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Research Article

Stakeholder-Associated Risks and Their Interactions in PPP Projects: Social Network Analysis of a Water Purification and Sewage Treatment Project in China

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As a result of complex contractual relationships, multiple stakeholders with different interests are involved in public-private partnership (PPP) projects. Compared to traditional models, PPP projects have more uncertainty. This study integrated stakeholders and risk factors in PPP projects from a network perspective to better determine how to control risks. Using social network analysis (SNA), a case study was conducted to identify the critical risk factors, and mitigation actions are proposed. The results indicated that, compared to other stakeholders, local governments play the most important role in PPP projects. Managers should therefore pay more attention to political and legal risk factors and develop reasonable risk-sharing plans. This study expands PPP risk research from the individual level to the network level and provides a visualized, innovative research paradigm for PPP risk analysis. The results can also be used by project managers for decision-making, risk management, and other processes, thus helping to achieve the sustainable management of PPP projects.

1. Introduction

A public-private partnership (PPP), which refers to cooperation between governments and private entities, provides an efficient way to achieve value for money (VFM) in procuring public infrastructure or services [1]. PPPs have made great contributions to sustainable urban development. Compared to traditional models, PPPs can relieve governments' financial pressures and technical constraints by taking advantage of the private sector's capital and expertise, thereby improving the efficiency and performance of projects [2]. The PPP model was first proposed in the UK, initially to realize the privatization of public infrastructure projects by adopting a private finance initiative (PFI) model [3]. Since the 2008 global economic crisis, there has been increasing interest in adopting PPP policy in both developed and developing countries [4].

PPP was once considered a panacea for the financial and technical deficits of public investment [5]. However, as a result of characteristics such as enormous investment, long-term contract periods, and multiple stakeholders with different objectives, PPPs face greater uncertainties than traditional projects [2]. Practical experiences of infrastructure PPP projects have revealed many problems. Many such projects have encountered various crises, and there are numerous cases of failed PPP projects. For example, the D47 Motorway in the Czech Republic and the M9 Motorway in Pakistan were ultimately canceled [6]. Meanwhile, the failure of the Quanzhou Citong Bridge project in China provides a good example of a project being nationalized in advance [7]. Further, the Channel Tunnel Rail Link in the UK was a failure in that VFM was not achieved [6]. Therefore, the complex, long-term, systematic nature of PPP projects inevitably gives rise to various risks and challenges.

In recent years, several studies have investigated the risk management of PPP projects [8]. Based on conventional risk-management processes, these studies can be categorized into three themes: risk identification, risk assessment, and risk response [9]. Many studies have examined risk identification in PPP projects, especially in the early stages of the research [10–12]. Such studies mainly used literature reviews [10], case studies [7], questionnaire surveys [13], and other qualitative methods to identify and classify the risks of various PPP projects. Risk assessment, meanwhile, has been shown to play a crucial role in PPP project success; accordingly, researchers have tried to construct suitable risk assessment models for PPP based on various theories and methods [14–16]. Regarding the risk-response theme, most studies have focused on risk-sharing principles [17, 18], decision-making processes [19–21], and distribution methods [14, 22]. Such studies have provided valuable information for managing risk in PPP projects. However, many studies are limited in that they only approach risk from a single perspective, do not analyze causal relationships, and do not consider the entire supply chain as a risk network.

With the maturation of stakeholder theory, stakeholder analysis has been applied in various research fields [23], including investigations of PPP projects [24–28]. Kerzner [29] suggested that "people" is the primary factor affecting project performance. Indeed, when looking at the risks identified in previous studies, most are associated with PPP project stakeholders. Stakeholders need to analyze their individual risks and make corresponding responses. Stakeholder-risk analysis can therefore help identify risk resources to develop a comprehensive risk list for PPP projects, thereby contributing to effective decision-making. Stakeholder analysis can support efficient communication in PPP project management. However, the interactions among stakeholders in PPP projects have not been clearly analyzed. Construction projects take place in nonlinear, complex, iterative, and interactive environments [30]. Therefore, the impacts of stakeholders are best understood not as a two-party framework but as a "network." Most prior studies have used linear impact analysis to evaluate the impacts of risks or stakeholders on PPP projects; however, there has been little consideration of the associated risks and stakeholders. Relatively few studies have specifically explored risk-stakeholder interrelationships in PPP projects.

This study aimed at analyzing stakeholder-associated risks in PPP projects from a network perspective. The rest of this paper is organized as follows. In the next section, the risk and stakeholder categories of PPP projects are identified through a literature review. Then, an SNA model is proposed to analyze stakeholder-associated risks in PPP projects. In the fourth section, an exploratory case study is conducted, and the final section presents the conclusions and limitations.

2. Risks and Stakeholders in PPP Projects

With the worldwide application of PPPs, it is critical for participants to find appropriate ways to manage project risk. Researchers and practitioners both recognize that PPP projects face uncertainties because of their complex, long-term nature [31]. The body of research on PPP risk has grown significantly in recent years [32]. Risks must be accurately identified in advance to effectively analyze them and make quick responses. Eaton et al. [33] proposed that participants need to identify risks as early as possible in the life cycle of PFI projects to take measures to reduce them.

