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Enhancing Program Risk Management: A Social Network Approach

Wenxin SHEN[1]*, Xiaofan ZHAI[2], Jingjie XIONG[3]

[1] *Department of Construction Management, School of Economic and Management, Beijing Jiaotong University, China,* E-mail address: shwenxin@bjtu.edu.cn
[2] *Department of Logistics Management, School of Economic and Management, Beijing Jiaotong University, China,* E-mail address: 21241282@bjtu.edu.cn
[3] *Department of Construction Management, School of Economic and Management, Beijing Jiaotong University, China,* E-mail address: 21241277@bjtu.edu.cn

Abstract: Program management presents unique challenges due to the complexity of interrelated projects and increased stakeholder engagement. While existing literature mainly focuses on project-level risk management, inter-project risks remain underexplored. This research addresses this gap by proposing a program risk analysis method that integrates project interdependence and stakeholder engagement. Leveraging social network analysis, the model enhances program risk management efficiency by identifying four types of inter-project risks and suggesting tailored response strategies. Through a case study of the Expo 2020 construction program, the effectiveness of the framework is demonstrated. This study enriches program and risk management literature, deepening our understanding of enhanced risk management in multi-project contexts.

Key words: Risk management; Social network; Program management.

1. INTRODUCTION

Program management, with its inherent complexity and wide stakeholder engagement, demands a sophisticated approach to risk management distinct from traditional project-level strategies[1]. Recognizing the elevated risk complexity and increased stakeholder engagement in managing a set of interrelated projects, organizations are increasingly adopting program management to achieve broader objectives[2]. Despite extensive experience in construction project risk management, the unique challenges of program-level risks—due to the additional management layer and interdependencies among projects—require distinct management approaches. Current research primarily addresses risks at the individual project level[3–6], with scant attention to the nuances of inter-project risks and the comprehensive impact of stakeholder dynamics. This study aims to fill this gap by introducing a risk identification and classification model that utilizes risk registers to automatically discern inter-project risk categories. This innovation promises to streamline program risk management by guiding managers on which risks warrant heightened focus and resource allocation, thereby elevating management efficiency and effectiveness.

2. LITERATURE REVIEW

2.1. Risk management in programs

In risk identification, traditional methods based on experiential knowledge, such as surveys, interviews, workshops, and literature reviews, continue to be widely adopted for pinpointing risks and stakeholders, as commonly practiced by numerous researchers [3,4,7]. Moreover, a subset of researchers has ventured into leveraging data-driven technologies, including Bidirectional Encoder Representations from Transformers (BERT) and equipment perception, aiming to refine the accuracy of risk perception and identification. For example, Ding et al. (2012) developed a safety risk identification system specifically for subway construction projects, laying the groundwork for dynamic risk alerts and mitigation strategies.

Regarding risk analysis, there's an observable shift towards employing more structured and intelligent methodologies in the construction sector, with the goal of diminishing the dependency on subjective human judgment. Yildiz et al. (2014) introduced a knowledge-based application for risk mapping, aimed at identifying risk factors that could lead to cost escalations in international projects [8]. Moon et al. (2022) implemented a clause classification model utilizing BERT for the automated detection of risk categories from contractual clauses[6], while Zhou et al. (2023) devised a risk response generation algorithm through the integration of Knowledge-enabled BERT, marrying deep learning techniques with explicit knowledge bases[5].

Despite recognition of project-to-project risks, few studies have delved into identifying critical inter-project risks within program settings.Moreover, program risks involve numerous stakeholders, necessitating attention to the interplay between risks and stakeholders. While some research has considered stakeholder-related risks, integrating the impact of risks on stakeholders within programs remains underexplored.

2.2. Social network analysis in risk management

Social Network Analysis (SNA) offers a quantitative approach for examining relationships among entities, including risks and stakeholders, and is emerging as a valuable tool in construction risk management [9]. Although previous studies have applied SNA to risk identification and stakeholder interactions[7,10,11], they primarily focus on individual projects without addressing the complexities of program-level risk management or the interdependencies among projects. Existing methods often assume risks are associated with single stakeholders[4,10], overlooking the broader stakeholder engagement in programs. Therefore, analyzing risks in construction programs requires considering both project interdependence and the influence of multiple stakeholders. Additionally, assessing the impact of risk events should differentiate between effects on various project objectives to account for the interconnected nature of programs and the potential for cascading effects.

