INTERORGANIZATIONAL KNOWLEDGE SHARING IN MEGAPROJECTS: ANTECEDENT IDENTIFICATION, STAKEHOLDER SYNERGY, AND INNOVATION CAPABILITY ENHANCEMENT

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ABSTRACT

Megaprojects are large-scale infrastructure interorganizational projects with massive investment commitments, long construction durations and involving multi-source integration of cross-border knowledge in technical and managerial from multiple stakeholders. Interorganizational knowledge sharing (IKS), referring to transferring practical information, technical know-how, and expertise across organizational boundaries, has become an important strategy for megaproject stakeholder organizations (MSOs) to adapt to the dynamic environment, drive innovation, and enhance megaproject performance. Although the benefits of IKS in megaprojects are apparent, stakeholders are still impassive about it. Three major reasons lead to the insufficiency of IKS. *First,* a systematic framework for knowledge classification and corresponding IKS mechanisms for facilitating IKS is lacking. *Second,* MSOs could achieve maximal benefits and value when they reciprocally implement IKS. However, MSOs are generally unclear how to collaborate with others to reach value co-creation by stakeholder synergy. *Third,* the antecedents and consequences of IKS are not fully realized by MSOs, which further impedes their motivations for implementing IKS.

This research aims to use qualitative and quantitative methods to elaborate on mapping, facilitating, and applying IKS in megaprojects. Specifically, this research first investigated the knowledge shared in megaprojects and IKS practices through grounded analysis of multi-source data. Then, an innovative IKS-BN model encompassing 16 influencing factors of IKS was established through a Bayesian network analysis approach to explore their cause-effect interconnections and their joint effects on the IKS efficiency. Third, from the value-focused thinking and network-based perspective, it identified three types of stakeholder powers of various MSOs and proposed stakeholder synergy strategies in megaprojects using stakeholder value network analysis. Lastly, a longitudinal case study of the Hong Kong-Zhuhai-Macau bridge project was conducted to reveal how IKS enhances organizational innovation capability and the owner's role in IKS governance.

The results identified four categories of knowledge and four-dimensional IKS mechanisms to form a configuration to facilitate IKS in different scenarios. Then, this study revealed the top influential factors of IKS efficiency. The joint effect of controlling various factors on improving the efficiency of IKS was greater than a single factor. Third, four internal strategies (i.e., *exchange, value, integrated, and adaptive*) and two external strategies (i.e., *power incongruence and knowledge broker*) were proposed to help different types of MSOs in the IKS network realize stakeholder synergy for value co-creation. Lastly, four types of organizational innovation capabilities (i.e., *institutional, business, technology, and managerial)* would be improved through IKS. The project owner plays the role of "*leader*", "*coordinator,*" and "*supporter*" in IKS governance in distinct project stages.

This study contributes to the theoretical and practical knowledge of construction megaproject management. This study makes an essential effort to govern IKS mechanisms in megaprojects from the socio-technical perspective. To the best of the author's knowledge, it is also the first to explore stakeholder synergy and value co-creation in the megaproject IKS network. The findings can provide an insightful reference for practitioners in identifying efficient approaches to facilitate IKS and improve MSOs' innovation capabilities and the overall megaproject performance.

Keywords: Interorganizational knowledge sharing (IKS); Megaproject stakeholder organizations (MSOs); IKS mechanisms; Stakeholder synergy; Innovation capability

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This is a moment worth commemorating for me on a bright afternoon just before Christmas. Outside the window, the chilly winter wind rustles through the time-worn glass windows of the library, harmonizing with the chirping sound of the air conditioning at work. Fortunately, until the moment the concluding keystroke sounded for the doctoral thesis, this symphony did not interrupt the flow of my thoughts. In the midst of this tranquil atmosphere, I would like to express my gratitude to all those who guided, assisted, and accompanied me throughout my five-year doctoral journey.

