quantitative analysis was carried out based on density, degree centrality, betweenness centrality, and cohesive subgroup. The results showed that the key safety risk factors in the construction phase of the metro were in action of the contractor's construction site managers, lack of safety protection at the construction site, insufficient detailed survey and design information provided by the designer, unfavorable government regulation, and bad weather. Moreover, the results of 20 cohesive subgroups illustrated the interrelationship between safety risk factors. S1H2 ("violations by operatives" related to contractor) and S1H4 ("lack of safety precautions" related to contractor) and S5H5 ("ineffective supervision" related to supervisor) both belonged to subgroup G1, which means that there is a high probability that these three safety risk factors would occur simultaneously. This paper provided a basis to improve the level of safety risk management and control from the stakeholder's perspective.

1. Introduction

With the rapid growth of urban expansion, the development of metro has become an inevitable choice to relieve the pressure of urban surface traffic. According to China's 13th Five-Year Plan, the investment in the construction of the metro will reach 2 trillion yuan by 2020 and the total mileage of the completed metro will be 8,600 kilometers. As the mileage and speed of metro construction increases, the frequency of accidents during the metro's construction phase has been increasing every year [1]. In 2013, the total number of accidents during the construction phase of the metro nationwide was 11 [2], but in 2018, the total number was 20 [3]. Safety risk management of metro construction is still an urgent problem to be solved.

Metro construction process is complex, with many construction procedures, long construction periods, and complex technology. Multiple stakeholders are involved in this process, such as contractors, designer, suppliers, and government [4]. Once an accident occurs, the injuries and economic losses are extremely serious. For example, in November 2008, there was a massive collapse at the construction site of Line 1 of the metro in Hangzhou, Zhejiang province, which resulted in 21 deaths and 24 injuries. According to the accident investigation report, the accident was caused by ineffective supervision by the government and the supervisor indulged the contractor's illegal work; the contractor chose untrained farmers as professional construction workers and did not take proper safety protection measures; and the contractor's on-site management even did nothing when they identified the precursors of the accident. Obviously, there are multiple stakeholders involved in this case, as well as multiple safety risk factors. So, it is important to improve the safety management level of the metro construction from the stakeholder's perspective. At the same time, the interrelationship between the causes of accidents is also crucial. There have been many studies on accident-causing theory, such as domino theory, accident causation sequence theory, and trajectory cross theory [5]. Most of these theories believe that the occurrence of accidents is the result of the joint action of a series of safety risk factors. Therefore, it is necessary to figure out the relationship between safety risk factors related to different stakeholders.

Much research has been carried out on the safety risk factors of metro construction, but most of these studies have focused on risk identification, risk analysis, and risk management from the hazard's perspective. Few studies have taken a stakeholder's perspective to study safety risk factors. Therefore, this study is conducted from the stakeholder's perspective, using the case study and literature review method to analyze the relationship between stakeholders and safety risk factors derived. Then, the key safety risk factors of the metro construction process can be identified and the analysis can draw the interrelationships between the safety risk factors of metro construction through the application of social network analysis. The results of the study can assist governments and managers to develop rational risk governance to improve risk management and reduce the frequency of accidents.

2. Literature Review

2.1. Research on Issues Related to Safety Risks in Metro Construction. The construction phase of the metro is long, complex, and involves many processes and procedures, and because it is underground, the geological conditions are complex and uncertainties increase. All of this can cause accidents to occur [6]. Safety risk factors of metro construction refer to potential uncertainties that cause economic loss, personal injury, environmental damage, project delays, or quality problems during metro construction process [7]. It is extremely important to manage and control the safety risk in the construction phase of metro.

The existing research mainly focuses on three aspects of risk identification, assessment, and management. Risk identification is the basis for carrying out risk assessment and management. Smith identified 33 safety risk factors from the cases by collecting more than 50 cases of Asian metro construction [8]. Ding built a safety risk identification system on the basis of construction drawings; it can enable risk identification before construction [7]. Li established a metro construction risk identification system based on BIM technology [9]. Xing standardized the representation of safety risk factors in metro construction by establishing a domain ontology, which lays the foundation for risk identification for all parties involved in the construction [4]. On the basis of risk identification, Wang combined the fuzzy appraisal method with Bayesian network to construct a fuzzy integrated Bayesian network system for the assessment of uncertainty safety risk in metro construction [10]. Yoo built an IT-based risk assessment system for metro tunnels based on GIS and artificial intelligence [11]. Ding proposed a safety risk management system for the whole process of metro tunnel construction and applied it to the Wuhan Yangtze River Metro [6]. Ding combined the work breakdown structure with three-dimensional technology to build a visual risk management system for metro construction [12]. Overall, most of the existing studies are mainly from a risk perspective.

2.2. Research on Stakeholder Assessment. The concept of a stakeholder was first proposed by the Stanford Research Institute and more full definition was given by Freeman in 1984: a stakeholder is an individual or group of people who can influence the achievement of an organization's goals or have an influence on the process of achieving the organization's goals [13]. Stakeholder management, which has its roots in business management, is mainly applied in corporate governance and strategy development and consists of four main steps: stakeholder identification, classification, analysis, and strategy development [14].