Current research on PPP risk identification usually classifies risks into different categories. Li et al. [34] divided PPP risk into "macrolevel," "mesolevel," and "microlevel" factors. Zheng et al. [35] proposed analyzing critical risk factors in two dimensions: "system" and "nonsystem." Li-Yin et al. [36] grouped risks into seven categories: "project-related risks," "government-related risks," "client-related risks," "design-related risks," "contractor-related risks," "consultant-related risks," and "market-related risks." Askar and Gab-Allah [11], meanwhile, identified four aspects of risk factors, including "political risks," "construction risks," "operating risks," and "market and revenue risks." Zhang [12] divided the barriers of PPP projects into six aspects: "social, political, and legal risk," "unfavorable economic and commercial conditions," "inefficient public procurement framework," "lack of mature financial engineering techniques," "problems related to the public sector," and "problems related to the private sector." Although there is still no standard classification of PPP risk, the approach of Liu et al. has been widely adopted (i.e., macro-, meso-, and microlevel risk) [37]. Macrolevel risks include those outside the project, such as political and legal risks, economic exposures, social risks, and natural risks. Mesolevel risks are those within the project, including project development risks, project financing risks, design risks, construction risks, and operation risks. Finally, microlevel risks concern the relationships between stakeholders and specifically include organizational risks and contract risks.

Identifying risk resources is necessary for reducing risks and ensuring PPP project implementation. However, it is difficult to track the risk resources of the identified PPP risks. This is partly because some risks are related to different stakeholders; the main reason, however, is that stakeholder groups are still not comprehensive. PPP projects create a web of stakeholders with varying interests. Previous PPP risk studies have not sufficiently identified how multiple stakeholders bring various problems to PPP projects. Therefore, it is worthwhile to review the role of stakeholders.

According to the previous research on PPP projects, the basic stakeholders are the public and private sectors [27, 38, 39]; other stakeholders have been subsequently added. Ng et al. [40], for example, added "people" as a major stakeholder while Budayan [41] added "consultant" as the third key stakeholder. Sun et al. [42] identified the public sector, the private sector, and passengers as stakeholders for evaluating cooperation efficiency. Debt and equity investors, the state, users, suppliers, and service providers have all been regarded as PPP project stakeholders [24]. Yan et al. [43] extended the list to include 13 key stakeholders (i.e., local government, private investor, government implementing agency, project company, banking and financial institutions, contractor, operator, supplier, prospecting and design unit, consultancy, end user, public, and insurance company). Amadi et al. [44] suggested that internal stakeholders, such as the public and private sectors, and external stakeholders, such as communities and trade unions, both play important roles in delivering PPP projects.

Freeman defined stakeholders as the participants in the human process of joint value creation [45]. According to the Project Management Institute (PMI), stakeholders are involved in a project, and their interests will either affect or be affected by the development of the project. Olander [46] suggested that stakeholders are individuals or organizations who have a vested interest in the success of a construction project. Many subjects are involved in the long life cycle of PPP projects, and those subjects will have effects on or be affected by the projects. According to Freeman, the stakeholders involved in PPP projects comprise a huge hybrid, which only increases the difficulty of research. The present study aimed to examine risk management for the purpose of improving project management and promoting successful PPP project implementation. Accordingly, the focus needed to be on those who trigger risks in PPP projects. This article defines PPP project stakeholders as individuals or organizations who influence projects during the whole life cycle and are, in turn, affected by the implementation and the final results. This definition emphasizes the interaction between stakeholders and PPP projects.

3. Social Network Analysis

The concept of social networks and the social network analysis (SNA) method have attracted considerable attention from the social and behavioral science community [47]. This can be attributed to the focus on the relationships between social entities. As a system environment, a PPP project involves various relationships. The purpose of SNA is to explore the influence of relationship structures on behavior [48]; it emphasizes the importance of relationships and is suitable for analyzing relational data [47]. SNA can also perform precise quantitative analyses of various relationships, and it has been widely used in many areas, including the management of construction projects. For example, Yang et al. [30] applied SNA to stakeholder management in construction projects. Fang et al. [49] used it to investigate the risk relationships in large engineering projects, and Zhu et al. [50] studied value conflicts between local governments and the private sector in stoke PPP projects. However, the application of SNA to stakeholder-associated risk analysis in PPP projects remains unexplored.

Following Yang and Zou [51], Figure 1 shows the flowchart of the SNA method.

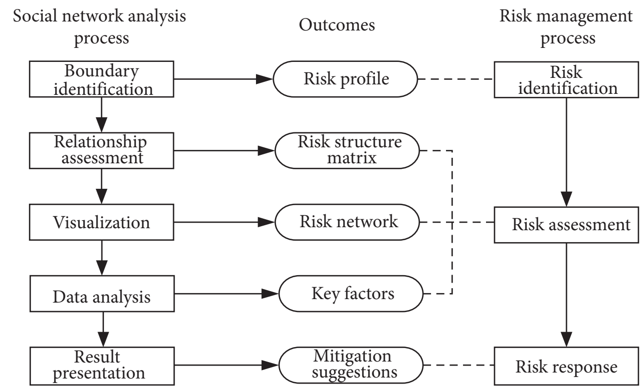

Figure 1: Flowchart of the SNA method.

In the SNA process, the first step is to identify the boundary of the network. All networks consist of nodes and links. The boundary of a network is determined by the nodes within it. This step aims to identify those nodes, which, in this study, are stakeholders and their risks in PPP projects. Laumann et al. [52] summarized the methods for identifying the boundaries of complete networks according to nominalist and realist approaches. The nominalist approach identifies network members from an observer's perspective while the realist approach is based on the subjective judgment of network members. Two different methods are often used to complete this step: the classical experience-based method and the snowball-rolling method [51]. Using the classical experience-based method, decisions can be made in a relatively short time, but the stakeholders and the identified risks will be limited. The snowball-rolling method can provide a complete list of stakeholders, but it is time-consuming and may encounter practical and ethical challenges. The choice of method should depend on the project situation considering the advantages and limitations of each.

The second step is to assess relationships in the network. Links representing the impacts between two nodes are defined in this step. In this study, this is used to determine the interrelations among the risks identified in the first step. A matrix can be used to express the relationship network [53]; it can be a binary or multivalue matrix. Workshops with project teams and other stakeholders, as well as Delphi surveys with key stakeholders, are often used to obtain a risk-structure matrix (RSM) [51]. Once the nodes and links are identified, a risk network for a PPP project can be drawn.