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1.1 Research Background

1.1.1 Megaproject management

Megaprojects are usually defined as large-scale infrastructure interorganizational projects with massive investment commitments (Brookes and Locatelli, 2015; Wang et al., 2018), long periods, high technical complexity (Flyvbjerg, 2014a; Sheng, 2018; Wang et al., 2017), generally commissioned by governments and delivered by multiple enterprises (Flyvbjerg et al., 2003; van Marrewijk et al., 2008). Besides, they greatly influence politics, society, economy, and the environment. Taking the Hong Kong-Zhuhai-Macau Bridge (HZMB) project as an example, it is one of the comprehensive cross-sea cluster projects with the longest span, the highest construction standard, and the most challenging in the world, which greatly contributes to the synergetic economic development of Guangdong-Hong Kong-Macao Greater Bay Area. The total investment reached RMB 127 billion (i.e., around 19.5 billion US dollars as 1 US dollar equals about 6.5 RMB), and the project period reached 15 years, from 2003 to 2018 (Chen et al., 2021). The successful delivery of the HZMB project significantly improves the comprehensive transportation system of Guangdong, Hong Kong, and Macao, strengthens the economic and social ties between the three places, and enhances the comprehensive competitiveness of the Pearl River Delta.

Recently, many countries, especially developing countries, have continuously increased their investments in infrastructure megaproject construction to promote economic development and well-being welfare. For instance, the Chinese government plans to finish 102 megaprojects earmarked for the 2021–25 development plan (Esposito and Terlizzi, 2023). Besides, China is going all-out with its mind-blowing Belt and Road Initiative, which encompasses 7,000 integrated infrastructure projects involving 146 countries in Asia, Africa, and Europe. Due for completion in 2050, the vast initiative could cost up to an astounding 8 trillion US dollars (Monitor, 2021). A study in 2019 estimated that once completed in 2040, the project will boost global GDP by 7.1 trillion US dollars per year (The Chartered Institute of Building, 2019). Another study in early 2023 reported that 159 large foreign direct investment megaprojects worth at least 1 trillion US dollars were announced globally in 2022 (Financial Times, 2023). Among them, the US was a major hotspot for megaproject investments in 2022, attracting approximately 14% of the megaprojects— 22 deals valued at an estimated 88 billion US dollars in capital investment. A perceived outlier in the data appears as Egypt ranked as the world's top destination for mega projects in terms of capital investment in 2022, attracting more than 96.8 billion US dollars in such projects, close to three times that of its previous record (34.9 billion US dollars in 2016).

Although megaprojects hold a vital role in regional and national development, fostering technological innovation and catering to the escalating demand for economic increase, they have encountered numerous challenges and dilemmas (Flyvbjerg et al., 2003). Specifically, the outcomes and performance levels of megaprojects have often been disappointing. Many megaprojects suffer from cost overruns, schedule delays, and benefit shortfalls (Davies et al., 2009; Flyvbjerg, 2014b; Locatelli et al., 2017; Söderlund, 2017). Failures in project delivery and low efficiency during implementation are common (Flyvbjerg and Dan Gardner, 2023). As a result, the management of megaprojects is immensely significant and challenging. Recent research has delved into the reasons behind failures in megaproject management, shedding light on the mechanisms that influence megaproject performance and the factors that impact megaproject success (Flyvbjerg and Dan Gardner, 2023). Exploring organizational issues and behavior in megaprojects is key to improving megaproject performance. Redefining megaprojects from the organization theory perspective has been considered an important direction in rethinking megaproject management (Li et al., 2019b).

1.1.2 IKS enhancing performance in megaprojects

With the advent of the sharing economy, knowledge has become a key source of innovation and competitive advantage for business organizations (Bosch-Sijtsema and Henriksson, 2014; Tee et al., 2019). In the megaproject context, interorganizational knowledge sharing (IKS) is regarded as an essential kind of organizational behavior for enhancing megaproject performance (X. Chen et al., 2021; Iftikhar and Mawra, 2023; Jin et al., 2022; H. Liu et al., 2020; Liu et al., 2022), which is defined as the process of transferring practical information, know-how, and expertise across organizational boundaries of megaproject stakeholders according to temporal or permanent agreements (Appleyard, 1996; Iftikhar and Ahola, 2022; Iftikhar and Lions, 2022; Loebbecke et al., 2016; Nodari et al., 2016).