3. RESEARCH FRAMEWORK

The proposed framework of risk management comprises three parts (Figure 1), namely, inter-project risk identification, assessment, and classification. Firstly, risk events across various projects and their associated stakeholders within the program are identified. Secondly, two-mode risk-project network and risk-stakeholder network are developed and then transformed into two one-mode networks respectively for further analysis. Thirdly, inter-project risks are classified into four kinds to prioritize the criticalness of the inter-project risks.

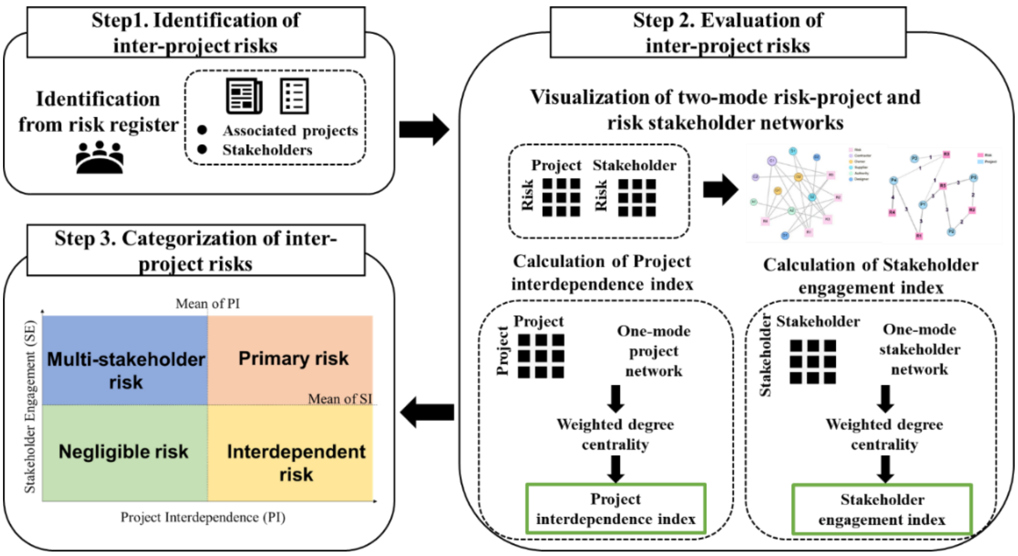

Figure 1. Research framework

3.1. Identification of inter-project risks

The risk management process in construction projects commences by identifying both relevant and potential risks; this initial phase is pivotal as only the identified risks are subjected to further analysis and response management. This paper predominantly examines risks that span across multiple projects, known as inter-project risk events. To capture data on these inter-project risks, our study directly utilizes risk events documented in the risk register. The risk register, a critical tool for risk management widely adopted in construction projects, is typically divided into three main sections [12]E: 1) Event: This section includes the risk's description, its estimated likelihood, types of risks, and the owner of the risks. 2) Impact: This section details the project objectives affected (e.g., scheduling, cost), the severity of the impact, and the specific items and groups of activities impacted by the risk. Using information extracted from the risk register, we also manually identify the relevant projects within the program and the stakeholders involved in each risk event.

3.2. Evaluation of inter-project risks

Drawing from the risk information identified in the preceding step, two types of two-mode networks can be developed to illustrate the complex interdependencies between risk events and their associated projects and stakeholders: the risk-project network and the risk-stakeholder network. In the two-mode risk-project network, there are two distinct types of nodes: one representing the risk event (R_i) and the other representing the sub-project within the program (P_i). A link between these nodes ($R_i - P_i$) signifies the association of a risk with a specific project. Similarly, the two-mode risk-stakeholder network consists of nodes representing the risk event and those representing stakeholders (S_i) engaged with the risks. In this study, the nodes for projects, risks, stakeholders, and the pertinent links are delineated using information from risk registers.