The third step is to visualize the risk network. Nodes of different shapes and colors can be used to represent different stakeholders and risk categories. Arrows represent the interrelationships among PPP risks, and their thickness indicates the degree of impact. After establishing the PPP risk network, the next step is to analyze it. Various software packages have been developed to visualize and analyze relationship networks (e.g., UCINET, Netdraw, NetMiner, and Pajek). To decipher the structure of the PPP risk network, SNA indicators such as density, cohesion, block models, degree, betweenness centrality, and brokerage are calculated.

(i) Density is defined as the ratio of the actual number of relationships in a network to the maximum number of possible links [47]. For a directed network, the density can be measured by equation (1), where L represents the existing relationships and N the total number of nodes. The value range of this measure is [0, 1]. With the increase in the number of relationships in a network, the network density increases. The density of a complete network graph is 1:

$$\text{density} = \frac{L}{N(N-1)}. \tag{1}$$

(ii) Cohesion is an index based on the distance of nodes in a network [54]. The distance between two nodes refers to the number of links connecting them. Adjacency matrices (AdjM) are often used to calculate the distance between all actors to obtain the average distance. Node i and node j are both actors in a network. The cohesion can be measured by equation (2), where z is calculated by the average walks between each pair of nodes in the network [51]. It is a measure of the tightness of the network structure and reflects the complexity of the network:

$$\text{cohension} = \frac{\sum_{i,j\in N} \text{AdjM}_{i,j}^{z}}{N(N-1)}. \tag{2}$$

(iii) Block modeling analysis was first proposed by White et al. in 1976 [55]. It divides the actors in a network into different positions, named B_1; B_2;. . .; B_B. There is a corresponding rule Ø that divides the actors into different positions. If actor i is in position B_k, then $Ø(i) = B_k$. We use b_{klr} to represent whether there is a relationship between B_k and B_l according to relation X_r. It is assumed that $b_{klr} = 1$ if there is a relationship and $b_{klr} = 0$ otherwise. Block models are simplified expressions of a relationship network that represent the overall structure of the network.

(iv) According to Burt's theory, the positions in a network can be categorized into four types [56]. The first type is "isolate," whose members have no contact with the outside. The second type, "sycophant," transmits more relationships to other positions than to itself, and it does not accept many relationships. The third type, "broker," is one in which its members both send and receive external relationships, but there are fewer contacts between internal members. The last, "primary," accepts both relationships from other positions and relationships from its own members.

(v) Degree indicates the number of other nodes directly connected to a node [47]. In a directed network, the degree of each node can be divided into in-degree and out-degree. The in-degree of a node refers to the number of direct relationships pointing to it, while out-degree refers to the number of relationships emitted by it. We use out-degree minus in-degree to represent the degree difference (equation (3)). The greater the difference, the stronger the impact of node i on others compared to the impact it receives:

$$\text{GapDegree}_i = \text{OutDegree}_i - \text{InDegree}_i. \tag{3}$$

(vi) Betweenness centrality measures how far a node/link falls in between two other nodes/links in a network [57]. It reflects the node/link's ability as a medium in a network [58]. Take the betweenness centrality of a node as an example. Assuming that node i, node j, and node k are three different nodes in a network, the number of geodesics linking j to k is expressed by g_{jk}, and $g_{jk}(i)$ represents the number of geodesics passing through i. The absolute betweenness centrality of node i can be calculated by equation (4). In the same way, the betweenness centrality of a link can be obtained:

$$\text{Betweenness}_i = \sum_{j}^{n}\sum_{k}^{n}\frac{g_{\text{jk}}(i)}{g_{\text{jk}}}, \quad j \neq k \neq i, j < k. \tag{4}$$

(vii) In a tripartite relationship consisting of A, B, and C, if A has a relationship to B, B has a relationship to C, but A does not have a relationship to C, then B is a broker. There are five kinds of brokerage relationships based on the groups to which A, B, and C belong. As shown in Figure 2, if B is a broker, and A, B, and C are in the same group, we call B the "coordinator;" if A and C are in the same group, and B who acts as a broker belongs to another group, we call B the "consultant;" if C and the broker B are in the same group, and A belongs to another group, we call B the "gatekeeper;" if A and the broker B are in the same group, and C belongs to another group, we call B the "representative;" if A, B, and C belong to three different groups, we call the broker B the "liaison."

The results for the SNA indicators in Step 4 are used to identify risk mitigation actions for PPP projects. Density and cohesion are two overall descriptive indexes of the network [47]. Block models divide network risks into different parts according to structural equivalence. The out-degree of nodes can help identify risks that have a greater immediate impact on others while the in-degree can reflect the more susceptible risks to others. Betweenness centrality helps to identify risks and the relationships that have stronger control over the relationships passing through them. Brokerage identifies the risks that play critical roles between different categories. Therefore, the risks with a higher degree, higher betweenness centrality, and higher brokerage value, as well as relationships with higher betweenness centrality, should be mitigated with higher attention.

