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IMPACT OF INNOVATION ORGANIZATION NETWORK ON THE SYNERGY OF CROSS-ORGANIZATIONAL TECHNOLOGICAL INNOVATION: EVIDENCE FROM MEGAPROJECT PRACTICES IN CHINA

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Abstract. The construction industry has made an indispensable contribution to China's environmental and economic development. With the advent of the volatile, uncertain, complex, and ambiguous (VUCA) era, cross-organizational collaboration has enabled megaproject participants to engage significantly in problem-solving and technological innovation. The impact of innovation organization network on the synergy of cross-organizational technological innovation (COTI synergy) in megaprojects is imperative for theoretical researchers and engineering practitioners. Therefore, this study aims to develop a hypothetical model of innovation organization network and COTI synergy, focusing on the mediating role of interorganizational relationships and the moderating effect of the technological innovation environment. The results of 211 questionnaires from the Chinese construction industry show that innovation organization network improves COTI synergy. Trust and communication play a vital mediating role between innovation organization network and COTI synergy. Moreover, innovative culture has a significant positive moderating effect on innovation organization network and interorganizational relationships. From the perspective of organization network, this study provides new insights into the development of technological innovation management research on megaprojects, theoretical references, and practical suggestions for project teams in developing countries to improve collaborative technological innovation efficiency.

Keywords: innovation organization network, cross-organizational technological innovation, inter-organizational relationships, technological innovation environment, collaboration innovation, megaprojects.

Introduction

Megaprojects refer to large-scale investment projects with long implementation cycles and complex technologies that significantly affect the progress of the national economy and socio-ecological environments, such as the Three Gorges Project, Beijing-Shanghai High-speed Railway, Sichuan–Tibet Railway, Vajont Dam, The World Islands, and Hong Kong-Zhuhai-Macao Bridge (Chen et al., 2020; Lehtinen et al., 2019). Engineering innovation is imperative in the construction of national innovation systems. In developing countries such as China, Egypt, and India, megaprojects directly improve productivity and are a powerful driver of economic development (Brunet & Forgues, 2019; Choi et al., 2009). As the scale of megaprojects and the span of professional categories involved increase, traditional innovation is often closed within a single scope, limited to institutional, regional, and other conditions, and unable to integrate resources, technologies, and achievements in various field (Witz et al., 2021). Therefore, traditional innovation cannot meet the technological innovation needs of megaprojects. Collaborative innovation, on the other hand, is an effective convergence of innovation resources and elements that can effectively

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improve the innovation efficiency of megaprojects by breaking through the barriers between innovation subjects (Ji & Miao, 2020). It can fully release the integration and flow of talent, capital, information, technology, and other innovation elements, sharing scientific and technological achievements and technical resources, and reducing the division, waste, and duplication of resources (Gloor, 2006). Therefore, carrying out cross-organizational technological innovation collaborative management activities among multiple sub-units has become a widely discussed topic in academic and engineering circles (Denicol et al., 2020; Wang & Pitsis, 2020).

Innovation organization network is the leading force for achieving synergy in cross-organizational technological innovation (COTI synergy) and is closely related to the realization of COTI synergy. Technological innovation in megaprojects relates to all innovation activities carried out around megaprojects (Jussila et al., 2016; Li et al., 2018a), having the characteristics of multiple participants, multiple goals, multiple levels, and cross-organizations. Thus, innovation organization network plays a crucial role in improving COTI synergy. A systematic review of the literature and current projects reveals an inevitable trend toward inter-organizational network cooperation, integrating knowledge, technologies (Gann & Salter, 2000), and resources of multiple organizations and departments (Rutten et al., 2009). Moreover, megaprojects involving different government, social, and corporate innovation entities provide a solid foundation for forming innovation organization networks, which helps promote critical measures for developing and disseminating megaprojects' technological innovations. However, research on organizational networks has traditionally focused on the operational mechanism of collaborative innovation networks, governance methods, and cross-regional cooperation models among enterprises (Duarte & Picchi, 2021; Castillo et al., 2018). With the advent of the VUCA era, collaborative innovation management for megaprojects has become more complex because of the complexity of stakeholders and the increased uncertainty in the environment. Existing research on organization networks focuses on knowledge sharing (Ahlfänger et al., 2022), conflict management (Khosravi et al., 2020), and relationship governance in construction projects (Brunet & Forgues, 2019), which cannot fully meet the implementation requirements of collaborative innovation management in megaprojects. Thus, innovation organization networks play a vital role in COTI synergy; however, existing organization network research findings can provide insufficient theoretical support. Therefore, it is necessary to explore the mechanism of the influence of innovation organization network on synergy in the process of megaprojects' technological innovation.

A variety of studies have focused on interorganizational relationship management in megaprojects, such as promoting relational contracts, advocating relational governance, and exploring the role of guanxi in the Chinese context (Martin & Benson, 2021; Vukomanović et al., 2021; Zheng et al., 2021). Many organizations are involved in the technological innovation of megaprojects, and forming an excellent interactive relationship to carry out collaborative innovation is closely related to trust commitment and communication coordination in the innovation process. The level of trust and communication between innovative organizations can be somewhat representative of the interaction between innovative organizations. Most previous studies have analyzed the impact of project- or organizational-level subject relationships on the performance of megaprojects in terms of trust and close communication (Gulati & Nickerson, 2008; Li et al., 2018b). Each organization is a fulcrum for network formation in an innovation network. The formation of innovation organization networks means that innovation subjects have reached a certain mutual trust and friendly commitment relationship (Xu et al., 2021). However, the degree of mutual trust and commitment practice in the process of technological innovation will directly or indirectly affect the collaboration efficiency of innovation organization networks and then affect the degree of COTI synergy. Therefore, the relationship between organizations is crucial for cross-organizations. The willingness of each organization to communicate, cooperate, and promote communication of cross-organizational technological innovation is enhanced under the constraints of common goals. Active and effective communication allows for the rapid understanding and mastery of technological innovations and their engineering applications. This study speculates that the interorganizational relationship is a mediation mechanism that affects the relationship between innovation organization network and COTI synergy.

In addition, existing studies have conducted useful research on the technological innovation environment in terms of policy, market, and economic environments (Kluza et al., 2021), which provides a reasonable research basis and vision for this study. Previous studies have explored the influence of the external environment of project organizations on technological innovation. However, it is undeniable that this study focuses on the project organization level, so the impact of the internal environment of project organizations, such as engineering demand, on cross-organizational collaborative innovation is also crucial. Therefore, previous studies have rarely considered the endogenous demand for collaborative innovation in project organizations and cannot fundamentally reveal the mechanism of the influence of the innovation environment on COTI synergy. Megaprojects face intense innovation pressures and competing demands. innovation organization networks feature intricate stakeholder networks that contain multiple and often misaligned rationalities, cultures, and agendas in megaprojects. Different organizations operating under varying contractual arrangements bring their interests, values, and ways of thinking and doing (Witz et al., 2021). The socio-political environment is usually distinctive in the context of megaprojects (Patanakul et al., 2016). In particular, the organization of megaprojects in China is influenced by the dual role of the "government-market" (Băzăvan, 2019; Zhai et al., 2020), which only adds to the complexity and peculiarities of megaprojects. It is essential to explore how innovation organization networks can improve COTI synergy in such an environment.