Subsequently, weighted risk-project networks and weighted risk-stakeholder networks are established for in-depth risk analysis. The weights of ties in these networks are determined by multiplying a given risk event's probability by its impact, a methodology extensively employed in risk assessment. This calculation can be formalized as follows:

$$\mathrm{W}(R_i - P_i) = \mathrm{P}(R_i) \times \mathrm{I}(R_i) \quad (1)$$

Let $\mathrm{W}(R_i - P_i)$ denote the weight representing the severity of risk for the link between risk event (R_i) and project (P_i) ; $\mathrm{P}(R_i)$ represents the probability of risk event affecting the associated project. The impact of risk event is denonted by $\mathrm{I}(R_i)$.

Risk events' probabilities and impacts are assessed using a five-point Likert scale by the on-site project team. For example, a probability rating of 1 translates to a "very low probability" of occurrence, whereas a rating of 5 indicates a "very high probability." Similarly, in impact assessment, a rating of 1 denotes "very low impact," and 5 reflects "very high impact." UCINET and NetDraw, which are the social network software, were used for the visualization and analysis of two-mode networks.

3.2.1 Calculation of project interdependence index

Recognizing the significance of project interdependence is essential for effective program risk management, as risks within interdependent projects may escalate over time, leading to cascading effects across the entire program.To address this, the risk-project network is visualized and analyzed to understand the interdependencies among projects within the program. The two-mode risk-project network, which exhibits greater complexity than traditional one-mode networks, poses unique challenges in evaluation. However, projection has been identified as a beneficial method for analyzing such a two-mode network, facilitating the transformation of the complex network into a more manageable form. Through this projection, the two-mode risk-project network is simplified into a one-mode project network and a one-mode risk network. This simplification is based on the multi-stakeholder risks between projects, with projects sharing more risks linked by stronger connections in the one-mode project network. This method's advantage lies in its ability to encapsulate the interactions between projects and risks, enhancing the assessment of critical elements within the program. Similarly, the projection method is used to transform the two-mode risk-stakeholder network into the one-mode stakeholder network, which will subsequently be used to analyse the criticalness of stakeholders.

Degree centrality, the measure of how many connections a node has within the network, serves as an indicator of a node's involvement in the network [13]. This metric has been extensively applied in construction project network studies to identify and prioritize critical nodes [14]. In this study, weighted degree centrality is employed to prioritize project nodes within the network, defined as follows:

$$D^w(P_i) = \sum_{j=1}^{N} w_{ij} \ (i \neq j) \tag{2}$$

where P_i is the ith project in the one-mode project network, j represents all other projects, N is the total number of projects, and w is the weighted adjacency matrix, in which wij is greater than 0 if the project i is connected to project j, and the value represents the weight of the tie. The project interdependence index of risk events can be measured by the average of $D^W(P_i)$ as described in Eq. (3).

$$PI(R_i) = \frac{\sum_{i=1}^{n} D^W(P_i)}{n} \tag{3}$$

Here, $PI(R_i)$ calculates the average degree centrality of n involved projects of risk event R_i.

3.2.2 Calculation of Stakeholder engagement index

Within a program, managing a risk often requires the involvement of multiple stakeholders, and conversely, a single stakeholder may be impacted by several risks. It's crucial to assess the influence of stakeholders in program risk analysis, as their interests and behaviors can significantly determine the perceived severity and importance of a threat. Operating under the premise that risks engaging a greater number of stakeholders hold a more pivotal strategic position in program risk management, we introduce the concept of the stakeholder engagement index for a risk event, denoted as $\mathrm{SE}(\mathrm{R}_i)$. This index is calculated as the average degree centrality of stakeholders linked to a specific risk event, as illustrated in Equation (4). A higher $\mathrm{SE}(\mathrm{R}_i)$ value indicates a more substantial involvement of stakeholders in relation to the risk event within the program.

$$SE(R_i) = \frac{\sum_{i=1}^{n} D^W(S_i)}{n} \tag{4}$$

Here, $SE(R_i)$ calculates the average degree centrality of n associated stakeholders of risk event R_i.

3.3. Categorization of inter-project risks

The risk management framework, as depicted in Figure 1, utilizes a two-dimensional approach to categorize risks based on project interdependence and stakeholder engagement. On this map, the x-axis measures the level of a risk event's interconnectedness with other projects, using degree centrality within the project network to indicate the extent of its influence on, or its influence by, other projects. The y-axis assesses the degree of stakeholder engagement in a risk, indicative of the risk event's strategic importance to the program. Each risk event is positioned as a point on the map according to its project interdependence and stakeholder engagement metrics.