Since the introduction of stakeholder theory into the engineering field, based on Freeman's definition, PMI defined the stakeholder in the engineering field as an individual or organization that is actively involved in an engineering project [15]. And stakeholder management was enriched with six steps: developing detailed project processes, stakeholder identification, assessing the impact of stakeholders, publication of assessment reports, developing management strategies, and testing the effectiveness of management [16]. There have been many stakeholder-related studies in the field of construction engineering. For example, Michael developed a construction program for new large port infrastructure based on stakeholder theory [17]. Li developed a comprehensive quantitative method to improve the satisfaction of various stakeholders with green buildings [18]. Yu investigated the influence of different stakeholders on the quality defects at the construction site [19]. Tao compared the influence of different conceptual stakeholders on urban development decisions [20]. However, no scholar has introduced stakeholder theory into the field of metro construction safety risk research.

2.3. Research on Social Network Analysis. Social networks are an effective way to analyze the interrelationships and organizational structure of individuals or groups, which is usually based on theories such as matrix and graph theory [21]. Social network analysis is widely used in the fields of social sciences, communication, economics, and more recently in engineering.

The application of Social Network Analysis (SNA) in the field of engineering has focused on stakeholder relationships and risk factors. Social network analysis treats a project as a system of relationships connected together [22]. Mok has used SNA to explore the relationships between stakeholders in large construction projects [14]. Zheng has used literature review to conclude that the general direction of the application of SNA in construction is to explore the network structure of internal and external stakeholders in different processes [23]. Mok combined case study and SNA to summarize the key challenges that large public construction projects pose to stakeholders [24].

Social network analysis is also widely used for risk analysis. Luo used social network analysis to establish a stakeholder-related supply chain risk network for a prefabricated project in Hong Kong and concluded the main challenges in the supply chain of prefabricated projects [25]. Yuan used SNA's bimodal network to analyze the social risks of a high-density urban construction project [15]. Yang chose a complex green building as the object of study to analyze the stakeholder-related safety risk network and related relationships [22].

Therefore, using social network analysis (SNA) to analyze the interrelationships between safety risk factors in metro construction is feasible. In this paper, social network analysis will be adopted to link stakeholders to the safety risk factors of metro construction and analyze the interrelationships between safety risk factors, filling the gap of the application of SNA in metro construction.

3. Materials and Methods

On the basis of the literature review and through the study of the 42 cases collected, the stakeholders and safety risk factors among metro construction were identified. Then, the relationships between stakeholders and safety risk factors were further identified. In order to explore the interrelationships between safety risk factors of metro construction, social network analysis was adopted. Netdraw was used for safety risk network visualization, while Ucinet was used for social network analysis. The research framework is shown in Figure 1.

3.1. Identification of Stakeholders and Risk Factors. Due to the numerous construction steps and the complexity of metro construction process, accidents are usually caused by multiple safety risk factors and involving many stakeholders. Therefore, identifying stakeholders and safety risk factors is the first step in building an SNA network.

3.1.1. Identification of Stakeholders. Since the introduction of the stakeholder concept into the engineering field, different scholars have identified the stakeholders of different engineering projects with reference to the definition of stakeholders by Freeman [13], Clarkson [26], Olander [27], and others. The common stakeholders of engineering projects are shown in Table 1.

So, it can be seen that the stakeholders of construction projects generally include the government, owners, contractors, designers, suppliers, supervisors, operators, media, and the public.

Based on the literature review, a preliminary understanding of stakeholders has been obtained, followed by a case study approach to determine the final list of stakeholders.

The basis of the case analysis is the collection of a case bank. In this paper, cases were collected according to the following three criteria. (1) The case must be in the construction phase of metro. (2) The case should have a specific accident investigation report. (3) The case must be able to characterize the safety risk factors of the construction phase of the metro. Through Internet searching, 42 cases from 2001–2018 were collected. These 42 cases occurred in different cities, as shown in Figure 2.

Then, the 42 cases collected were statistically analyzed by analyzing the case accident investigation reports. Generally, reports of investigations into metro construction phase accidents are published in major official media outlets or on the official websites of local emergency management agencies. Three examples of incident case identification results are shown in Table 2.

Based on the frequency of occurrence of stakeholders, excluding consulting agencies and subcontractors with a frequency of 0 occurrence, the 6 stakeholders of this paper were obtained and characterized, as shown in Table 3.

3.1.2. Identification of Safety Risk Factors. At present, the commonly used methods of risk identification are literature review, questionnaire, and case study method [4, 6–8]. In this paper, the representative literature is selected to organize the relevant safety risk factors, and 30 safety risk factors are initially screened in the metro construction stage, as shown in Table 4.

Through the analysis of the investigation reports collected on 42 incidents, the main safety risk factors that led to the incidents were deduced backwards from the process and outcome of the incidents. The partial results are shown in Table 2.

Based on the derivation of the accident cases, the list of safety risk factors initially identified through the literature-combing method was compared to screen and supplement. The final results are shown in Table 5. For further research, safety risk factors need to be categorized. Zhang divided them into unsafe human behavior, unsafe state of objects, managerial factors, and environment [33]. This paper classified safety risk factors into five categories, namely, environment-related (E); human-related (H); material-related (MAT); machinery-related (MACH); and technology-related (T).

3.2. Identifying the Relationship between Stakeholders and Safety Risk Factors. After identifying the list of stakeholders and the list of safety risk factors, the relationship between the stakeholders and the safety risk factors needs to be identified. A stakeholder is usually associated with multiple safety risk factors, and a safety risk factor may also be affiliated with multiple stakeholders. Based on the accident investigation report and the identification of stakeholders and safety risk factors in Table 1, the relationships between the two are derived, as shown in Table 6.