Consequently, this study explores the following research questions:

RQ1: How do innovation organization networks influence COTI synergy?

RQ2: Do innovation organization networks influence COTI synergy by affecting the level of interorganizational relationships between project participants?

RQ3: How does technological innovation environment moderate the relationship between the innovative organizational network and COTI synergy?

The remainder of this paper is organized as follows. Section 1 explores the literature and the arguments that lead to various hypotheses. Section 2 deals with the sample selection, scale design, reliability testing, methods, and hypothesis testing. Section 3 and 4 discusses the results and provides significant findings and implications for both theory and practice. Finally, the limitations of the study and opportunities for future research are discussed in the Section 4.

1. Theory and hypotheses

1.1. Innovation organization network and the synergy of cross-organizational technological innovation

Gloor (2006) proposed the concept of innovation organization network. The new management model optimizes the organizational structure and business processes, promoting more effective communication, collaboration, and innovation. The technological innovation organization network is a primary carrier in construction innovation (Dulaimi et al., 2002; Tatum, 1989), whose direct linking mechanism is the technological innovation cooperation relationship between subjects. By establishing an organization network, megaprojects can efficiently overcome resource limitations, combine the technological innovation forces inside and outside the subject, absorb and apply specialized innovation knowledge, and stimulate technological innovation behaviors more quickly (Yström et al., 2018; Lu et al., 2019). The collaborative innovation network of megaprojects' technological innovation is constructed by the primary bearers of technological innovation practices and innovation awareness activities as the fulcrum of the network. Innovation subjects include organizational units or institutions involved in construction engineering and technological innovation. In this study, the categories of collaborative innovation subjects involved in construction engineering technological innovation activities are mainly government departments, core enterprises (owners), design and consulting units, construction contractors, material and equipment suppliers, universities, research institutes, and other cooperative enterprises, as shown in Figure 1. These are all essential components of megaproject technological innovation organization networks. Their respective innovation missions and responsibilities in megaprojects' technological innovation activities have certain differences due to their different innovation organization statuses (Lu et al., 2021). Therefore, efficient integration of interactive organizational relationships in technological innovation activities can help improve innovation synergy among organizations.

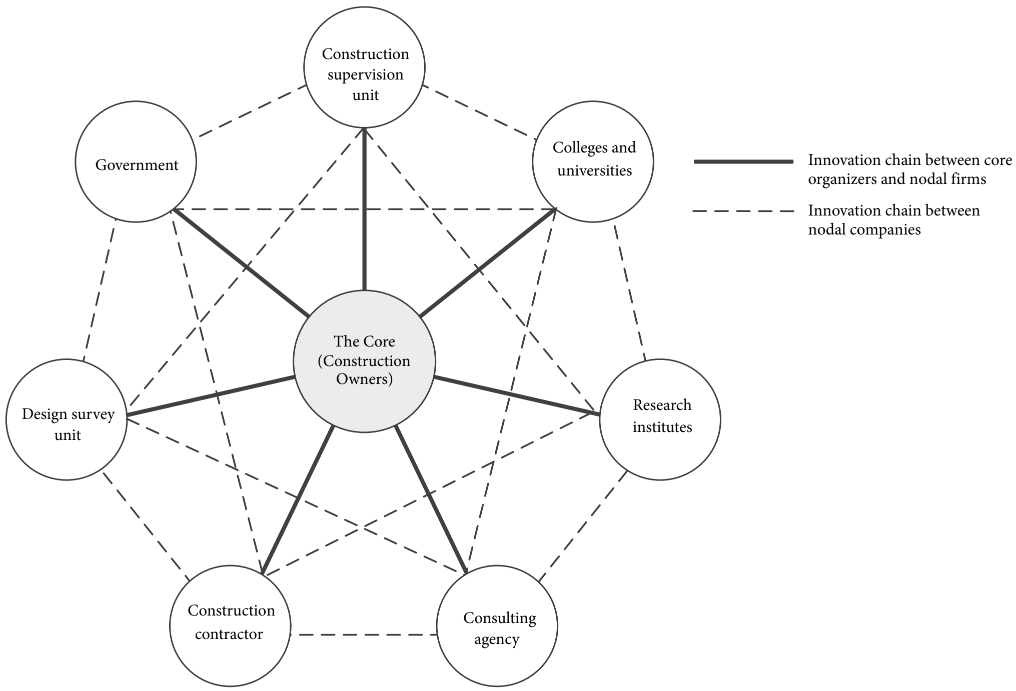

Figure 1. Cross-organizational collaborative network of technological innovation in megaprojects

With the rapid development of infrastructure construction, the scale of projects and the span of professional categories involved are increasing. Usually, multiple parallel project innovations are synchronized to achieve the systematic goal of technological innovation in an entire construction project. To obtain the maximum successful benefits of megaprojects' technological innovation and to ensure the achievement of innovation goals, it is challenging to achieve breakthrough innovation by simply relying on individual integrated enterprises with innovation advantages. The only way to achieve technological innovation problems and promote innovation goals is to unite multiple innovation organizations, coordinate internal and external innovation relationships, strengthen the internal management of innovation organizations, and improve COTI synergy. Recently, some scholars have determined the main organizational variables by analyzing the literature on collaborative networks (Bakker, 2010; Boland et al., 2007) and have built internal and external network management frameworks to increase innovation output by strengthening network collaboration in a cross-organizational network environment (Rothschild & Darr, 2005; Shields & West, 2003). Cao et al. (2018) empirically found through interviews in five industries that inter-organizational cooperation may contribute to improved performance in the construction industry. Zhang et al. (2018a) used case comparisons to reveal that organization network and management could rely on formal mechanisms and training network managers to achieve project innovation success. In addition, Choi et al. (2021) and Rutten et al. (2009) found that the collaborative innovation relationship between organizations and technologies impacts collective innovation performance. Innovation networks are the main element in cross-organizational joint innovation activities and are closely related to achieving cross-organizational collaboration in technological innovations (Van Marrewijk & Smits, 2016). Previous studies have shown that organization networks' centrality, structure, and strength, built with technical cooperation as connection points, will affect cross-organization collaboration (Petrov & Geraskina, 2017; Zhai et al., 2020). The more centralized the organization network is, the more beneficial it is to unite and motivate its members toward innovation collaboration activities (Castillo et al., 2018). Innovation participants at the core often play crucial roles in coordinating and leading technological innovation across the innovation network (Keast & Hampson, 2007). In this research, centrality, density, and strength are adopted as the measurement dimensions of innovation organization network. Accordingly, we propose the following hypothesis:

H1: Innovation organization network is positively related to COTI synergy.