This analytical map organizes risk events into four quadrants by comparing their scores against the average values on both axes, effectively segmenting them based on their interproject dependencies and stakeholder engagement levels:

- Primary risk: Risks that exhibit both high levels of project interdependence and significant stakeholder engagement.
- Interdepedent risk: Risks characterized by high project interdependence but lower levels of stakeholder engagement.
- Multi-stakeholder risk: Risks with pronounced stakeholder engagement despite lower project interdependence.
- Negligible: Risks that are low in both stakeholder engagement and project interdependence.

This division allows for a nuanced analysis of risks, enabling targeted management strategies tailored to each quadrant's distinct characteristics.

4. CASE STUDY

4.1. Case selection

To evaluate the effectiveness of the proposed method for assessing and categorizing inter-project risks, a case study was carried out, focusing on the World Expo 2020 construction program in Dubai, United Arab Emirates (Expo 2020). This extensive program was chosen due to its systematic approach to risk management at both individual project and overarching program levels, supported by a dedicated professional program management consultant(PMC). The construction efforts began in March 2016 and were completed by April 2020, covering an area of roughly 4 km².

During the main construction phase of Expo 2020, a comprehensive review of the risk register captured data on 395 risk events, automating the process for generating risk networks. The details concerning the projects and stakeholders associated with these risk events were extracted from the 'Risk Description' section of the risk register.

4.2. Results of inter-project risk assessment and classification

Based on the information from risk register, two-mode networks for risk-project and risk-stakeholder analysis were constructed using UciNet software, as illustrated in Figures 2 and 3. In Figure 2, the red and other colarful nodes visually represent the 395 risk events and the 24 projects of Expo 2020, respectively.