4. Case Study

This research used a single case study. One reason is that this study aimed to address a "how"-type question to understand how risks are connected in PPP projects. At the same time, since PPP models are being widely used around the world, an exploratory case study was an appropriate approach [59]. The case selection was not random. To make the stakeholder and risk analysis more meaningful, a typical case with high project complexity involving numerous stakeholders was chosen. The case is a water purification and sewage treatment PPP project in the Changchun City Airport Economic Development Zone in China. The contract sum was over $21 million. This project consists of five subprojects: a water purification plant project, water supply pipe network

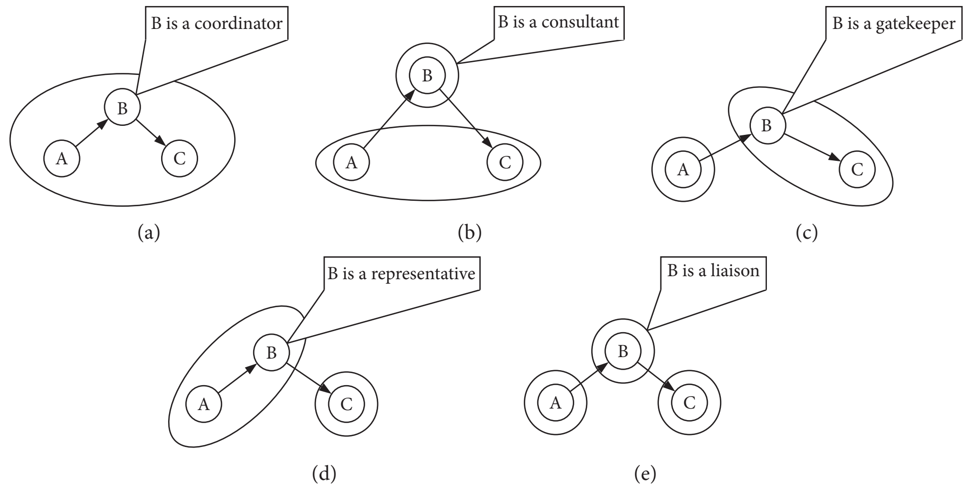

Figure 2: Descriptions of five kinds of brokerage roles.

project, core area sewage treatment plant project, northern sewage treatment plant project, and tailwater wetland project. It was launched in December 2017. A foreign-investment company won the bid in April 2018 and then formed a special-purpose vehicle (SPV) together with a financing platform company. Next, in June 2018, the government signed a concession agreement with the SPV; the contract period may last 30 years. Given the long-term payoff period, vast investment, complex contractual relationships, and numerous stakeholders with contradictory interests, this project is bound to face a number of potential risks [2]. Such risks could include a failure to acquire the land within the stipulated time [34], the actual cost of the project during the construction phase exceeding expectations [60], and a mismatch between the technology used in the operation of the project and the actual situation [61].

4.1. Identification of Stakeholders and Their Risks. In the SNA method, the first step in building a risk network for this case project is identifying stakeholders and their risks. This study used the classical experience-based method. Predefined categories of risks and stakeholders were given in the previous section. The core stakeholders in this PPP project could easily use them as a reference to identify stakeholders and risks.

To identify project stakeholders, a four-hour group discussion was conducted with key project participants, including two senior officers from the local government, two senior managers from the financial platform company, the chief operating officer (COO) of a private investment firm, the vice president of a commercial bank, and a vice general manager from a construction company. Figure 3 shows the structure of stakeholders in this PPP case project. The SPV was formed by the private investor and a financial platform company authorized by the local government; then, the local government granted this SPV a concession. A state-owned commercial bank was the main creditor for the project's financing sources. The SPV commissioned different design units and contractors to design and construct this PPP project. Suppliers provided the main equipment and material for the project. The SPV as the operator was responsible for the operation and maintenance of the built-up PPP project according to the concession agreement. Consultancies provided intellectual support for the successful implementation of the project. The ultimate purpose of the project is to provide high-quality clean water and sewage treatment services to the public.

The seven respondents who participated in the group discussion provided contact persons of the 10 stakeholders in the case project. Semistructured interviews were used to identify the risks related to each stakeholder. Thirty-five semistructured interviews were conducted from June 2019 to October 2019; each lasted more than 30 minutes. Questions about the risks related to each stakeholder were asked. According to the risk categories, a total of 37 risks associated with these 10 stakeholders were identified. These identified risks were coded numerically as SaRb, where Sa represents a stakeholder and Rb represents the risk related to that stakeholder. A risk checklist was developed, as shown in Table 1.

4.2. Determination of Risk Interrelations. Based on the identified risks, expert scoring was used to further identify the relationships between risk factors. A total of 20 experts, including scholars and management personnel, were asked to determine whether there were impacts between each pair of risks. Questionnaires were collected through interviews and e-mail. Based on the experts' professional knowledge and practical experience, a value of 0-1 was assigned to the interrelations among the identified risk factors. If it was determined that the risk factor in a row had an impact on the risk factor in the column, it was represented by 1; otherwise, 0. The assignment results from the 20 experts were then processed. If more than 10 experts assigned a value of 1 to the same relationship, the relationship was determined to be 1; otherwise, it was 0. The results were then given back to the experts so they could adjust their judgments. This process was repeated until an agreement was reached. Table 2

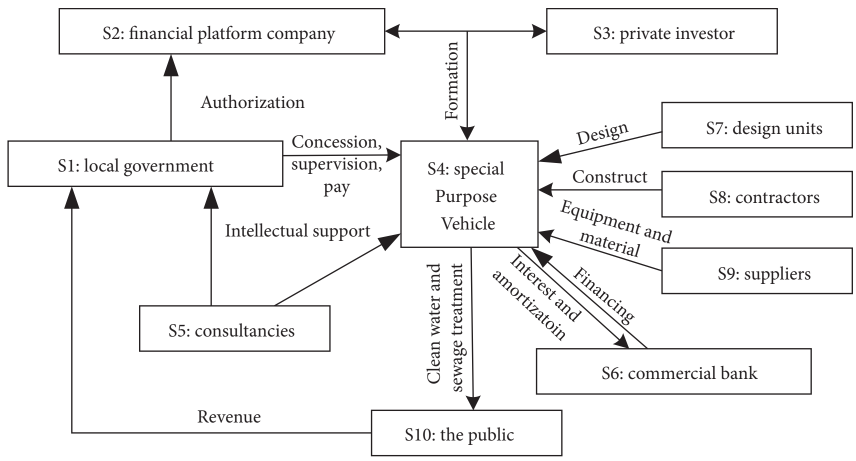

Figure 3: Structure of stakeholders in the water purification and sewage treatment PPP project.