1.2. Mediation effects of inter-organizational relationships

Inter-organizational relationships refer to repetitive and enduring interactions and transactions between the unit and other organizations in the construction process (Lehtinen & Aaltonen, 2020). The involvement of many stakeholders in megaprojects leads to complex interorganizational relationships (Zhang et al., 2022). High-quality inter-organizational relationships have been found to significantly affect successful megaproject delivery. In general, inter-organizational relationships are reflected in trust and communication. As Munns (1995) points out, trust is an essential social resource that also positively influences the management of stakeholders by building trust-based relationships, helping to promote effective interactions between innovative organizations, and increasing innovation collaboration. In megaprojects, trust development is an ongoing process. Trust is vital for megaprojects embedded in the context of the organization. Various types of trust are deeply embedded in megaprojects that involve many stakeholders and civil society layers. In a study by the National Aerospace Safety Administration, the author identified that the key to cross-organizational coordination is establishing trust relationships between organizations (Rottner, 2019). Trust is the core of collaborative innovation capability, with a fair division of the organizational hierarchy for reliable corporate alliances (Forcada et al., 2017). The latest research on temporary organizations and project-based work explains how parties involved in megaprojects respond to emergencies through contractual relationships and trust, including establishing and maintaining a clear division of role structures and harmonious collaborative relationships (McLaren & Loosemore, 2019). Therefore, the innovation participants of megaprojects enable technological innovation to be developed in a crosscutting and coherent manner through network nodes. Information feedback can facilitate communication and trust between organizations, resulting in better interorganizational relationships. Conversely, inter-organizational relationships fail in the absence of trust and communication.

Similarly, the formation of innovation networks results from the demand for heterogeneous innovation resources from megaproject stakeholders, which are usually the source of the core competencies of construction companies, such as technical know-how and technical methods (Locatelli et al., 2021). Stakeholders are usually reluctant to share heterogeneous resources to maintain core competitiveness in the market. This conflicts with the motive for forming innovative organization networks and is not conducive to cross-organizational synergy. On the other hand, trust facilitates the sharing of heterogeneous resources by enhancing the expectations and commitments of mutual relationships among organizations, thus enabling the development of cross-organizational technological innovation activities in megaprojects. Forcada et al. (2017) declared that partnership and willingness to cooperate significantly promote inter-organizational communication, with flow structures, information management plans, and communication channels relevant to project success. Li et al. (2018b) analyzed the cost performance in megaprojects using inter-organizational trust as mediation, revealing that inter-organizational trust significantly influences technological innovation network practices. Park et al. (2020) demonstrated that great inter-organizational relationships contribute to building innovation organization networks. In addition, its centrality, connection strength, and scale have far-reaching impacts on breakthrough and progressive innovation (Sedita & Apa, 2015). Therefore, we propose the following hypotheses:

H2: Innovation organization network is positively related to inter-organizational relationships.

H3: Inter-organizational relationship positively influences COTI synergy.

Because inter-organizational trust and communication are fundamental to cross-organizational collaborative creation (Miozzo & Dewick, 2004), innovation organization networks can be developed by collaborating with employees' knowledge, experience, and skills. Previous studies have concluded that trust between companies affects their information communication and sharing abilities, which influences cross-organizational innovation (Lau & Rowlinson, 2009; Van Marrewijk et al., 2016). The deeper the level of trust among government agencies, owners, designers, construction units, material and equipment suppliers, and research institutions, the more willing they are to share knowledge to form new ideas, and the more likely they are to increase cross-organizational collaboration. Thus, we propose the following hypothesis:

H4: Inter-organizational relationships strongly mediate the relationship between innovation organization network and COTI synergy.

1.3. Moderation effects of the technological innovation environment

Technological innovation in megaprojects is becoming increasingly complex because the entities in the collaborative innovation network of megaprojects are closely connected with other entities in the network (Manley & McFallan, 2006), and are related to macro-politics (Clegg et al., 2002), economics (Băzăvan, 2019), and environmental factors outside the network (Ji & Miao, 2020). These factors directly affect the relationship between collaborative innovation networks and innovation (Akintoye & MacLeod, 1997). In this study, the technological innovation environment is divided into two parts, with megaproject organizations as the dividing line. One part is the external environment of project organizations, including the engineering innovation policies issued by government agencies and the technological innovation reward and punishment system formulated by construction enterprises for frontline project departments (Atuahene & Baiden, 2017). The other part is the internal environment of the project organization, which is the endogenous demand for technological innovation activities by megaprojects. Compared with general projects, megaprojects must overcome more technical problems. In addition, cross-organizational collaborative innovation is inevitably influenced by the cultural conditions of the project in which it is located, with some differences in the innovation values of each participant and a variety of views on the attitude towards technological innovation. Therefore, this study defines the technological innovation environment as the sum of various external factors that influence innovation subjects to carry out technological innovation in the process of cross-organizational technological innovation in megaprojects. It mainly includes socio-political and economic macro-policy, legal environment, innovation demand of the project itself, and the innovation culture of each innovation subject.

Most studies confirm that innovation culture moderates the relationship between leadership and innovation in the construction industry (Caniëls et al., 2019; Li et al., 2019; Xie et al., 2019). A positive innovation culture helps transform an organizational network's positive role in improving collaborative innovation performance (Wang et al., 2018). Zheng et al. (2017) applied multiple linear regression to find that ambidextrous leadership positively affects project performance and ambidextrous culture. Liu and Chan found that the interaction between individual and environmental factors has different driving effects on construction innovation using a dynamic innovation model (Liu & Chan, 2017). In the actual construction process of megaprojects, especially, many countries are vigorously supporting megaprojects, increasing the demand for technological innovation. Simultaneously, technical problems encountered during megaproject construction drive all organizations in the innovative organization network to overcome these issues (Patanakul et al., 2016; Assaf & Al-Hejji, 2006).

Moreover, In the process of innovation activities in engineering projects, institutions are part of the innovation environment, which includes laws, regulations, customs, social and professional norms, culture, ethics, etc. The synergistic effect between multiple parties in a project can impact cooperation benefits related to particular local policies and corporate culture (Van Marrewijk & Smits, 2016). Ji and Miao (2020) highlighted that both direct and indirect support provided by the government enhance responsibility's positive impact on collaborative innovation (Ji & Miao 2020; Young et al., 2020). Therefore, realizing technological innovation in megaprojects requires an open and inclusive environment that affects the formation of this cross-organizational collaboration through technology and information exchanges among various organizations (Forcada et al., 2017; Zheng et al., 2017). Under mass innovation and entrepreneurship, project participants should follow the fundamental needs of construction (Dingle, 1991), apply relevant technological innovation policies (Qian et al., 2019), and actively create a friendly cultural atmosphere for construction innovation. Thus, this study proposes the following hypothesis:

H5a: The technological innovation environment moderates the relationship between innovation organization network and COTI synergy. The relationship between the innovation organization network and

COTI synergy will be stronger (weaker) when the level of the technological innovation environment is high (low).

H5b: The technological innovation environment moderates the relationship between innovation organization network and inter-organizational relationships. The relationship between innovation organization network and inter-organizational relationships is stronger (weaker) when the level of the technological innovation environment is high (low).

H5c: The technological innovation environment moderates the relationship between interorganizational relationships and COTI synergy. The relationship between inter-organizational relationships and COTI synergy will be stronger (weaker) when the level of the technological innovation environment is high (low).

In summary, this study constructs a conceptual model that takes COTI synergy as the dependent variable, the innovation organization network as the independent variable, the inter-organization relationships as the mediation variable, and the technological innovation environment as the moderation variable in Figure 2.