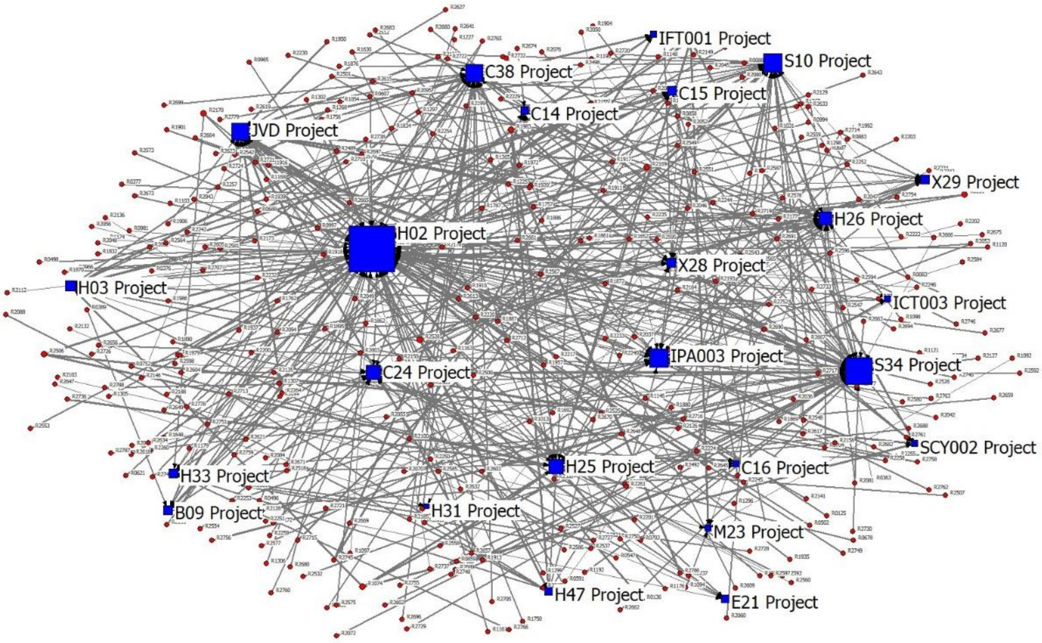

Figure 2. Risk-Project network

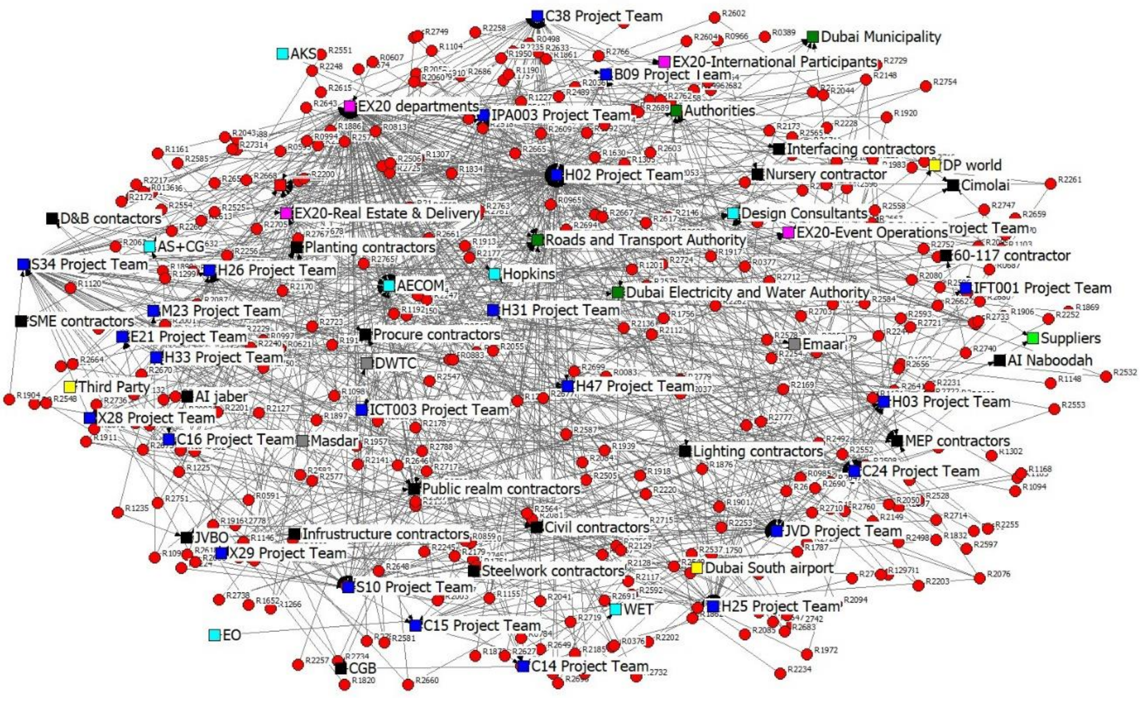

Figure 3. Risk-Stakeholder network

Figure 2 showcases the risk-project network, with node colors indicating different projects and the edge thickness denoting the risk magnitude (calculated as the product of impact and likelihood). Figure 3 presents the risk-stakeholder network, where node colors signify stakeholder groups and edge colors indicate types of inter-project risks. This network includes seven stakeholder groups, such as owners, designers, PMC project management teams, contractors, authorities, external partners, and suppliers, all implicated in the inter-project risks.

The two-mode risk-project network and risk-stakeholder network were then transformed into two one-mode networks respectively. Based on the methods described in the section of "3. Research Framework", project interdependence index and stakeholder engagement index were calculated and ranked. The examples of four types of program risks are shown in Table 1.

Table 1. Examples of four types of program risks

ID	Risk Description	PI index	SE index	Risk Type
R0496	IF an international participant country fails to complete their plot and there are empty plots during the EXPO event, THEN urban planning will be required to landscape the areas, which leads to cost increase.	11.77	2	Primary risk
R0136	IF the level of construction activity during 2018-2019 exceeds suitable contractor market capacity, THEN the construction works will extend beyond the RE&D major milestone of October 2019.	4.99	2	Multi-stakeholder risk
R0981	IF the design of the opportunity pavilion impacts the current public realm design THEN changes may be required to the public realm design, incurring additional costs.	11.77	1	Interdependent risk
R1168	IF there is failure of temporary works on Site THEN HSE impacts.	5.02	1	Negligible risk

The map illustrating inter-project risk management were developed for examination, as shown in Figure 4. This figure categorizes project-to-project risk events into four distinct segments based on the average normalized indices for project interdependence (0.450) and stakeholder engagement (0.196). As a result, project-to-project risks fall into four categories: primary, multi-stakeholder, interdependent, and negligible risks.