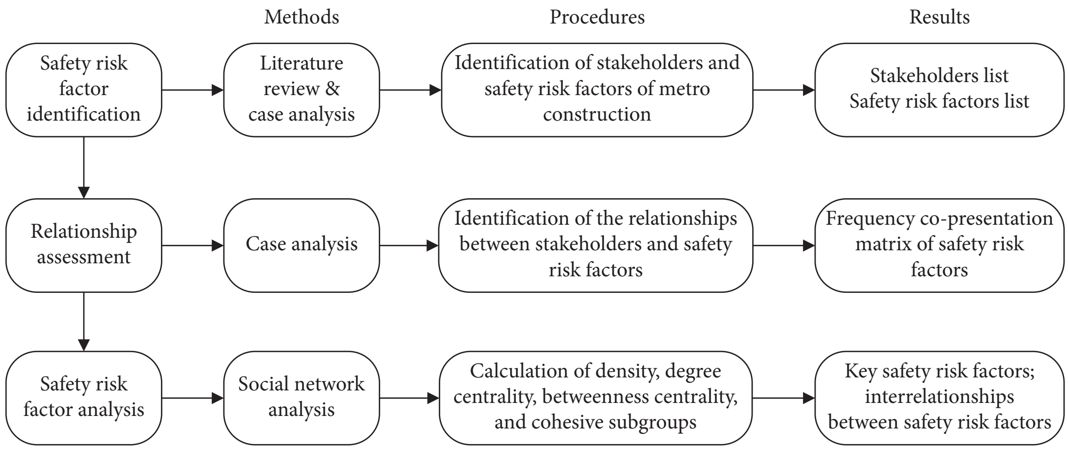

Figure 1: Research framework.

Table 1: Stakeholders in the engineering project.

Authors	Research object	Stakeholders
Jingfeng Yuan	Construction projects	Owner; contractor; subcontractor; supplier; supervisor; designer; residents; government; community; media [15]
Jin Xue	Construction projects	Owner; consultant; suppliers; government; local community; public media [28]
Lizi Luo	Prefabricated building project	Client; designer; main contractor; manufacturer; transporter; assembly subcontractor; government [25]
Rebecca J. Yang	Green building projects	Client, consultant, contractor, subcontractor/supplier, end user, financial organization, government, environmental organization, professional association, media, public, labour union, assessor/certifier, researcher/educator, and others [22]
Zhengqi He	Large hydraulic engineering projects	Government; project developers; contractors; experts; relocated residents; local residents; general public [29]

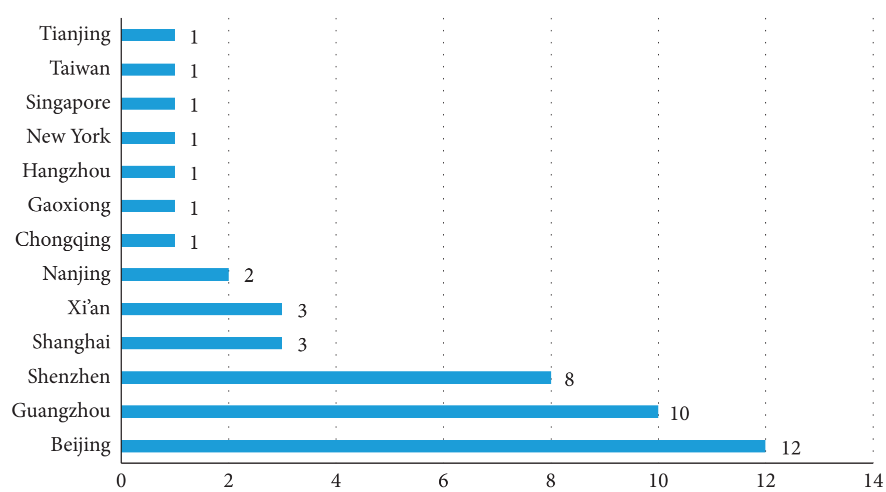

Figure 2: The number of cases in different regions.

3.3. Safety Risk Factors' Network Development. The matrix of interrelationships between safety risk factors was constructed by the frequency of simultaneous occurrence of different safety risk factors in the case, as shown in Table 7. For example, S1E1-S1E2 = 2 means the contractor encountered both bad weather and unknown geological conditions as safety risk factors in 2 cases.

Then, the safety risk factors co-presentation matrix was imported into NetDraw to visualize the SNA network, as shown in Figure 3. The color of the nodes indicated the type of safety risk factors, and the shape of the nodes represented the relevant stakeholders. On the basis of the SNA network, four sets of indicators were calculated to assess the interrelationships between safety risk factors.

Table 2: Three examples of incident case identification results.