2. Data and methods

2.1. Sample and procedures

The design of the measurement items and questionnaire collection of research variables were carried out in three stages, and the specific questionnaire survey process is shown in Figure 3. In Phase I, on the one hand, the initial measurement items of each variable were clarified by gradually extracting and identifying the main influencing factors of the synergy degree of technological innovation in megaprojects through a large-scale literature collection and analysis. On the other hand, the initial measurement questions of each variable were revised through small-scale expert interviews. The criteria for selecting the prominent interview experts for the study are as follows: (a) the interviewees are mainly front-line technological

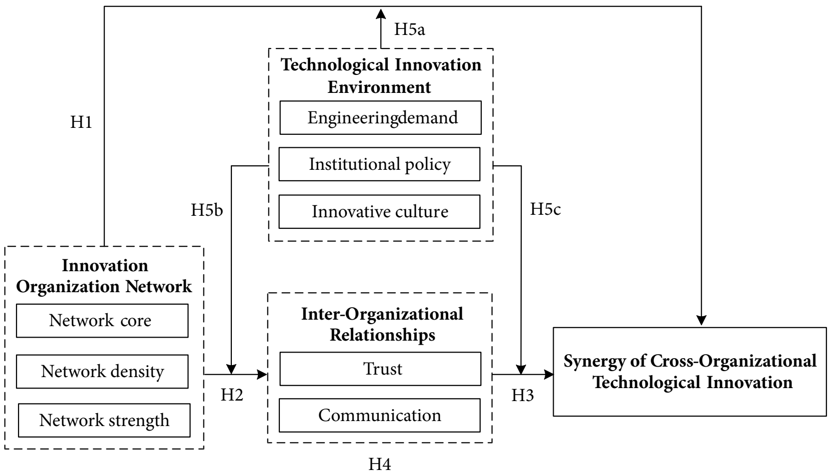

Figure 2. Theoretical model

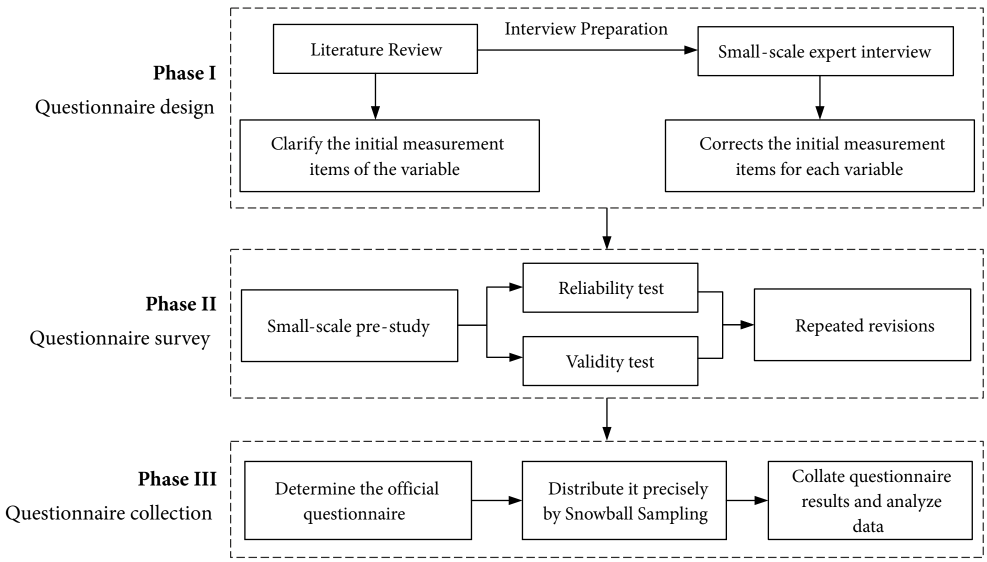

Figure 3. Flow chart of the questionnaire

innovation management and participation personnel of megaprojects, with rich technological innovation management experience and solid basic theoretical knowledge. These experts should ensure that they have participated in, engaged in, organized, or guided technological innovation R&D work for more than three years and are very familiar with the essential requirements, standards, and procedures of engineering technological innovation R&D; (b) the interviewees are mainly middle- and above-cadres in government owner management departments or well-known experts and scholars in the construction engineering industry who are familiar with the current situation of technological innovation development in the industry and are more familiar with innovation networks, innovation alliances, and other cross-organizational collaborative innovation communities. The purpose is to ensure the accuracy and practicability of questionnaire design. In Phase II, some domestic megaproject project organizations were selected to conduct a small-scale pre-study, including the Qinghai-Tibet Railway, Beijing-Shanghai Railway, Shuohuang Railway, Hong Kong-Zhuhai-Macao Bridge, and other engineering project organizations. In this study, the reliability and reliability analysis of the collected data from a small sample helped correct incorrect expressions of questions or additional measurement questions to form a formal questionnaire. Finally, the revised questionnaire was used for large-sample data collection in Phase III. This study investigated multiple regions extensively. The participants were screened for their working years and knowledge of the research topic to ensure the accuracy and validity of the sample collection structure using a pre-survey test. Then, the questionnaires were distributed and collected mainly from front-line personnel and middle and senior managers from the owner unit, research institutes, and construction contractors of various megaprojects. The centralized distribution of the questionnaires lasted eight days. The questionnaires were distributed in multiple ways. The first was through one-to-one email and Tencent QQ distribution; the other was making online questionnaire links and circulating them on WeChat, Weibo, and other online platforms. Snowball sampling was used to maximize the number of qualified responses. For example, one response was allowed per IP per device to ensure that participants did not repeat the questionnaire.

A total of 400 questionnaires were distributed centrally and 265 were recalled. Invalid questionnaires were excluded based on the following criteria: (1) excluding questionnaires with multiple fillings or those not filling carefully; (2) excluding incomplete questionnaires; (3) deleting the questionnaires with all options being the same, for example, selecting "fully satisfied" in all questions; (4) removing questionnaires with regular and continuous selection options, such as 5, 6, 7, 5, 6, 7, 5, 6, 7. A total of 211 valid questionnaires were obtained, with an effective questionnaire rate of 79.62%. Detailed statistical results of the demographic characteristics of the participants are presented in Table 1.

Table 1. Characteristics of the sample

	Type	N	%
Gender	Male	172	81.5
	Female	39	18.5
Types of engineering projects mainly involved (or familiar with)	Railway engineering	65	30.8
	Road construction	22	10.4
	Municipal Public Highway	56	26.5
	Building engineering	51	24.2
	Water resources and hydropower engineering	8	3.8
	other	9	4.3
Working years	≤3	36	17.1
	4–6	74	35.1
	7–10	45	21.3
	10–15	27	12.8
	15–20	20	9.4
	≥20	9	4.3
Education	Under junior college	27	12.8
	Junior college	107	50.7
	Master	59	28
	Ph.D. and above	18	8.5
Role in project management (technological innovation management)	Government	12	5.7
	Design consultancy	17	8.1
	Construction Contractor	116	55
	Higher education institutions	3	1.4
	Research Institutes	28	13.3
	Material supplier organizations	6	2.8
	Construction Owners	19	4.3
	Others	10	9.5

2.2. Measurement

This study improved the scales based on established scales from existing literature, combined with the context associated with Chinese megaproject enterprises. Scale development procedures included an exploratory factor analysis, confirmatory factor analysis, reliability test, discriminant validity test, and others. The final items of the studied constructs were then developed by making ION modifications based on subsequent reliability and validity testing. All scales were constructed using a five-point Likert-type scale ("1" = strongly disagree, "7" = strongly agree).