The map delineates the spread of risk events into these four categories. Specifically, within the analyzed program, it was found that there are 87 primary risks, 178 multi-stakeholder risks, 36 interdependent risks, and 94 negligible risks among a total of 395 risk events. Primary risks, which are deemed the most critical type of inter-project risk, constitute 22% of the total, ranking them third in prevalence among the categories. The findings indicate that the bulk of inter-project risks are categorized as multi-stakeholder risks (45%), with negligible risks accounting for 24%.

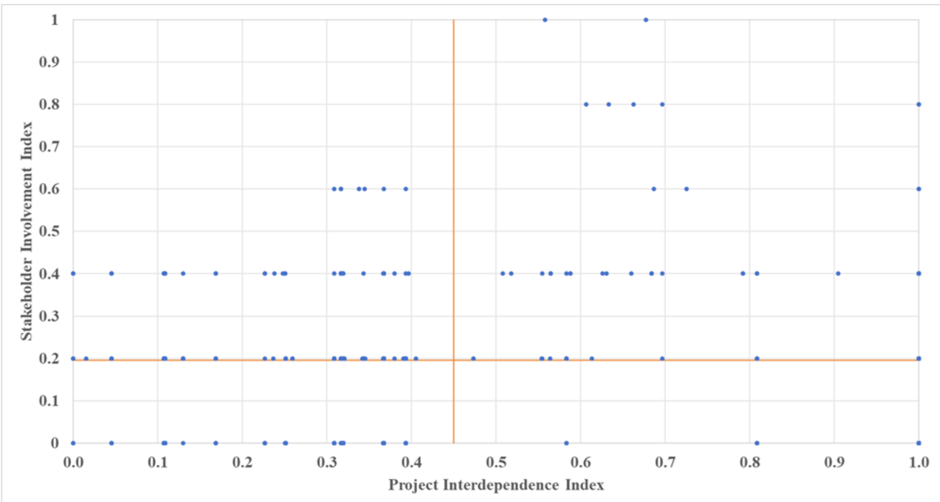

Figure 4. Program risk management map

5. DISCUSSION

This study presents a more precise and effective strategy for evaluating, classifying, and prioritizing risks among projects, enhancing traditional risk assessment techniques. First, traditional approaches typically categorize risks into broad levels (such as low, medium, high, very high) based on a risk score derived from the multiplication of risk probability and impact [4]. While this method offers a basic understanding of risk severity, it falls short in recognizing and addressing the nuances of inter-project risks within a programmatic framework. Our approach goes beyond merely assessing the likelihood and impact of risks by incorporating the dynamics of project interrelations and stakeholder influences into the risk quantification process. Through the implementation of a two-dimensional classification system tailored for inter-project risks, our methodology facilitates a finer and more targeted assessment of these risks.

Secondly, our methodology enhances the application of network analysis within the field of construction management. Traditional uses of social network analysis, particularly metrics such as degree and betweenness centrality, have been prevalent in risk management studies but typically restricted to binary networks [3,7]. Such applications fail to capture the depth of insights afforded by weighted networks, where the nuances of degree centrality versus weighted degree centrality reveal distinct layers of analysis. Degree centrality evaluates a node's significance through the sheer number of its connections, while weighted degree centrality incorporates the strength of these connections, providing a more nuanced view of a node's role and influence in the network.

Thirdly, our approach introduces an automated analysis of both the risk-project and risk-stakeholder networks, culminating in the development of a program risk management map. This innovation not only accelerates the process for managers to pinpoint inter-project risks but also simplifies the comprehension of these risks' impacts for stakeholders, fostering a more intuitive understanding.

6. CONCLUSION

This study presents a methodical framework that leverages social network analysis to refine risk management in programs, specifically targeting the nuances of inter-project risks. The framework is structured around four principal stages: identification and visualization of inter-project risks, followed by their evaluation and strategic management. Initially, the framework maps out the intricate web of connections between risks and projects using two-mode networks, encapsulating both risk-project and risk-stakeholder dynamics. These networks are subsequently simplified into one-mode networks to streamline analysis. The evaluation stage assesses project risks against three primary benchmarks: (1) a risk score derived from the probability and impact of the risk; (2) a Project Interdependence Index (PI) that quantifies the extent of risk-related interactions across projects; and (3) a Stakeholder Engagement Index (SE), determined by the volume of stakeholders involved with the risks. Based on these assessments, risks are classified into four distinct categories—primary, interdependent, multi-stakeholder, and negligible—each accompanied by bespoke management strategies. The practicality and effectiveness of this social network analysis-enhanced approach to risk management are demonstrated through an examination of the World Expo 2020 construction program in Dubai.