Table 1: Risk checklist for the PPP case project.

Risk level	Risk category	Code	Risk factor	Corresponding stakeholder
		S1R1	Unstable government	Local government
		S1R2	Corruption	Local government
		S1R3	Expropriation or nationalization in advance	Local government
	Political and legal risks	S1R4	Government credit risk	Local government
		S1R5	Policy risk	Local government
		S1R6	Immature laws and regulations	Local government
		S1R7	Government intervention	Local government
		S1R8	Inadequate supervision	Local government
Macrolevel	Economic exposures	S6R9	Interest rate risk	Commercial bank
		S6R10	Foreign exchange risk	Commercial bank
	Social risks	S10R11	Public opposition risk	The public
		S10R12	Market demand risk	The public
		S1R13	Land acquisition risk	Local government
	Project development risks	S1R14	Delay in approval	Local government
		S2R15	High financing costs	Financial platform company
		S2R16	Project financial attractiveness	Financial platform company
	Project financing risks	S2R17	Availability of finance	Financial platform company
		S4R18	Design change	SPV
		S7R19	Design deficiency	Design unit
	Design risks	S7R20	Design delay	Design unit
		S8R21	Construction cost overrun	Contractor
		S8R22	Construction technical risk	Contractor
		S8R23	Schedule delay	Contractor
	Construction risks	S8R24	Quality risk	Contractor
Mesolevel		S9R25	Material/equipment procurement risk	Supplier
		S3R26	Operation and maintenance cost risk	Private investor
		S10R27	Revenue risk	The public
		S3R28	Quality of service	Private investor
	Operation risks	S3R29	Insufficient operation capacity	Private investor
		S4R30	Residual value risk	SPV
		S1R31	Lack of supporting infrastructure	Local government
		S4R32	Environmental pollution	SPV
		S5R33	Inadequate experience in PPPs	Consultancy
	Organizational risks	S4R34	Inefficient communication	SPV
Microlevel		S5R35	Inadequate distribution of risks	Consultancy
	Contract risks	S5R36	Inadequate distribution of authority	Consultancy
		S5R37	Contract change risk	Consultancy

Table 2: Risk-adjacent matrix of the PPP case project.

Risk factor	S1R1	S1R2	S1R3	S1R4	S1R5	S1R6	S1R7	S1R8	S6R9	S6R10	S10R11	S10R12	S1R13	S1R14	S2R15	S2R16	S2R17	S4R18	S7R19	S7R20	S8R21	S8R22	S8R23	S8R24	S9R25	S3R26	S10R27	S3R28	S3R29	S4R30	S1R31	S4R32	S5R33	S4R34	S5R35	S5R36	S5R37
S1R1	0	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0	0	1	0	1	0	1	1	1	0	0	0	1	0	1	1	0	0	1
S1R2	1	0	1	1	0	0	1	1	0	0	1	0	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1
S1R3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1
S1R4	0	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1
S1R5	0	0	1	1	0	1	1	0	1	1	0	0	1	1	1	0	1	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	1	0	0	0	1
S1R6	0	0	1	1	1	0	1	1	0	0	0	0	1	1	1	0	1	0	0	0	0	0	0	0	1	0	1	0	0	1	0	0	1	0	0	0	1
S1R7	0	0	1	1	0	0	0	0	0	0	0	0	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	1
S1R8	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	1	0	0	0	1	1	0	0	1	0	1	1	1	0	0	0	0	0
S6R9	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
S6R10	0	0	0	0	0	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
S10R11	0	0	1	1	0	0	1	0	0	0	0	1	1	1	0	1	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	1
S10R12	0	0	1	1	0	0	1	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	1
S1R13	0	1	1	1	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
S1R14	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
S2R15	0	1	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	0
S2R16	0	1	0	1	0	0	1	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
S2R17	0	1	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
S4R18	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	1	1	1	1	1	0	0	1	1	0	1	1	1	0	0	0	0	0	1
S7R19	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	1	0	1	0	1	1	1	1	1	0	1	1	1	1	1	0	1	0	0	0	0	0
S7R20	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S8R21	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	1	1	1	0	1	0	0	0	0	0	0	0	0	0	1
S8R22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0
S8R23	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
S8R24	0	0	1	0	0	0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	1	0	0	1	1	1	1	1	0	1	0	0	0	0	0
S9R25	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	1	0	1	0	1	0	1	0	0	0	0	0
S3R26	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	1	0	0	0	0	1
S10R27	0	0	1	1	0	0	1	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	0	0	0	0	1
S3R28	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
S3R29	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	0	1	0	0	0	0	0
S4R30	0	0	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
S1R31	0	0	1	1	0	0	0	0	0	0	0	0	0	1	1	1	0	1	1	0	0	0	1	0	0	1	1	1	1	1	0	1	0	0	0	0	1
S4R32	0	0	1	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1
S5R33	0	0	1	1	1	1	1	1	0	0	0	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	1	1
S4R34	0	1	1	1	0	0	1	1	0	0	1	1	0	1	1	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	1	1
S5R35	0	0	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1
S5R36	0	0	1	1	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1
S5R37	0	0	1	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	0

provides the risk-adjacent matrix of the case project. The first row and column are the risk number coded in the risk checklist; 0 or 1 indicates whether a relationship existed.

4.3. Visualization of the Risk Network. After identifying the risks and their interrelations, the risk network for the PPP case project was established. NetDraw was used to visualize the risk-structure matrix. The risk network was depicted in a graph with 37 nodes and 378 arrow lines, as shown in Figure 4. The colors of the nodes represent different stakeholders, and the node shapes show the risk levels. The arrows indicate the directions of the relationships between risk factors.