2.2.1. Innovation organization network

The nine items developed by Keast and Hampson (2007), Gardet and Mothe (2012), and Boland et al. (2007) were used to measure innovation organization network. The reliability of all the items, which was measured using the alpha coefficient, was 0.872. The nine items were divided into three dimensions: network core (e.g., "in innovation cooperation, owners actively develop innovation leadership and control", three items), network density (e.g., "the number of participants in technological innovation in engineering projects has gradually increased", three items), and network strength (e.g., "the continuous connection time of innovation collaboration becomes longer, and the frequency of communication increases", three items). The reliability values were 0.893, 0.817, and 0.865, respectively.

2.2.2. Inter-organizational relationships

Two-dimensional scales developed by Buvik and Tvedt (2017), Gulati and Nickerson (2008), Han and Hovav (2013), Sedita and Apa (2015), and Castillo et al. (2018) were used to measure inter-organizational relationships, including trust commitment (e.g., "trust each other in the strength or level of their technological innovation", four items), and communication (e.g., "innovative organizations are willing to share innovative experiences and innovative technologies", three items). The reliabilities were 0.793 and 0.811, respectively, and the reliability of all 7 items scales was 0.802.

2.2.3. Technological innovation environment

The 12 items developed by Zhang et al. (2018b), Erbil et al. (2013), and Liu et al. (2017) were used to measure the technological innovation environment. The reliability of all the items was measured using the alpha coefficient. The nine items were divided into three dimensions: institutional policy (e.g., "China has formulated a series of macro development strategies on technological innovation", four items), engineering demand (e.g., "difficulty coefficient of engineering technological innovation needs to be tackled jointly", four items), and innovative culture (e.g., "enterprises drive and stimulate technological innovation by establishing innovative incentive mechanisms", four items). The reliabilities were 0.893, 0.917, and 0.925, respectively, and the reliability of all nine item scales was 0.905.

2.2.4. Synergy of cross-organizational technological innovation

Based on Wei et al. (2019), Montarnal et al. (2018), Li et al. (2019), and Yström et al. (2018), five items were generated to measure the synergy of cross-organizational technological innovation; for example, "increased interdependence and coordination among innovative organizations" and "it can actively play the joint effect of technological innovation in megaproject ". The reliability coefficient was 0.875.

2.2.5. Control variables

This study considered gender, education, and years of work experience as the control variables. A categorical question (1 = male and 0 = female) was used to assess gender. A 4-point scale measured education from 1 (under junior college) to 4 (PhD and above). These factors were controlled for because of their potential effects on COTI synergy.

2.3. Analytic strategies

This study adopted Hayes' PROCESS macro for SPSS 22.0 to test the proposed hypotheses. This approach does not rely on the assumption in Baron and Kenny's causal steps approach that total and indirect effects are normally distributed (Baron & Kenny, 1986). In addition, it is suitable for empirical small-sample detection models to improve study accuracy. It also incorporates the bootstrapping technique, which involves multiple sampling (on the order of thousands) from the original dataset with replacement to estimate the indirect effect of the independent variable on the dependent variable via mediator variables, as recommended by many scholars (Benítez-Ávila et al., 2018; Horta et al., 2012). Bootstrapping also estimates the conditional indirect effects at high and low levels of moderating variables and is considered effective in reducing type I errors and improving statistical power (Edwards & Lambert, 2007). Hayes' PROCESS macro calculated the regression coefficients and generated 95% confidence intervals for indirect effects. If the confidence intervals do not include zero, the indirect effects are considered significant. For the analysis, innovation organization network, COTI synergy, and inter-organizational relationships were considered the independent variable, dependent variable, the mediator using Model 4 of Hayes' PROCESS macro and bootstrapping validation (5,000 bootstrap resamples), respectively. To test for moderated mediation and examine the conditional indirect relationships among innovation organization network, COTI synergy, and inter-organizational relationships in high to low levels of technological innovation environments, Model 59 of Hayes' PROCESS macro was used. This approach enables the implementation of bootstrapping methods and explores the significance of the conditional indirect effects at different values of the relevant moderator.

3. Results and analysis

3.1. Descriptive statistics and related analysis

The means, standard deviations, and bivariate correlations among variables are reported in Table 2. The square root of all AVE values is larger than the correlation coefficient between all latent variables, indicating a specific correlation between each latent variable, as expected. There is also a certain degree of discrimination, indicating that the partition validity of the scale data is ideal, and the difference validity of the latent variable passes the test. Inter-organizational relationships were positively correlated with COTI synergy ($r = 0.318$, $p < 0.01$). The synergy between COTI synergy and innovation organization network also suggests a positive correlation ($r = 0.185$, $p < 0.01$). This finding concurs with the results of previous studies (Lim & Peltner, 2011). It is worth noting that all correlation relationships among the variables were significant. Overall, this study assumes that all the considered variables have received preliminary support.

3.2. Control and inspection of common method deviations

This study avoids the drawbacks of conventional methods by allowing anonymous answers, modifying ambiguous sentences, and explaining sentences that are easy to confuse. Furthermore, according to existing research, Harman's single factor test is used to factorize all the items in the questionnaire together and obtain the first principal component without rotation. The results revealed that the nine factors had characteristic roots that were more significant than those after factor analysis. The variance explained by the first factor is 25.80%, which is far less than the critical value of 40%, indicating that a single factor fails to explain most of the variance. Therefore, the influence of the standard deviation on the results can be excluded.

3.3. Tests of the research hypotheses

The results reveal that innovation organization network plays a significant role in predicting COTI synergy (B = 0.818, t = 11.811, $p < 0.01$). The direct prediction effect is still considerable (B = 0.445, t = 6.111, $p < 0.01$), thereby establishing H3. innovation organization network has a meaningful effect on the positive prediction of interorganizational relationships (B = 0.679, t = 16.051, $p < 0.01$), thereby establishing H1. Inter-organizational relationships also have a stimulating influence on the positive prediction of COTI synergy (B = 0.315, t = 3.957, $p < 0.01$), so establishing H2.

The results of the 5000 bootstrap resampling and conditional indirect effect macro tests on the adjusted mediation effect, as suggested by Edwards and Lambert (2007), are shown in Table 3. The analysis of the direct effect of innovation organization network on COTI synergy and mediation effect analysis of inter-organizational relationships reveals that the total effect of innovation organization network on COTI synergy is significant (95% CI: 0.015 to 0.082), with the upper and lower limits of the 95% confidence interval of its bootstrap excluding 0. The mediation effect of inter-organizational relationships is significant (95% CI: 0.213–0.523), excluding 0, indicating that innovation organization network can directly predict COTI synergy. Moreover, it is possible to predict COTI synergy through the mediating role of inter-organizational relationships to supplement the assumption that H3 holds. The direct (0.315) and mediation (0.364) effects accounted for 46.4% and 53.6% of the total effect (0.679), respectively.