Time	Place	Description of the accident	Stakeholder	Safety risk factors
2005.09.27	Beijing	September 27, 2005 at 1:40 am, Beijing Xizhimen subway platform ready for transformation because the drawings used is not marked pipeline; while surveying, the ground will be buried in the underground gas pipeline chiseled, resulting in a large number of natural gas leakage; the construction company's permit had also expired	Client; contractor; designer; government	Missing drawings; underground pipe breaks; missing construction permits; ineffective supervision
2018.01.25	Guang zhou	At 17:10 on January 25, 2018, Guangzhou city rail transit line 21 water west station to Suyuan station interval left line shield machine with pressure to open the warehouse fire operation, welding cable short circuit caused a fire, in man gate main warehouse video monitoring, there is a fault, did not find the fire seedlings in time, the warehouse personnel lack of fire safety and emergency protective equipment, unable to implement effective self-help, outside the warehouse operating personnel extremely fast pressure relief so that shield mud film failure, and palm surface destabilization collapse buried the operating workers	Contractor; supplier	Inaction by site managers; lack of contingency plans; lack of safety precautions; mechanical breakdown
2018.02.07	Guang zhou	At 20:40 on February 7, 2018, the construction of Foshan city Rail transit line 2, phase 1 of the civil engineering section of the site suddenly permeable, causing tunnel and road collapse, resulting in 11 deaths, 1 missing, and 8 people injured; during the construction, the sealing performance of the shield tail decreased, resulting in permeable sand channel, which was not evacuated in time, resulting in serious casualties	Contractor; supplier	Unknown geological conditions; mechanical breakdown; lack of contingency plans; inaction by site managers

Table 3: Stakeholder identification list.

Code	Name	Description
S1	Contractor	Construction and submission of the project to the owner
S2	Supplier	Responsible for providing equipment and materials required
S3	Client	Initiating a construction project, financing it, and benefitting from it
S4	Designer	Participation in the design of the project
S5	Supervisor	Responsible for supervision and inspection of projects
S6	Government	National government, local government, quality inspection, administrative approval, and other relevant government departments

4. Results

This paper identified 25 safety risk factors and 6 stakeholders. In order to explore the interrelationships between safety risk factors, four metrics in the SNA model were selected for analysis: density, degree, betweenness centrality, and cohesive subgroup analysis. Finally, key safety risk factors as well as the interrelationships between safety risk factors can be derived.

4.1. Density. Density indicates how tightly the nodes in a network are connected. The density is calculated by dividing the number of existing relationships by the number of all possible relationships [34]. It is shown as

$$\text{Density} = \frac{l}{n * (n-1)/2}, \quad (1)$$

where l is the number of existing relationships in the network and n is the number of nodes in the network.

The density of the binary overall network is between [0, 1], the density value of 1 indicates that all nodes in the network are interrelated, and the value of 0 indicates that none of the nodes in the network are correlated [34]. The closer it is to 1 indicates that the denser the network is, the closer the relationship between the safety risk factors and the greater the interrelationship between them; conversely, the less the interrelationship between them. The density of the safety risk factors network is calculated as 0.86, which

Table 4: Identification of safety risk factors.

Code	Name	Reference
R1	Unknown subsurface geological conditions	[10, 30, 31]
R2	Unidentified hydrological conditions	[10, 31, 32]
R3	Unclear pipeline layout	[10, 31]
R4	Lack of detailed exploration information	[31, 32]
R5	Poorly targeted special construction programmes	[10, 30, 31]
R6	Substandard quality of materials	[10, 32]
R7	Design changes	[31, 32]
R8	Lack of planning for the schedule	[10, 31, 32]
R9	Unreasonable sequence of work	[10, 31]
R10	Noncompliance with safety regulations by construction workers	[32]
R11	Untrained construction workers	[30, 31]
R12	Lack of safety precautions	[30, 32]
R13	Lack of contingency plans	[32],
R14	Bad weather conditions	[32]
R15	Undetailed construction programme	[10, 30]
R16	Illegal subcontracting or subcontracting by construction units	[32]
R17	Inadequate skill level of construction personnel	[30, 31]
R18	Workmanship omissions during construction	[10, 31]
R19	Mismanagement by construction managers	[32]
R20	Inadequate foresight of safety incidents	[31, 32]
R21	Irrational design scheme	[10, 32]
R22	Inadequate implementation by supervisory engineers	[10, 32]
R23	Inadequate oversight by government safety management	[10, 30]
R24	Unstable foundations of adjacent buildings	[10, 31]
R25	Construction machinery failure	[30, 31]

Table 5: Metro construction safety risk factors.

Classification	Code	Name
E	E1	Bad weather
	E2	Unknown geological conditions
	E3	Underground pipe breaks
H	H1	Lack of contingency plans
	H2	Violations by operatives
	H3	Inadvertent handling by operatives
	H4	Lack of safety precautions
	H5	Ineffective supervision
	H6	Unclear construction site markings
	H7	Inappropriate communication with other units
	H8	Negligent site management
	H9	Inaction by site managers
	H10	Inadequate qualification levels of operatives
MAC	MAC1	Mechanical breakdown
MAT	MAT1	Falling material from high places
	MAT2	Missing drawings
	MAT3	Insufficient awareness of material properties
T	T1	Lack of a dedicated construction programme
	T2	Lack of detailed exploration information
	T3	Poor construction workmanship
	T4	Missing construction permits
	T5	Incorrect construction procedure

indicates that the network is highly dense and can be used to analyze the interrelationships between safety risk factors.

4.2. Degree Centrality. Degree centrality is calculated by the number of relationships directly connected to a node; the higher the value of the node's degree centrality, the greater the number of nodes associated with it. For node i, the degree centrality is calculated as[35]

$$\text{Degree centrality} = \frac{\sum_{j=1}^{i}\left(z_{ij} + z_{ji}\right)}{\sum_{i=1}^{n}\sum_{j=1}^{n} z_{ij}}, \tag{2}$$

where z_{ij} is the number of relationships from node j to i and n is the number of nodes in the network.

Table 6: Relationship between stakeholders and safety risk factors.