4.4. Analysis of the PPP Risk Network. Ucinet 6.0 was used to calculate the indicators of the risk network in the case project. Density and cohesion were calculated first. The density of the PPP risk network is 0.298, which means the risk network is dense; there are relatively more interrelations between the PPP risk factors [49]. The cohesion of the PPP risk network is $0.615 > 0.298$, which means the PPP risk network has high complexity [51].

Block modeling analysis was used to divide the risk factors into different positions and explore the relationships between them [47]. This is a simplified expression of the risk network in the case project, and it represents the overall structure of the network. The steps for building a PPP risk network block model are as follows: first, the CONCER method was used to partition the risk factors into blocks; then, the overall network density was used as an α-density index to determine the values of the blocks. Considering the effect of the final partition, the number of nodes in each block should generally be greater than three. Therefore, the above risk factors were divided into four subgroups, as shown in Table 3. Table 4 shows the density matrix of the block models. Comparing the values in the density matrix with the overall network density, values greater than 0.298 were replaced with 1 and values less than 0.298 with 0. The image matrix of the risk network was obtained as shown in Table 5. Investigating how messages were sent and received between blocks based on Burt [56], and it was found that the risk factors in Block 1 sent more relationships to other blocks but received no foreign relationships. So Block 1 is a "sycophant." Blocks 2, 3, and 4 accepted both relationships from other blocks and their own; therefore, they are "primaries." The risk factors in Block 1 are at either macrolevel or microlevel.

For the risk network, the degree of a risk factor indicates the links between it and its neighbors. In-degree refers to the number of other risk factors that can have a direct impact on it, and out-degree refers to the number of other risk factors that can be directly influenced by it. As shown in equation (3), degree difference is equal to out-degree minus in-degree. The greater the difference, the stronger the risk factor's impact on others compared to the impact it receives. Seven risk factors with a high out-degree and high degree difference were identified, as shown in Table 6. S5R35 ("inadequate distribution of risks" associated with consultancy) had the highest out-degree of 31, followed by S1R2 ("corruption" associated with local government) and S1R1 ("unstable government" associated with local government). These identified risk factors all belong to Block 1, which is the "sycophant."

In this PPP risk network, the greater the betweenness centrality, the stronger the control of the risk factor/link over the relationships passing through it. Table 7 shows the top 10 risk factors and risk relationships with the highest betweenness centrality. The calculation results show that S1R7 ("government intervention" associated with local government), S5R35 ("inadequate distribution of risks" associated with consultancy), and S1R2 ("corruption" associated with local government) have the highest betweenness centrality, and all of the most important links are related to them. The trigger factors in the risk relationships should receive more attention. Comparing the risk factors in Tables 6 and 7, S1R14 ("delay in approval" associated with local government), S10R27 ("revenue risk" associated with the public), S5R37 ("contract change risk" associated with consultancy), S2R15 ("high financing costs" associated with financial platform company), S2R16 ("project financial attractiveness" associated with financial platform company), S10R11 ("public opposition risk" associated with the public), S4R18 ("design change" associated with SPV), and S8R23 ("schedule delay" associated with contractor) show low outward influence but still play important intermediary roles. These risk factors with high betweenness centrality values are located in the geodesics of many other pairs of nodes. The connections between other nodes are established through them. These risk factors are neither the initiators nor the ultimate recipients of the risk transmission. They are in the middle of the risk transmission, playing the role of connecting risk initiators and recipients.

Brokerage roles, including coordinator, gatekeeper, representative, consultant, and liaison, were determined based on analyzing the ego network from the whole network [62]. Brokerages often hold secrets among multiple groups and occupy important positions in a network. Given a one-mode network and a partition vector, brokerage analysis can be conducted. Table 8 shows the top 10 risk factors with the highest brokerage values. Stakeholder categories and risk categories were selected as the partition vectors. These risk factors are regarded as playing critical roles in connecting different groups. The identified risk factors are basically consistent with the betweenness centrality results. Only one risk factor, S1R31 ("lack of supporting infrastructure" associated with local government), was newly identified as an important risk due to its brokerage role.

4.5. Risk Mitigation Actions. Through the above SNA, a list of critical risk factors was finally obtained, as shown in Table 9. They either have the most direct effect on other risk factors or have strong risk transmission ability according to the results for degree, betweenness centrality, and brokerage. To mitigate risk, these 17 risk factors, related to six different stakeholders in the PPP project, should be prioritized.