The moderated mediation results for H5a to H5c use Model 59 of Hayes' PROCESS macro, as shown in Table 4. To obtain more easily interpretable regression results, the regression process was centered on ION, IOR, and TIE, and the regression results are shown in Table 4. With COTI synergy as the dependent variable, to test H5a and H5c, the independent variables included ION, IOR, TIE, and the interaction terms of TIE with ION and IOR; with IOR as the dependent variable, to test H5b, the independent variables included ION, TIE, and the interaction term of TIE with ION. As shown in Table 4, the interaction term of TIE with ION has a marginally significant positive relationship with COTI synergy, $\beta = 0.139$, $p = 0.073$, 95% confidence interval [0.002, 0.314], and the 90% confidence interval was [−0.278, −0.013], validating H5a. The interaction terms of TIE and ION showed a significant positive relationship with IOR, $\beta = 0.217$, $p = 0.035$, 95% confidence interval [0.011, 0.142], and H5b was validated. The interaction term of TIE and the interaction term of TIE and IOR showed a significant positive relationship with COTI synergy, $\beta = 0.076$, $p = 0.012$, 95% confidence interval [0.003, 0.164], and H5c was verified.

Comparative analysis of individual pathways at different TIE levels allowed for further validation of H5a to H5c. Using the mean value plus or minus the standard deviation to represent the level of TIE, it can be seen from Table 5 that when the TIE level was low, the effect of ION on COTI synergy was positive but not significant ($\beta = 0.108$, $p = 0.140$, 95% confidence interval [0.005, 0.169]); when the TIE level was high, the effect of ION on COTI synergy was positive and significant ($\beta = 0.201$, $p = 0.0003$, 95% confidence interval [0.002, 0.213]).

Table 2. Descriptive statistics and correlations

Variable	M	SD	TIE	ION	IOR	COTI synergy
TIE	3.959	0.603	0.507			
ION	3.780	0.592	0.101***	0.531		
IOR	3.786	0.649	0.169***	0.212**	0.511	
COTI synergy	3.977	0.629	0.115***	0.185**	0.318**	0.503

Notes: Sample size = 211; the square root of the average variance extraction is in parentheses on the diagonal. SD – standard deviation; ION – innovation organization network; IOR – inter-organizational relationships; TIE – technological innovation environment; COTI – synergy, synergy of cross-organizational technological innovation. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

Table 3. Decomposition table of the total effect, direct effect, and mediation effect

Effect category	Effect value	Standard error of boot	LL 95% CI	UL 95% CI	Relative effect
Total effect	0.679	0.014	0.015	0.082	
Direct effect	0.315	0.061	0.691	0.928	0.464
The Moderation effect of the mediation between organizations	0.364	0.079	0.213	0.523	0.536

Note: Bootstrap size = 5000. LL – lower limit; CI – confidence interval; UL – upper limit.

Table 4. Regression analysis results for the moderating effects

Variables	COTI synergy				IOR			
	Estimated value	Standard error	P	95% CI	Estimated value	Standard error	P	95% CI
ION	–0.050	0.100	0.616	[–0.247,0.147]	0.347	0.141	0.015	[0.068,0.626]
IOR	0.218	0.060	0.0002	[–0.100,0.336]				
TIE	0.168	0.098	0.089	[–0.246,0.362]	0.418	0.132	0.002	[0.157,0.680]
TIE*ION	0.139	0.080	0.073	[0.002,0.314]	0.217	0.101	0.035	[0.011,0.042]
TIE*IOR	0.076	0.043	0.012	[0.003,0.164]				
Gender	–0.144	0.097	0.367	[–0.280,0.104]	0.231	0.138	0.097	[–0.007,0.407]
Education	–0.088	0.060	0.147	[–0.206,0.031]	0.245	0.084	0.004	[0.073,0.417]
Working years	0.229	0.139	0.191	[–0.389,0.161]	0.027	0.201	0.894	[–0.416,0.577]
Constants	3.523	0.668	0.0001	[2.303,4.946]	–1.467	0.857	0.126	[–2.247,0.268]

Note: Sample size = 211; ION – innovation organization network; IOR – inter-organizational relationships; TIE – technological innovation environment; COTI synergy – synergy of cross-organizational technological innovation.

Table 5. Regression analysis results for the moderating effects

	Condition effects	Standard error	t	P	95% CI
Conditional effects of ION on COTI synergy					
High TIE levels	0.108	0.125	0.866	0.140	[0.005,0.169]
Low TIE levels	0.201	0.140	–1.485	0.0003	[0.002,0.213]
Conditional effects of IOR on COTI synergy					
High TIE levels	0.113	0.080	1.513	0.134	[–0.027,0.278]
Low TIE levels	0.324	0.072	4.361	0.0002	[0.172,0.466]
Conditional effects of ION on IOR					
High TIE levels	0.101	0.195	0.570	0.861	[–0.224,0.491]
Low TIE levels	0.536	0.152	3.256	0.0004	[0.267,0.914]

Note: Sample size = 211; ION – innovation organization network; IOR – inter-organizational relationships; TIE – technological innovation environment; COTI synergy – synergy of cross-organizational technological innovation.

This indicates that TIE enhanced the positive relationship between ION and COTI synergy. When the TIE level was low, the effect of IOR on COTI synergy was positive but not significant ($\beta = 0.113$, $p = 0.134$, 95% confidence interval [–0.027, 0.278]), and when the TIE was high, the effect of IOR on COTI synergy was significantly positive and significant (β = 0. 324, p = 0. 00002, 95% confidence interval [0.172, 0.466]. This indicates that TIE enhanced the positive relationship between IOR and COTI synergy. When the TIE level was low, the effect of ION on IOR was significantly positive, but not significant ($\beta = 0.101$, $p = 0.861$, 95% confidence interval [–0.224, 0.491]). When the TIE level was high, the effect of ION on IOR was positive but not significant ($\beta = 0.536$, $p = 0.0004$, 95% confidence interval [0.267, 0.914]). This finding indicates that TIE enhances the positive relationship between ION and IOR. The above analysis results again verify H5a–H5c.

To express the moderating effect of TIE more intuitively, an interaction plot of the moderating effect was drawn in this study, as shown in Figure 4. Because the IOR was centered in the regression analysis, the centered IOR was reduced in the drawing of Figure 4b to maintain the consistency of the interaction plot. From Figure 4a, it can be seen that as the TIE level changes from low to high values, the slopes of the relationship between ION and COTI synergy are all positive and increase in slope, indicating that TIE enhances the positive relationship between ION and COTI synergy, and H5a is verified; from Figure 4b, it can be seen that as TIE changes from low to high values, the slopes of the relationship between ION and IOR are all positive and The slope increases, indicating that TIE enhances the positive relationship between ION and IOR, and H5b is verified; from Figure 4c, it can be seen that as TIE changes from low to high values, the slopes of the relationship between IOR and COTI synergy are all positive and the slope increases, indicating that TIE enhances the positive relationship between IOR and COTI synergy, and H5c is verified.