Risk ID	Stakeholder code	Stakeholder	Risk code	Risk	Cases
S1E1	S1	Contractor	E1	Bad weather	1, 4, 5, 6, 32
S1E2	S1	Contractor	E2	Unknown geological conditions	6, 9, 21, 27, 32, 34, 41, 42
S1E3	S1	Contractor	E3	Underground pipe breaks	9, 10, 24
S4E3	S4	Designer	E3	Underground pipe breaks	16
S1H1	S1	Contractor	H1	Lack of contingency plans	1, 5, 11, 12, 34, 40, 41, 42
S1H2	S1	Contractor	H2	Violations by operatives	2, 15, 17, 18, 19, 20, 23, 25, 28, 31, 33, 35, 36, 38
S1H3	S1	Contractor	H3	Inadvertent handling by operatives	3, 11, 13, 29, 30
S1H4	S1	Contractor	H4	Lack of safety precautions	3, 12, 13, 17, 18, 21, 31, 32, 33, 35, 36, 37, 38, 40
S5H5	S5	Supervisor	H5	Ineffective supervision	4, 28
S6H5	S6	Government	H5	Ineffective supervision	4, 16, 28
S1H6	S1	Contractor	H6	Unclear construction site markings	8
S1H7	S1	Contractor	H7	Inappropriate communication with other units	8
S6H7	S6	Government	H7	Inappropriate communication with other units	8
S1H8	S1	Contractor	H8	Negligent site management	10, 13, 14, 23, 25, 30
S1H9	S1	Contractor	H9	Inaction by site managers	8, 15, 19, 20, 21, 22, 26, 28, 31, 32, 33, 35, 36, 37, 38, 39, 40, 41, 42
S1H10	S1	Contractor	H10	Inadequate qualification levels of operatives	17, 28
S2MAC1	S2	Supplier	MAC1	Mechanical breakdown	2, 14, 39, 40, 41
S1MAT1	S1	Contractor	MAT1	Falling material from high places	7, 12
S3MAT2	S3	Client	MAT2	Missing drawings	16, 24
S2MAT3	S2	Supplier	MAT3	Insufficient awareness of material properties	29
S1T1	S1	Contractor	T1	Lack of a dedicated construction programme	4
S4T2	S4	Designer	T2	Lack of detailed exploration information	6, 9, 10, 24, 27, 42
S1T3	S1	Contractor	T3	Poor construction workmanship	7, 20, 22, 25, 26
S1T4	S1	Contractor	T4	Missing construction permits	16
S1T5	S1	Contractor	T5	Incorrect construction procedure	22

In the network of safety risk factors, the degree centrality of one point means the number of other safety risk factors associated with it. The larger the value of degree centrality is, the more other points are associated to it and the position of it is more important in the network.

Table 8 lists the top 8 safety risk factors in terms of degree centrality. These safety risk factors affect a large number of other safety risk factors and are influenced by multiple other safety risk factors.

The safety risk factor of highest degree centrality was S1H9 ("inaction by site managers" related to contractor), with the highest number and greater impact on other safety risk factors. From the top 8, the most important stakeholder in the entire network of stakeholder-related risks was the contractor, and the two types' most influential safety risk factors were human-related risk factors and environment-related risk factors.

4.3. Betweenness Centrality. Betweenness centrality measures the number of shortest paths through a node; the greater the intermediate centrality, the more the shortest paths through the node, indicating that the node has greater control over two other nodes that are not adjacent to it. The betweenness centrality is calculated as [36]

$$\text{Betweeness centrality} = \sum_{s,t,s\neq t\neq i} \frac{\partial_i (s,t)}{\partial (s,t)}, \quad (3)$$

where $\partial_i (s,t)$ is the number of paths from s to t through i and $\partial (s,t)$ the number of all paths from s to t.

In safety risk factors networks, risk nodes with high betweenness centrality, the more control they have over other nodes and these safety risk factors are key safety risk factors.

Table 9 lists the top 8 safety risk factors with the high betweenness centrality. These risk factors act as links in the network and had a decisive influence on other safety risk factors.

The top three safety risk factors for betweenness centrality are S1H9 ("inaction by site managers" related to contractor), S6H5 ("ineffective supervision" related to government), and S1H4 ("lack of safety precautions" related to contractor). These three safety risk factors link multiple pairs of nodes in the network and play an important role in risk propagation.

4.4. Cohesive Subgroup Analysis: "n-Faction". Cohesive subgroup analysis based on "*n*-Faction" means that, for a subgraph of a network in which the maximum distance

Table 7: Frequency co-presentation matrix of safety risk factors.