As a typical complex giant system, megaprojects are knowledge-intensive interorganizational projects involving multi-source integration of technologies or experience and cross-border knowledge fields from multiple stakeholders (Godsell et al., 2018). Boon et al. (2017) outlined different types of knowledge (e.g., explicit and tacit knowledge) in megaprojects, such as construction techniques, loaning of works, supplier selection, quality control process, working as a team, and knowledge of who knows what. Explicit knowledge consists of tangible documented knowledge formed in a structured, externalized, and fixed-content form that is easier to communicate and share (Hwang, 2020), while tacit knowledge refers to intangible thoughts, evaluation, advice, points of view, and repository skills, which generally reflect people's understanding, capabilities, and past experiences (Pathirage et al., 2008). Relative to explicit knowledge, tacit knowledge is more flexible and dynamic, better able to mitigate project risks, promote innovation, improve quality, make decisions, decrease project delays, and rationalize construction processes (Saini et al., 2019).

Megaproject stakeholder organizations (MSOs), defined as primary project participating organizations involved in the life-cycle megaproject delivery (e.g., the owner, contractors, suppliers, consultants, designers, project supervisors, and government), should not only utilize their internal knowledge but also absorb external knowledge efficiently to track the complexity and dynamic of natural and social environments where megaprojects are embedded.

IKS has become an important interorganizational collaboration strategy for MSOs to drive innovation and influence the successful delivery of megaprojects (van Marrewijk et al., 2008). From a managerial perspective, due to different MSOs being involved in different project stages, interactions between MSOs in projects are generally temporary and unprecedented (Luo et al., 2017). Hence, MSOs need knowledge or information from the last stage to finish follow-up work in megaprojects. The lack of IKS across MSOs (e.g., insufficient or weak links between contractors, designers, and suppliers and a lack of cooperation and innovation between fragmented elements) is a constraint to the successful delivery of large construction projects (Davies et al., 2014; Veenswijk et al., 2010; Worsnop et al., 2016). IKS allows MSOs to avoid "reinventing the wheel" (Ruuska and Vartiainen, 2005) and "innovation islands" (Chen et al., 2018), thereby promoting the co-creation of values-in-use during infrastructure delivery (Liu et al., 2019; Martinsuo, 2020).

From a technical perspective, large construction megaprojects require integrated knowledge management that combines multidisciplinary organizations' skills, expertise, and experience accessed through IKS (Mok et al., 2015). Megaprojects are emerging that demonstrate increasingly complex, dynamic, and interactive characteristics (Davies et al., 2017; Williams et al., 2015) and involve interdependent tasks (Iftikhar and Ahola, 2022). It is necessary to tackle megaprojects' complexity and environmental turbulence (Caldwell et al., 2009). Highly integrated knowledge from MSOs' experience in similar projects is valuable for dealing with new projects' technical and managerial challenges and extenuating risks (Li et al., 2018). Caldwell et al. (2017) emphasized that the key challenge in achieving project value is managing IKS across disciplinary boundaries and forming a basis for mutual knowledge. For example, the project owner, as the system integrator (Oliveira and Lumineau, 2017), organizes technological innovation alliances to establish platforms that integrate consultants (including academic research units in materials science, civil engineering, environmental science, etc.), contractors, and suppliers (Davies et al., 2009; H. Liu et al., 2020), to promote IKS to cope with technical challenges (H. Liu et al., 2020), determine practical solutions (Love et al., 2019) and mitigate the effect of project complexity (Cooke, 2013). Similarly, Veenswijk et al. (2010) introduced the concept of a community of practice as a form of public-private collaboration in megaproject alliances to facilitate knowledge flows across consultants, contractors, and suppliers.