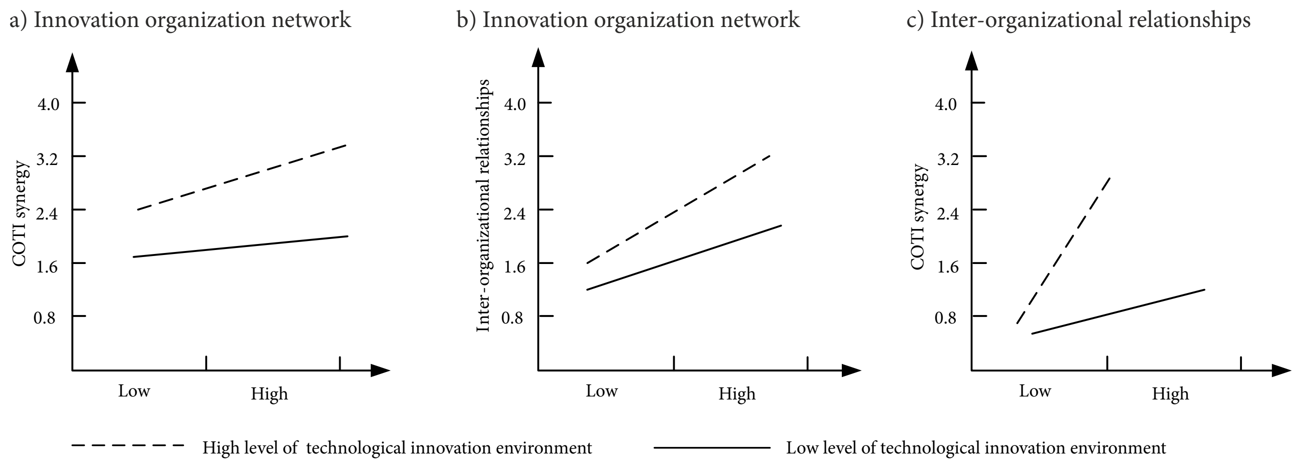

Figure 4. Moderating role of the technological innovation environment

4. Discussion and implications

4.1. Major findings

With the increasing importance of technological innovation, cross-organizational coordination has become a significant goal pursued by many organizations, particularly the managers of megaprojects in innovation organization networks (Mahmoudi et al., 2019). This study provides notable findings and novel knowledge in the project management domain. First, it represents an empirical model testing study that develops a conceptual model by integrating the innovation organization network, inter-organization relationships, COTI synergy, and technological innovation environment. It then validates the linkages between innovation organization network and COTI synergy in megaprojects. Empirical research data bridges the identified knowledge gap caused by the lack of understanding of cross-organizational technological innovation in megaprojects from the perspective of organization network. Though Chen et al. (2022) discussed about the innovation performance and innovation measurement in project level, while Jin et al. (2022) discussed how the collaboration between participant and their own position can influence their innovation capability from the project level. Previous scholars have provided theoretical support for this article, as well as a side-by-side look at trends and difficulties in collaborative engineering innovation. By introducing innovation organization network theory, this study helps us better understand the mechanism of COTI synergy in megaprojects and provides new ideas to effectively address the challenges of collaborative engineering innovation.

Second, the broad intent of this study draws attention to the human nexus in cross-project management by introducing innovation organization network and inter-organization relationship variables to establish a collaborative innovation framework. Inter-organizational relationships are a prerequisite for each participant in an innovation organization network to obtain the required knowledge, resources, and sustainable competitive advantages (Choi et al., 2018). However, stakeholders' lack of information needed to accomplish innovation in megaprojects, such as inferiority in a tightly linked network, is not conducive to achieving cross-organizational collaborative innovation. This study reveals that inter-organizational relationships play a mediating role in the relationship between innovation organization networks and COTI synergy. Moreover, inter-organizational relationships are positively related to COTI synergy. These research findings consolidate previous arguments (Zidane et al., 2013), and found that trust and communication could moderate the negative relationship between internal and external conflicts among various stakeholders and project performance. Therefore, this study reveals that trust and communication can supplement the weakness of rigid contracts by forming contract flexibility with different strengths of interorganizational relationships.

In addition, this study ascertains the role of the technological innovation environment in fostering COTI synergy processes in project-based organizations based on the organization's engineering needs, institutional policies, and innovation culture to improve cross-organization cooperation. Ozorhon and Oral (2017) points out that project complexity, innovation policy, and environmental sustainability are the main implicit motivations for innovation in project organizations. It has been found that the innovation environment has a differentiated impact on different stages of collaborative innovation performance. However, it is limited to the argumentation and testing of the impact of the first half of the path of a direct relationship. This study analyzes both the internal environment of an innovation organization network and the organization's external environment. It concludes that the technological innovation environment improves the positive effect of innovation organization network on COTI synergy. Similarly, the technological innovation environment enhances the ability of innovation organization networks to improve interorganizational relationships and, at the same time, does not diminish the positive effect of interorganizational relationships on COTI synergy, ultimately showing a positive moderating effect. In short, the technological innovation environment moderates COTI synergy in the same direction at different stages, but the moderating effect is significantly enhanced. This study clarifies the boundary conditions of the indirect influence of innovation organization networks on COTI synergy through interorganizational relationships. This confirms the differential moderating effect of the technological innovation environment on the different stages of COTI synergy.

4.2. Theoretical implications

First, this research enriches and extends the development of organizational synergy theory. The findings suggest that innovation organization network has a positive and significant relationship with COTI synergy, which provides a new research perspective for improving COTI synergy. In a megaproject's innovation organization network, task conflict and expertise integration of different cross-functional organizations provide powerful and complementary strategies to enhance innovation resilience and significantly improve COTI synergy. Organization networks and their effects on cross-organizational performance have been reviewed in prior research, mainly from the perspective of managerial or knowledge workers (Kipkosgei et al., 2020; Zhang et al., 2018a). This article introduces research variables, such as inter-organizational relationships and the technological innovation environment, which enrich theoretical research on COTI synergy in megaprojects. Moreover, the research results broaden the theoretical understanding of the innovation network, enhance the understanding of the inherent laws of the technological innovation network operation, and consolidate academic support for cross-organizational cooperation in construction projects. These findings help to reveal the formation mechanism of cross-organization collaboration in megaprojects.

Second, this study explains how inter-organizational relationships and the technological innovation environment can impact COTI synergy. Most previous studies have examined the impact of inter-organizational cooperation on the relationship between formal and informal organizations, ignoring the increasing difficulty of human management in modern megaproject management. Therefore, this study introduces communication and trust as measurement indicators of interorganizational relationships that are directly related to synergy between organization networks. Good interorganizational relationships indicate a certain level of trust between innovation subjects and an understanding of each other's contractual relationship spirit and professional ethics. In the process of innovation collaboration, the subjects have stronger communication and willingness to share innovation knowledge, which is conducive to breaking technical barriers and reducing innovation information asymmetry among the subjects. This study did not distinguish between the specific relationships between communication and trust. The same is true for environmental variables of technological innovation. Most studies have investigated the impact of innovation environments on collaborative performance. However, the global diffusion of megaproject innovations is driven by the political and policy lure to achieve significant tangible benefits and the potential to convey a powerful set of symbolic messages. This study starts from engineering reality and introduces measurement indicators, such as engineering requirements and the policy environment. The results enrich existing cross-organizational model research. However, realizing the evolutionary simulation of the cross-organizational technological innovation path based on the measurement coefficients of various indicators is worthy of further consideration and discussion by future researchers.