	S1E1	S1E2	S1E3	S4E3	S1H1	S1H2	S1H3	S1H4	S5H5	S6H5	S1H6	S1H7	S6H7	S1H8	S1H9	S1H10	S2MAC1	S1MAT1	S3MAT2	S2MAT3	S1T1	S4T2	S1T3	S1T4	S1T5
S1E1	—	2	—	—	2	—	—	1	1	1	—	—	—	—	1	—	—	—	—	—	1	1	—	—	—
S1E2	2	—	1	—	3	—	—	2	—	—	—	—	—	—	4	—	1	—	—	—	—	4	—	—	—
S1E3	—	1	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	1	—	—	3	—	—	—
S4E3	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	1	—	—	—	—	1	—
S1H1	2	3	—	—	—	—	1	2	—		—	—	—	—	3	—	2	1	—	—	—	1	—	—	—
S1H2	—	—	—	—	—	—	—	8	1	1	—	—	—	2	8	2	1	—	—	—	—	—	2	—	—
S1H3	—	—	—	—	1	—	—	2	—	—	—	—	—	2	—	—	—	—	—	1	—	—	—	—	—
S1H4	1	2	—	—	2	8	2	—	1	1	—	—	—	1	10	2	1	1	—	—	—	—	—	—	—
S5H5	1	—	—	—	—	1	—	1		2	—	—	—	—	1	1	—	—	—	—	1	—	—	—	—
S6H5	1	—	—	1	—	1	—	1	2	—	—	—	—	—	1	1	—	—	1	—	1	—	—	1	—
S1H6	—	—	—	—	—	—	—	—	—	—	—	1	1	—	1	—	—	—	—	—	—	—	—	—	—
S1H7	—	—	—	—	—	—	—	—	—	—	1		1	—	1	—	—	—	—	—	—	—	—	—	—
S6H7	—	—	—	—	—	—	—	—	—	—	1	1	—	—	1	—	—	—	—	—	—	—	—	—	—
S1H8	—	—	1	—	—	2	2	1	—	—	—	—	—	—	—	—	1	—	—	—	—	1	1	—	—
S1H9	1	4	—	—	3	8	—	10	1	1	1	1	1	—	—	1	3	—	—	—	—	1	3		1
S1H10	—	—	—	—	—	2	—	2	1	1	—	—	—	—	1		—	—	—	—	—	—	—	—	—
S2MAC1	—	1	—	—	2	1	—	1	—	—	—	—	—	1	3		—	—	—	—	—	—	—	—	—
S1MAT1	—	—	—	—	1	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—
S3MAT2	—	—	1	1	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	1	—	1	—
S2MAT3	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
S1T1	1	—	—	—	—	—	—	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
S4T2	1	4	3	—	1	—	—	—	—	—	—	—	—	1	1	—	—	—	1	—	—	—	—	—	1
S1T3	—	—	—	—	—	2	—	—	—		—	—	—	1	3	—	—	1	—	—	—	—	—	—	—
S1T4	—	—	—	1	—	—	—	—	—	1	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—
S1T5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	1	—	—

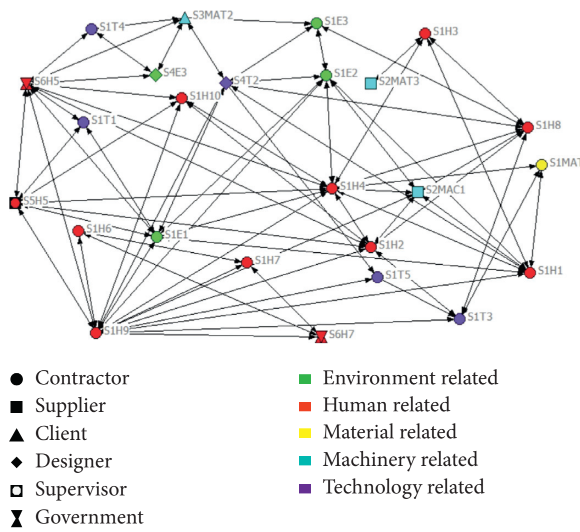

Figure 3: Social analysis network of safety risk factors.

Table 8: Top 8 safety risk factors with high-degree centrality.

Rank	Risk ID	Degree
1	S1H9	40
2	S1H4	32
3	S1H2	25
4	S1E2	17
5	S1H1	15
6	S4T2	13
7	S6H5	11
8	S1E1	10

Table 9: Top 8 safety risk factors with high betweenness centrality.

Rank	Risk ID	Betweenness
1	S1H9	187.844
2	S6H5	101.033
3	S1H4	86.939
4	S1H3	46.5
5	S4T2	36.256
6	S1H1	33.289
7	S1H8	29.878
8	S1E1	23.4

between any two points does not exceed "n," the graph is said to be a cohesive subgroup of the "n-Faction." The value of n is defined by the researcher according to the research objectives, and the smaller the value of n, the tighter the relationship within the subgroup. A cohesive subgroup study explores indirect relationships between nonadjacent nodes in addition to directly related relationships, and the members of the subgroup are closely related to each other, so cohesive subgroup analysis can also be called "small group analysis."

This paper specified that the value of n was 3. There were 20 coalescent subgroups in the network after calculating, as shown in Table 10, and the coalescent subgroup diagram is shown in Figure 4. Subgroup G1 was formed by these safety risk factors: S1H2 ("violations by operatives" related to contractor), S1H4 ("lack of safety precautions" related to contractor), S5H5 ("ineffective supervision" related to supervisor), S6H5 ("ineffective supervision" related to supervisor), S1H9 ("inaction by site managers" related to contractor), and S1H10 ("inadequate qualification levels of operatives" related to contractor).

Table 10: Cohesive subgroups.