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REFERENCES

[1] A. Davies, I. Mackenzie, Project complexity and systems integration: Constructing the London 2012 Olympics and Paralympics Games, Int. J. Proj. Manag. 32 (2014) 773–790.

[2] W. Shen, W. Ying, Large-scale construction programme resilience against creeping disruptions: Towards inter-project coordination, Int. J. Proj. Manag. 40 (2022) 671–684. https://doi.org/10.1016/j.ijproman.2022.06.004.

[3] L. Luo, G. Qiping Shen, G. Xu, Y. Liu, Y. Wang, Stakeholder-Associated Supply Chain Risks and Their Interactions in a Prefabricated Building Project in Hong Kong, J. Manag. Eng. 35

(2019) 1–14. https://doi.org/10.1061/(asce)me.1943-5479.0000675.
[4] N. Xia, R. Zhong, C. Wu, X. Wang, S. Wang, Assessment of Stakeholder-Related Risks in Construction Projects: Integrated Analyses of Risk Attributes and Stakeholder Influences, J. Constr. Eng. Manag. 143 (2017) 1–11. https://doi.org/10.1061/(asce)co.1943-7862.0001322.
[5] H. Zhou, S. Tang, W. Huang, X. Zhao, Generating risk response measures for subway construction by fusion of knowledge and deep learning, Autom. Constr. 152 (2023) 104951. https://doi.org/10.1016/j.autcon.2023.104951.
[6] S. Moon, S. Chi, S.B. Im, Automated detection of contractual risk clauses from construction specifications using bidirectional encoder representations from transformers (BERT), Autom. Constr. 142 (2022) 104465. https://doi.org/10.1016/j.autcon.2022.104465.
[7] R.J. Yang, P.X.W. Zou, Stakeholder-associated risks and their interactions in complex green building projects: A social network model, Build. Environ. 73 (2014) 208–222. https://doi.org/10.1016/j.buildenv.2013.12.014.
[8] A.E. Yildiz, I. Dikmen, M.T. Birgonul, K. Ercoskun, S. Alten, A knowledge-based risk mapping tool for cost estimation of international construction projects, Autom. Constr. 43 (2014) 144–155. https://doi.org/10.1016/j.autcon.2014.03.010.
[9] S.P. Borgatti, M.G. Everett, Network analysis of 2-mode data, Soc. Networks 19 (1997) 243–269. https://doi.org/10.1016/S0378-8733(96)00301-2.
[10] X. Wang, N. Xia, Z. Zhang, C. Wu, B. Liu, Human Safety Risks and Their Interactions in China's Subways: Stakeholder Perspectives, J. Manag. Eng. 33 (2017) 1–15. https://doi.org/10.1061/(asce)me.1943-5479.0000544.
[11] T. Yu, G.Q. Shen, Q. Shi, X. Lai, C.Z. Li, K. Xu, Managing social risks at the housing demolition stage of urban redevelopment projects: A stakeholder-oriented study using social network analysis, Int. J. Proj. Manag. 35 (2017) 925–941. https://doi.org/10.1016/j.ijproman.2017.04.004.
[12] F.D. Patterson, K. Neailey, A risk register database system to aid the management of project risk, Int. J. Proj. Manag. 20 (2002) 365–374. https://doi.org/10.1016/S0263-7863(01)00040-0.
[13] L.C. Freeman, Centrality in Social Networks Conceptual Clarification, Soc. Networks 1 (1979) 215–239. https://doi.org/10.1016/0378-8733(78)90021-7.
[14] W. Shen, J. Xue, Managing project-to-project interfaces for large-scale programmes: A network study in world expo 2020, Int. J. Proj. Manag. 41 (2023) 102438. https://doi.org/10.1016/j.ijproman.2023.102438.