Thirdly, it enriches the important boundary conditions and contextualized features of the role of innovation organization network in the COTI synergy in megaprojects. In the context of the "government-market" dualistic system in China, this paper finds that the participants of construction project innovation are conducive to the creation of a collectivist group atmosphere and the identification of engineering innovation needs (Qiu et al., 2019). On the one hand, the collectivist atmosphere of innovation organizations can regulate the interaction between innovation subjects across levels, effectively reduce cultural conflicts and enhance the cooperation and trust between organizations (Biesenthal et al., 2018). On the other hand, clear needs can help to achieve better collaboration and thus improve COTI synergy. This paper therefore enriches the study of COTI synergy in megaprojects from the perspective of the "government-market" dichotomy, helping to expand and deepen the crucial role of government in improving the technological innovation environment through policy planning and macro-incentives. In conjunction with the existing literature on collectivism and power distance, most of the research focuses on corporate performance, risk-taking and inefficient investment, but less on engineering innovation, especially megaprojects innovation. Therefore, this paper also provides a new research perspective on megaprojects and provides some theoretical support for subsequent research.

4.3. Practical implications

Handling the inter-organizational relationship in the innovation organization network of megaprojects (Oliveira & Lumineau, 2018), improving the COTI synergy, and maximizing the benefits of the internal and external environments is an arduous task, as different stakeholders have inconsistent project performance goals and technological innovation needs in megaprojects. Therefore, our research findings have meaningful managerial implications. First, cross-organizational network cooperation has become a new measure for promoting technological innovation development in megaprojects. Stakeholders should take advantage of the innovation organization network platform to enhance cross-organizational collaboration (Ozorhon et al., 2014). Therefore, it is necessary to investigate and analyze members' traits in terms of attitudes, abilities, and resources. Simultaneously, we should comprehensively strengthen the construction of technological innovation organization networks, enhance their leading role and primary position in the process of cross-organizational collaboration (Costa et al., 2019), and actively bring into play the joint effectiveness of innovation synergy. In conducting cross-organizational technological innovation activities, innovation tasks can be reasonably divided and coordinated to ensure the realization of technological innovation breakthroughs and innovation goals by forming a sustainability mechanism of communication commitment (Barendsen et al., 2021), regulating the regulation of organization networks, and establishing a common vision (Chi et al., 2022).

Second, innovation organization network is the main dependent force in reaching the cross-organizational synergy of technological innovation and is closely related to COTI synergy in megaprojects. The technological innovation of significant construction projects is based on the collaboration of engineering design, scientific research institutes, engineering consulting, material and equipment supply, construction contractors, and other units using contracts with trust as the link between stakeholders. In addition, the rights and obligations of the parties are clarified through contracts. In the absence of trust, effective communication cannot be achieved as information is not accurately transmitted, thereby reducing the cross-organizational coordination of technological innovation. To reduce information asymmetry between organizations, each organization can establish a contract-based collaborative mechanism based on trust and constrain the cooperative behavior of technological innovation organization networks (Maurer, 2010; Nagano et al., 2014). Meanwhile, each innovative entity can adopt new information technologies, such as BIM and 5G (Tan et al., 2021), to realize intelligent construction, such as build an information model (BIM) collaboration platform and reputation management mechanisms. They can also apply machine learning to delve deeper into new cooperative network models to promote collaborative technological innovation networks in megaprojects and improve efficiency.

Thus, the technological innovation environment is an essential factor that could be adjusted to improve cross-organizational collaboration in innovation network organizations. Managers should enhance the positive effect of the organizational environment on the synergy between the innovation network organization and cross-organization (Van Marrewijk, 2007). For instance, as a major sponsor of megaprojects, the government plays an essential role in regulating and routing funds to improve the technological innovation environment through policy planning and macro-incentives (Chen et al., 2018). Furthermore, in the process of implementing innovation activities in megaprojects, cultural factors manifest themselves through the beliefs and values associated with the innovation network organization itself. Therefore, establishing a network of collaborative relationships based on trust and contracts can mitigate cultural conflicts effectively. The related department clarifies the responsibilities of various organizations to ensure the orderly development of collaborative innovation in megaprojects. Simultaneously, construction enterprises should optimize talent training and innovative culture management mechanisms to encourage front-line employees to express innovative ideas. In technological innovation activities, the main body of the innovation network should give full play to the innovation initiative and motivation of project members to shape a valuable organizational innovation culture.

4.4. Limitations and avenues for future research

Although this study offers theoretical and practical implications for improving the success of cross-organization collaboration in megaprojects, there are some limitations that require further optimization and should be considered when interpreting the findings. First, this study considers megaprojects in China, and future research may be extended to other fields or different project results may be compared. Furthermore, this study applied a cross-sectional sampling method, which cannot describe the causal relationship between variables. Moreover, megaprojects have a long construction period and many potential risk factors, and the COTI synergy is a dynamic concept (Brattström et al., 2018). Therefore, future research could use the time-series longitudinal analysis method to test the dynamic effect of longitudinal data on cross-organizational synergy at different stages of megaprojects (Gurevich & Sacks, 2020). Finally, the research model only considers the mediating role of inter-organizational relationships. However, COTI synergy is related to many factors, such as organizational citizen behavior (Yang et al., 2018), the application of new-generation information technology (Fountain & Langar, 2018), and opportunism (Lu et al., 2016). Hence, future research should consider adding other factors to strengthen the explanatory power of the model. This study aims to motivate more scholars to pursue further research along these suggested directions and to reveal more facts on COTI synergy in construction projects.

Conclusions

With the increasingly drastic changes in the internal and external environments of construction projects, breaking the boundaries of traditional organizations and innovation through cooperation has become important in developing megaproject management. Therefore, this study provides a theoretical model based on SEM and reveals, through empirical analysis, the impact of innovation organization networks and their COTI synergy in megaprojects, the mediating role of inter-organizational relationships, and the moderating role of the technological innovation environment. The results demonstrate that innovation organization network is positively related to COTI synergy in megaprojects. Inter-organizational relationships play a vital mediating role in innovation organization network and COTI synergy. A technological innovation environment has a significant two-stage moderating effect. It has a positive moderating effect on the relationship between innovation organization networks and inter-organizational relationships. It has a significant positive moderating effect on the relationship between inter-organizational relationships and COTI synergy. These research results will inspire researchers to further explore the effects and influencing factors of COTI synergy and will help practitioners to optimize cooperation innovation management strategies in megaprojects from a new perspective of organization network.

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Author contributions

Study conception and design, N.Z., and C.W.; data analysis and interpretation of results; D.F., and N.Z.; draft manuscript preparation, Y.C., and D.F. All authors reviewed the results and approved the final version of the manuscript.

Disclosure statement

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