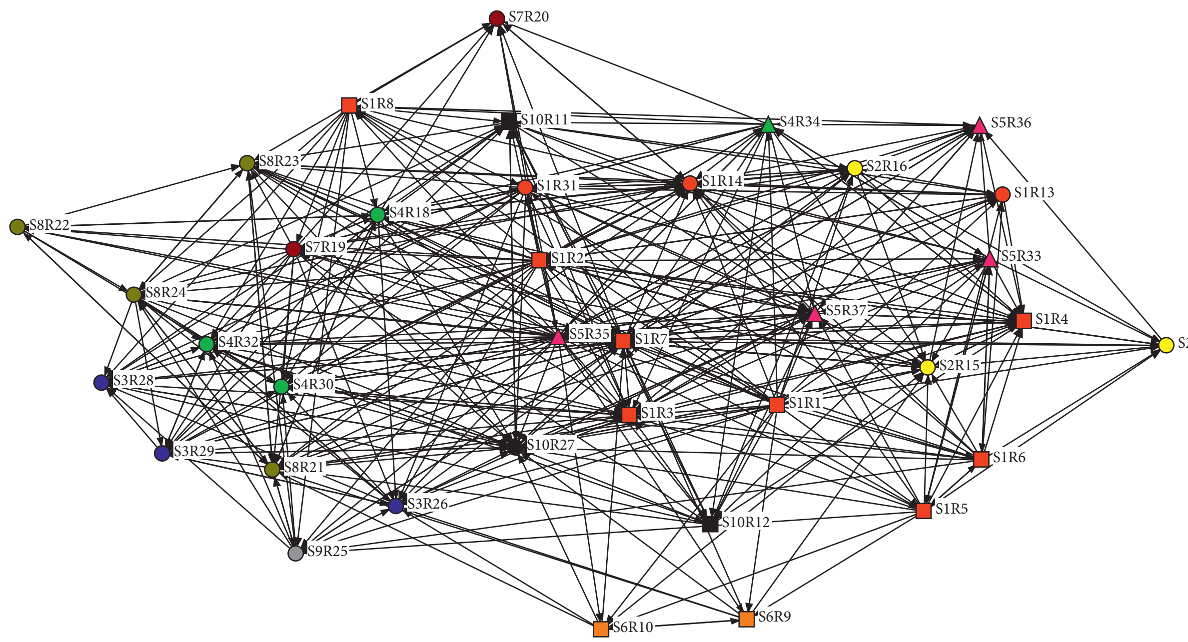

Figure 4: Stakeholder-associated PPP risk in the case project. ■ macrolevel, ○ mesolevel, Δ microlevel. ■ local government, ■ financial platform company, ■ private investor, ■ SPV, ■ consultancy, ■ commercial bank, ■ design unit, ■ contractor, ■ supplier, and ■1 the public.

Table 3: Partitions of the risk factors in the case project.

Block	Risk factors
1	S1R1, S1R2, S10R12, S1R8, S1R5, S1R6, S4R34, S5R35, S5R33
2	S1R4, S6R10, S1R7, S6R9, S5R36, S5R37, S2R15, S1R13, S2R17, S2R16
3	S1R3, S10R11, S4R32, S10R27, S3R29, S4R30, S3R28, S3R26
4	S8R22, S7R20, S8R21, S8R23, S1R14, S8R24, S9R25, S1R31, S4R18, S7R19

Table 4: Density matrix of the block models.

Block	1	2	3	4
1	0.458	0.600	0.486	0.478
2	0.144	0.389	0.200	0.190
3	0.028	0.213	0.625	0.050
4	0.011	0.150	0.425	0.456

Table 5: Image matrix of the block models.

Block	1	2	3	4
1	1	1	1	1
2	0	1	0	0
3	0	0	1	0
4	0	0	1	1

Seven are caused by local government. Local government plays an important role in managing PPP risks. A stable political and legal environment is necessary for the successful implementation of PPP projects. The Chinese government should therefore speed up the formulation and promulgation of laws related to PPP. At the same time, the local government should clarify its responsibilities and strengthen its internal management to avoid excessive interventions, delays in approval, and corruption. In this case project, the local government should ensure that all supporting infrastructures are complete before the project operation period.

Table 6: Risk factors with a high out-degree and high degree difference.

Risk factor	Out-degree	Degree difference
S5R35	31	23
S1R2	29	22
S1R1	25	24
S4R34	17	11
S5R33	15	10
S1R5	14	10
S1R6	14	10

Two project financing risk factors associated with the financial platform company were identified as critical factors. Fully exploring the profitability of the PPP project, the financial platform company should comprehensively analyze possible lenders for the project to expand the financing channels. At the same time, the company could ask the local government to provide appropriate guarantees for the PPP project, thereby reducing costs and improving the project's financial attractiveness.

As the core stakeholder, the SPV carries out the actual management of the PPP project. Based on the SNA results, the SPV of this case project should clarify the project objectives at the beginning and avoid changing the project design at will. The SPV should also seek to ensure effective communication between project participants. It should propose a feasible project communication plan with related measures, such as conducting meetings, regularly reporting on the project's progress, and carrying out irregular

Table 7: Key risk factors and relationships according to betweenness centrality.

Risk factor	Node betweenness centrality	Risk relationship	Link betweenness centrality
S1R7	271.399	S1R14 ⟶ S1R2	66.770
S5R35	185.831	S1R7 ⟶ S5R35	66.454
S1R2	127.433	S5R37 ⟶ S5R35	51.970
S1R14	73.106	S1R2 ⟶ S1R1	42.095
S10R27	67.710	S5R35 ⟶ S1R5	31.487
S5R37	61.060	S5R35 ⟶ S1R6	31.487
S2R15	43.996	S5R35 ⟶ S6R9	29.917
S2R16	38.791	S5R35 ⟶ S6R10	29.917
S10R11	29.969	S2R15 ⟶ S1R2	29.425
S4R18	29.655	S8R23 ⟶ S1R7	28.839

inspections to improve communication between stakeholders. In particular, attention should be paid to communication with the public. As the end users and payers of the project, public opposition should be avoided.

Consultancy also plays an important role in successful PPP project implementation by providing intellectual support. In the case project, consulting companies with sufficient PPP project experience should be selected to develop a reasonable risk-sharing plan and design a standard contract.

Lastly, the contractor should make a reasonable project schedule plan and choose a suitable construction plan to ensure the construction is completed on schedule.

In addition to resolving the above critical risk factors, cutting off the main interactions between risk factors is also an important means to mitigate the risk of the PPP project. Cutting the links can fragment the network and reduce the chain reaction between risk factors. Stakeholders should focus on the causal relationships between the risk source owners and the risk receivers and enhance communications between them. Key risk relationships identified with a high link of betweenness centrality values, as shown in Table 7, should receive more attention. Since the identified links are all related to risk factors in Table 9, the abovementioned actions for these critical risk factors can effectively reduce these risk relationships; therefore, specific control measures for these relationships are not proposed.