1.1.3 IKS cases in megaprojects

There are many typical cases of IKS among MSOs in megaprojects. *First*, the Shenzhen-Zhongshan Tunnel is a remarkable infrastructure megaproject and engineering marvel located in southern China, which was started in 2015 and finished in 2023 as shown in Figure 1.1. It is an underwater tunnel that runs beneath the Pearl River Delta in Guangdong, China, connecting the eastern side of Shenzhen with the western side of Zhongshan, both of which are vital economic and cultural hubs within the Guangdong Province. The tunnel stretches for a significant distance, measuring approximately 6.8 kilometers (4.2 miles) in length, making it one of the longest underwater tunnels in the world. State-of-the-art technology is used in the construction of the tunnel, such as innovative steel-concrete immersed tube construction methods. This advanced technique enables the tunnel to withstand the challenging underwater environment. In addition to the tunnel portion, the project also includes the construction of an impressive cable-stayed bridge with a main span of 1666 meters (approximately 1.03 miles), making it one of the world’s tallest cable-stayed bridges.

(a) Effect drawings of Shenzhen-Zhongshan Bridge Tunnel Link

(b) Real scene picture of Shenzhen-Zhongshan Bridge Tunnel Link

Figure 1.1 The panorama of the Shenzhen-Zhongshan Tunnel[1]

[1] Picture resource: *http://www.zs.gov.cn/ywb/news/photos/content/post_2285867.html* and *Shenzhen-Zhongshan Bridge Makes Key Progress (sasac.gov.cn)*

It could be imagined that different technological and managerial challenges could be encountered during the design and construction stage of the channel: How was the world's widest 6.8-kilometer-long underwater steel-concrete immersed tube tunnel constructed? How did they overcome the challenge of building the world's tallest cable-stayed bridge with a main span of 1666 meters in the sea? How was the first underwater high-speed highway interchange in the country achieved? Song Shenyu, the Deputy Director of the Management Center for the Shenzhen-Zhongshan Tunnel, revealed the answers in an open report (Yang, 2023).

"From the very beginning, the construction of the Shenzhen-Zhongshan Tunnel faced numerous technical challenges. To achieve groundbreaking results, the Shenzhen-Zhongshan Tunnel technical innovation team, since 2015, led efforts to collaborate with over 20 research institutions in the "industry, academia, and research" sectors. Over a span of four years, they conducted nearly a thousand model experiments, developed new equipment, successfully tackled technical challenges that had been bottlenecks for the project and the industry, and established a comprehensive set of technologies for the construction of steel-concrete immersed tube tunnels with independent intellectual property rights in Chinese standards". (Yang, 2023)

Similarly, the Baihetan Hydropower Station is another recent monumental infrastructure megaproject located in China, representing a remarkable achievement in hydroelectric power generation, as shown in Figure 1.2, situated on the Jinsha River, a major tributary of the Yangtze River in southwestern China. It spans the border between Sichuan and Yunnan provinces. Baihetan is one of the largest hydropower stations in the world. It boasts a massive installed capacity of 16 million kilowatts, making it a powerhouse in electricity generation with the world's largest individual capacity, signifying China's prowess in hydroelectric technology. It contributes significantly to reducing greenhouse gas emissions and provides a stable and renewable source of electricity for the region. The project also focuses on environmental sustainability, including measures to mitigate the impact on the local ecosystem.

(a) The panorama of Baihetan Hydropower Station

(b) The 16 units of Baihetan Hydropower Station

Figure 1.2 The panorama of Baihetan Hydropower Station and its 16 units[2]

[2] Picture resource: *https://www.nsenergybusiness.com/projects/baihetan-hydropower-project/* and *https://www.seetao.com/details/158554.html*

The research, development, and installation of the 16 million-kilowatt hydroelectric generator units presented challenges far greater than any other units under construction or in operation globally, which are considered the “Mount Everest” of the world’s hydropower industry. The project has been executed with precision and expertise, overcoming the formidable terrain and environmental considerations. As introduced by the deputy director of the electromechanical installation project department of Baihetan Project Construction Department at China Three Gorges Construction (Group) Corporation in the report of Du (2022), close collaboration, and frequent IKS among partners largely contribute to the project’s success.