Node	Members					
G1	S1H2	S1H4	S5H5	S6H5	S1H9	S1H10
G2	S1H2	S1H4	S1H9	S2MAC1	—	—
G3	S1E1	S1E2	S1H1	S1H4	S1H9	—
G4	S1E2	S1H1	S1H4	S1H9	S2MAC1	—
G5	S1E1	S1H4	S5H5	S6H5	S1H9	—
G6	S1H6	S1H7	S6H7	S1H9	—	—
G7	S1E1	S1E2	S1H1	S1H9	S4T2	—
G8	S1H9	S4T2	S1T5	—	—	—
G9	S1H2	S1H9	S1T3	—	—	—
G10	S1H9	S1T3	S1T5	—	—	—
G11	S1E3	S1H8	S4T2	—	—	—
G12	S1E3	S3MAT2	S4T2	—	—	—
G13	S1E2	S1E3	S4T2	—	—	—
G14	S4E3	S6H5	S3MAT2	S1T4	—	—
G15	S1H1	S1H3	S1H4	—	—	—
G16	S1H3	S1H4	S1H8	—	—	—
G17	S1H2	S1H4	S1H8	S2MAC1	—	—
G18	S1H2	S1H8	S1T3	—	—	—
G19	S1H1	S1H4	S1MAT1	—	—	—
G20	S1E1	S5H5	S6H5	S1T1	—	—

5. Discussion and Suggestions

5.1. Strategies for Managing Safety Risk Factors in Metro Construction. Based on the above analysis of the five categories of safety risk factors, specific strategies are proposed from the stakeholder's perspective.

Environment-related safety risk factors were present in 11 of the 42 cases. The accidents were mostly in the form of collapses and water damage, which could easily lead to economic losses. E1, E2, and E3 are safety risk factors for bad weather, unknown geological conditions, and underground pipe breaks, and the stakeholders involved are the contractor and the designer. E1 and E2 have high-degree centrality and betweenness centrality in the social network analysis, which shows that they are the key safety risk factors. So, the contractors should develop emergency plans and enhance the safety awareness of on-site construction workers. The designer should enhance exploration techniques to improve the accuracy of exploration results.

Human-related safety risk factors were the most frequently occurring and most influential, which were present in 38 of the 42 cases collected. Actions by individuals or organizations from contractors, supervisors, and the government can lead to accidents, along with injuries and fatalities. Of these 10 human-related safety risk factors identified, lack of contingency plans, inadvertent handling by operatives, lack of safety precautions, ineffective supervision, and inaction by site managers are key safety factors.

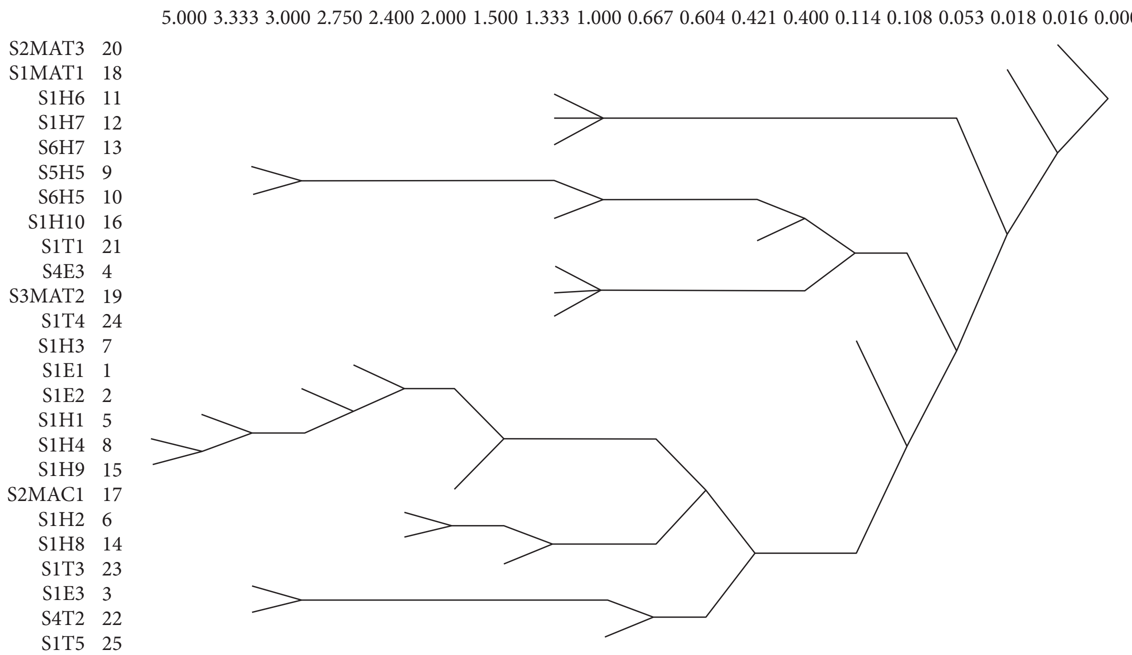

Figure 4: Cohesive subgroup analysis result map.

So, the contractors need to develop emergency plans for human-related accidents, take safety precautions at the site, and educate and train workers to avoid careless operation. And the site management personnel should perform site management responsibilities. The government should review the contractor's qualifications and work with the supervisor to monitor the construction site on time.

There were five cases related to machinery-related safety risk factors. Mechanical failures occur randomly, but reasonable prevention measures must be taken. Contractors need to conduct regular inspections of machinery and safety education and training of those using the machinery. Suppliers are required to provide repair and maintenance of the machinery on time.

The safety risk factors associated with the material were usually present along with other factors and appeared five times in the 42 cases collected. MAT1, MAT2, and MAT3 refer to falling material from high places, missing drawings, and insufficient awareness of material properties. Similar to the safety risk factors related to machinery, they were also not the key safety risk factors. To manage the safety risk factors related to materials, multiple stakeholders are required to participate in the daily management of materials. On the one hand, for all kinds of documents, construction drawings, and survey and design reports, the client and the designer need to ensure the completeness and the accuracy of these materials. The contractor needs to ensure the storage and interpretation of these materials. On the other hand, for the construction materials used in construction, the suppliers need to ensure the quality and suitability of the materials provided. The contractors need to be aware of the characteristics of the materials, store and manage construction materials properly, and the training of the workers who will use them.