By undertaking the above actions, the critical risk factors can be resolved, and the main interactions can be cut off. It is meaningful to verify the impact of the above risk mitigation actions on the risk network. By removing the three most important risk factors (S5R35, S1R7, and S1R2, based on degree, betweenness centrality, and brokerage values) and cutting off the most important risk relationship (S1R14 ⟶ S1R2, with the highest betweenness centrality of link), the density of this case project's risk network was reduced from 0.298 to 0.246, and the cohesion value was reduced from 0.615 to 0.533. This outcome means that there are fewer risk interactions in the new risk network, and the complexity of the risk network has been reduced.

5. Discussion and Conclusion

This paper first defined the stakeholders in PPP projects and then identified risk categories based on the literature. An SNA model was then proposed to analyze stakeholder-associated risks in PPP projects. Lastly, a case study was conducted for a water purification and sewage treatment PPP project in the Changchun City Airport Economic Development Zone in China. To identify how to better prevent and control risk, this study integrated stakeholders and risk factors in PPP projects from a network perspective. In this way, this study expands the research on PPP risk from the individual level to the network level, making up for the limitations of previous studies. Social network analysis is suitable for building and discussing a risk transmission network for PPP projects to discover the key risk factors and risk relationships. The advantages of using SNA for risk analysis are as follows: first, the risk network can be visualized. Second, it fully considers the influence of risk relationships in the risk assessment process. Third, the mitigating actions can be proposed from two aspects of risk factors and risk relationships. Last, the effectiveness of risk mitigation actions can be tested. This research provides a visualized, innovative research paradigm for PPP project risk analysis. Project managers can use the results for decision-making, risk management, and other processes.

There are several risk transmission chains in the risk network. Risk is transferred from the risk initiators to the intermediary risk factors and finally to the ultimate risk recipients. Block modeling analysis and the degree difference help to identify the source risks in this risk network. These risk factors will induce the generation of subsequent risks. According to the degree results, all identified risk factors belong to Block 1, and the block models indicate that the risk factors in Block 1 are at the macrolevel and microlevel. Therefore, macrolevel risks and microlevel risks are more inclined to the identity of risk initiator. The risk transmission process must contain many intermediary risk factors. For example, "government intervention" is often in the chain between "policy risk" and "revenue risk." In other words, a change in policy may lead to local government intervention on the PPP project, which may lead to a revenue deficiency. A "government intervention" associated with the local government is neither the initiator nor the ultimate recipient; it establishes a connection between "the policy risk" associated with the government and "the revenue risk" associated with the public. The intermediary risk factors can be all three risk levels.

By conducting an SNA of the case project, 17 factors were identified as the most influential risk factors. Macrolevel, mesolevel, and microlevel risks were all involved and are therefore important in the PPP risk network. Among

Table 8: Key risk factors according to brokerage values.

Risk factor	Brokerage values based on stakeholder group					Brokerage values based on the risk category					Total
	Coordinator	Gatekeeper	Representative	Consultant	Liaison	Coordinator	Gatekeeper	Representative	Consultant	Liaison	
S1R7	2	47	68	9	252	0	18	53	15	292	378
S5R35	0	3	65	10	99	0	3	47	7	120	177
S1R2	7	19	50	3	60	0	18	11	1	109	139
S10R27	0	16	8	7	91	3	47	18	3	51	122
S1R14	8	34	7	0	16	0	13	1	4	47	65
S1R31	6	2	45	4	7	0	34	0	2	27	63
S4R18	1	3	7	2	46	0	9	2	0	48	59
S10R11	1	8	8	6	31	0	6	4	3	41	54
S2R15	0	0	4	7	39	0	0	4	4	42	50
S5R37	0	26	2	5	15	0	26	1	2	19	48

Table 9: Critical risk factors in the case PPP project.

Code	Risk factor	Stakeholder	Risk category
S1R1	Unstable government	Local government	Political and legal risks
S1R2	Corruption	Local government	Political and legal risks
S1R5	Policy risk	Local government	Political and legal risks
S1R6	Immature laws and regulations	Local government	Political and legal risks
S1R7	Government intervention	Local government	Political and legal risks
S1R14	Delay in approval	Local government	Project development risks
S1R31	Lack of supporting infrastructure	Local government	Operation risks
S2R15	High financing costs	Financial platform company	Project financing risks
S2R16	Project financial attractiveness	Financial platform company	Project financing risks
S4R18	Design change	SPV	Design risks
S4R34	Inefficient communication	SPV	Organizational risks
S5R33	Inadequate experience in PPP	Consultancy	Organizational risks
S5R35	Inadequate distribution of risks	Consultancy	Contract risks
S5R37	Contract change risk	Consultancy	Contract risks
S8R23	Schedule delay	Contractor	Construction risks
S10R11	Public opposition risk	The public	Social risks
S10R27	Revenue risk	The public	Operation risks

them, political and legal risks associated with local government were seen most frequently. This means that, compared to other stakeholders, local governments play the most important role in PPP projects, and political and legal risks are key to PPP project success. The inadequate distribution of risks associated with consultancy ranked second in the results for betweenness centrality and brokerage and first in the results for degree centrality. This highlights the significance of reasonable risk sharing. Construction and operation risks were not as important as perceived. Although these conclusions need to be further verified through additional case studies, this study's findings can nevertheless provide a reference for similar PPP projects in China.

This study has some limitations. First, a 0-1 value was used to evaluate the relationships between risk factors. This only considered the existence, not the strength, of the relationships. In fact, there are differences in the degree of influence between risk factors. In the risk transmission process, risk factors can only be induced when the degree of influence exceeds a certain threshold. Future research should consider the weight of the relationships between risk factors. Meanwhile, this study built a static risk network for the PPP project. As a long-term process, different stakeholders become involved in different phases of PPP projects. The risk network of a PPP project should be dynamically monitored during its whole life cycle. In the future, we should pay attention to changes in the PPP risk network in different stages. Finally, additional case studies should be conducted to corroborate the conclusions of this research.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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