“Starting in 2006, the Three Gorges Group embarked on a collaborative research mission alongside institutions, such as the East China Survey and Design Research Institute, the Yangtze River Survey Planning and Design Research Institute, the Dongfang Electric Corporation, and the Harbin Electric Corporation. Together, they organized and spearheaded research efforts to develop million-kilowatt hydroelectric generating units. Over a period spanning three phases and more than a decade, extensive research and experimentation were conducted to develop critical technologies, such as hydraulic design, electromagnetic design, ventilation cooling, thrust bearings, structural integrity, and manufacturing processes. These efforts yielded a wealth of research outcomes, laying a strong foundation for the successful development of the Baihetan million-kilowatt generator units“. (Du, 2022)

“The assembly and commissioning of the million-kilowatt generator units leave no room for error. Through collaborative efforts from all parties involved, all 16 generator units were successfully assembled and started on the first attempt, with installation quality meeting top-tier standards. The post-installation operation of the units results in vibrations and deflection values of approximately 0.06 millimeters, equivalent to the diameter of a single strand of human hair. This level of precision ensures that even if a coin were placed on the unit’s frame cover, it would not topple”. (Du, 2022)

The above two classical cases denote the successful situation of IKS in megaprojects. Nevertheless, there are typical cases showing that the loss of experience and the lack of IKS could lead to poor project performance in megaprojects. Professor Flyvbjerg and Dan Gardner (2023) proposed that experience is invaluable for megaproject delivery by giving a simple example, the California High-Speed Rail project as shown in Figure 1.3, in his recent book “How Big Things Get Done”.

Figure 1.3 California High-Speed Rail Network connecting San Francisco to Los Angeles[3]

“Before the California High-Speed Rail project was built, there was no real high-speed rail in the United States, suggesting the poor experience of US companies. When California started to consider this type of rail seriously, foreign companies with lots of experience—notably SNCF, the French National Railway Company—set up offices in California, hoping to land a sole-source contract or at least be a major partner in the project development. But the state decided not to go that way. Instead, it hired a large number of mostly inexperienced, mostly US contractors and oversaw them with managers who also had little or no experience with

[3] Picture resource: https://www.railway-technology.com/projects/california/?cf-view

high-speed rail. Finally, the California High-Speed Rail project became a mes". (Flyvbjerg and Dan Gardner, 2023, *P*.110)

Another case depicts that the insufficiency of IKS among MSOs causes terrible project cost control. The Roertunnel is a 2.45 km long land tunnel in Roermond, Netherlands, as shown in Figure 1.4 (Rijkswaterstaat, 2023). Opening in 2008, it is one of the longest land tunnels for road traffic in the Netherlands. The tunnel is a part of the A73-south highway, connecting the A73-north in Venlo to the A2 near Echt. The estimated opening on 1 January 2008 was delayed due to the underestimated technical challenge and inefficient IKS among MSOs, especially between the owner and contractor. At first, the owner planned to use new technology, Compressed Air Foam (CAF), instead of traditional hard shoulders to guarantee fire safety. During the test stage, the consultants reported that the CAF system turned out to be more expensive than initially expected. However, the contractor recommended continuation with CAF. The final cost was twice as much as predicted. The following shows the description of the reasons by the project owner (Hertogh and Westerveld, 2010).

Figure 1.4 Roertunnel-A73[4]

[4] Picture resource: *htthttps://www.rijkswaterstaat.nl/nieuws/archief/2023/06/a73-roertunnel-en-de-tunnel-swalmen-dicht-zomer-2023*

The uncoordinated IKS among us (i.e., the owner, contractors, and consultants) led to the final over costs. "It is a black box to me". We are unfamiliar with the Compressed Air Foam technology. The contractors and consultants did not analyze the potential problems of applying this new technology. They evaluated the potential cost increase by themselves within the project budget. However, it is us to pay the final bill. (Hertogh and Westerveld, 2010, *p.* 138)

1.2 Research Problem

Although MSOs realize the importance of IKS in megaprojects, poor IKS in megaprojects is a common and inherent problem (Flyvbjerg, 2014a). "Reinventing the wheel" due to the lack of IKS happens frequently and brings time delay and cost waste (Liu et al., 2019, 2021). Five essential problems, in practice, lead to the insufficiency of IKS, shown as follows.