Technology-related safety risk factors were present in a total of 12 cases. T1, T2, and T3 refer to lack of a dedicated construction programme, lack of detailed exploration information, poor construction workmanship, missing construction permits, and incorrect construction procedure. Safety risk factors' management related to technology requires the designer to improve the level of investigation and design to ensure the safety of the technology from the theoretical point of view. Contractors need to formulate the right construction plan, select the right construction procedure, and ensure the safety of the technology from a practical point of view. It is also necessary to strengthen the inspection and supervision of the construction site to detect risk precursors in a timely manner.

In conclusion, the key safety risk factors were S1H9 ("inaction by site managers" related to contractor), S1H4 ("lack of safety precautions" related to contractor), S4T2 ("lack of detailed exploration information" related to designer), S6H5 ("ineffective supervision" related to government), and S1E1 ("bad weather" related to contractor). These five risk factors were classified as significant risk factors in both degree centrality and betweenness centrality analysis. These key safety risk factors involved three stakeholders (contractor, designer, and government) and fell into three categories (human-related, technology-related, and environment-related). This was generally consistent with the five important safety risk factors (safety attitude, construction site safety, government supervision, market restrictions, and task unpredictability) in metro construction as suggested by Yu et al. [37].

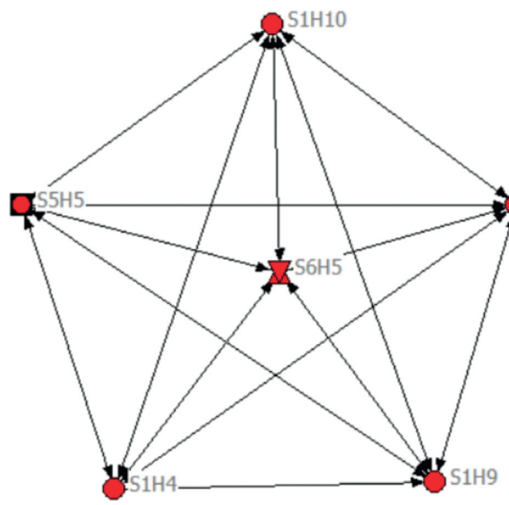

Figure 5: The network between these 6 safety risk factors in G1 (based on frequency co-presentation matrix).

5.2. Management of Safety Risk Factors in One Subgroup. According to Table 10, there were at least three safety risk factors in each subgroup. The safety risk factors in each subgroup were closely related with each other. Once the interconnection between safety risk factors were severed, the interaction between safety risk factors will be reduced to avoid an accident [22]. The following is an example of how to manage the safety risk factors in one subgroup.

In subgroup G1, there were six safety risk factors: S1H2 ("violations by operatives" related to contractor), S1H4 ("lack of safety precautions" related to contractor), S5H5 ("ineffective supervision" related to supervisor), S6H5 ("ineffective supervision" related to government), S1H9 ("inaction by site managers" related to contractor), and S1H10 ("inadequate qualification levels of operatives" related to contractor). The network between these 6 safety risk factors is shown in Figure 5.

These six safety risk factors often appeared together in accidents. Accident can be avoided by breaking one of the connections. The contractors should be responsible for the qualification and training of their personnel and the responsibility of site management. The supervisor and the government need to perform supervisory and management duties and communicate with the contractor in a timely manner. Once a safety risk factor occurs, other safety risk factors need to be monitored as well. If the supervisor finds deficiencies in the site's safety precautions, more attention needs to be paid to worker practices and the management of site managers.

6. Conclusions

Based on social network analysis theory, this paper focuses on the risk governance by stakeholders through the analysis of safety risk factors and the relationships, which provides a new perspective of the management and control of safety risks in the metro construction phase. Previous research has focused on the hazard's perspective, but the stakeholders are the main subjects who manage the risk. Accidents usually involve multiple stakeholders and multiple safety risk factors, and the existence of correlations between safety risk factors can lead to a range of other problems. This paper identified 6 stakeholders and 25 safety risk factors through literature review and case study analysis. Through social network analysis and the calculation of corresponding indicators, 6 key safety risk factors and 20 cohesive subgroups were analyzed. Contractors, designers, and governments were found to be important stakeholders, while the three categories of environment-related, human-related, and technology-related were found to be key safety risk factors. Therefore, this paper proposed corresponding governance measures for the 5 categories of safety risk factors from the stakeholder's perspective and governance approaches for risks belonging to the same subgroup. For one thing, the list of identified safety risk factors can be used as a checklist for stakeholders to develop appropriate risk management programme; for another, through the development of the safety risk factors network, the relationship between the safety risk factors was shown and the core safety risk factors were analyzed. This can effectively improve the level of risk management during the construction phase of the metro.

The research methodology used in this paper also has some limitations. Firstly, the identified safety risk factors were not separated according to the different time periods during the construction process, and the dynamics of safety risk factors were not reflected. Secondly, the number of cases was not complete and most of the cases used in this paper were from China. For the future research, the dynamics of risk factors need to be included in the scope of the study to propose specific governance measures. Moreover, more cases need to be collected to enrich the list of stakeholders and safety risk factors and improve the applicability of this study.

Data Availability

The data collected in the article is taken from accident investigation reports issued by government agencies and official media reports.

Conflicts of Interest

There are no conflicts of interest.

Acknowledgments

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