1.2.1 Mapping IKS: lack of efficient knowledge guideline

The construction sector is used to suffering from inadequate knowledge accumulation and knowledge loss, as discussed over the last two decades (Godsell et al., 2018). On the one hand, MSOs involved in the project delivery are mostly united temporally by the owner and disposed once the project is finished. Different from the permanent organization (e.g., enterprises) collaborating with each other for many years under a unified goal (e.g., maximizing profits), MSOs (e.g., contractors, designers, consultants) have different interest demands and are not willing or motivated to share knowledge with each other (Flyvbjerg, 2014a; Sheng, 2018; Wang et al., 2017). On the other hand, most megaprojects are unique and one-time. MSOs do not have enough time and motivation to summarize their knowledge from the current project delivery for future projects, which may involve different technical and managerial tools or methods. For example, different project delivery models bring different collaboration modes. Some technology applications under certain natural and social environments could not be used in the future in other conditions (Ma et al., 2008).

Although temporary organization features and one-time project features impede IKS in megaprojects, the lack of efficient knowledge guidelines is the direct reason for the hard implementation of IKS. All kinds of project information and knowledge are flooded with the life-cycle project delivery. MSOs are always confused about what knowledge is needed by others (X. Chen et al., 2021; Iftikhar and Mawra, 2023; Jin et al., 2022; H. Liu et al., 2020; Liu et al., 2022). In practice, some associations in the field of project management or construction management provide some standard handbooks and guidelines for project management, such as the Project Management Body of Knowledge, and divide project management knowledge into different areas, such as schedule, quality, safety, risk, and procurement management (Kolloch and Reck, 2017; Sammarra and Biggiero, 2008),

However, these guidelines have several flaws when applied in megaproject management. *First*, megaprojects are a kind of special large interorganizational construction projects. Technical and managerial challenges are unprecedented compared with general construction projects, so the previous guideline considering primary principles or best practices for general project management is not so matched with the new context (Liu et al., 2019; Martinsuo, 2020). *Second,* only a single knowledge characteristic is considered (i.e., knowledge heterogeneity in content). A multi-dimensional framework referring to multiple knowledge characteristics, combining *tacitness* and *heterogeneity* should be formed (Li et al., 2023). *Third,* the current guideline is established from the individual perspective to integrate project management with knowledge management and is not suitable for exploring knowledge sharing (only one essential process of knowledge management) at the interorganizational level (Iftikhar and Ahola, 2022). Hence, a more efficient knowledge guideline fitting to the megaproject context, integrating multi-dimensional knowledge characteristics, and focusing on the IKS process should be formed to help MSOs identify what knowledge they should share with others. (Iftikhar and Ahola, 2022; Olaniran, 2017)

1.2.2 Mapping IKS: lack of matched IKS mechanisms

IKS mechanisms are defined as the effective utilization of various methods, tools, or strategies by MSOs to engage in IKS activities. These activities, ranging from regular meetings, interdisciplinary training courses, and email systems, should be tailored to different types of knowledge. For instance, rapid and timely mechanisms are suitable for sharing project status information across MSOs, such as project schedules or exterior environment conditions. Conversely, technical experiences in construction safety management may necessitate face-to-face discussions in construction sites or offices. Establishing the matching between the IKS mechanism with the sharing of different types of knowledge is essential for optimizing knowledge-sharing endeavors among MSOs, yet less explored.

As Hoetker and Mellewigt (2009) presented, the socio-technical perspective offers a valuable framework for elucidating and categorizing IKS mechanisms. Each mechanism can be broadly characterized by its “socialization” and “technicalization” features. Socialization emphasizes the human aspect, delving into soft institutional arrangements like values, norms, and cultures. Such arrangements aim to foster interorganizational relationships and boost organizational readiness for IKS (Oesterreich and Teuteberg, 2019), as seen in initiatives like regular training programs (Ben-Menahem et al., 2016) and communities of practice (Choi et al., 2020). Conversely, technicalization enhances IKS by focusing on tasks and providing hard infrastructure, useful methods, and tools essential for the IKS process, such as documentation systems (Wang and Ko, 2012). In essence, the socio-technical perspective offers a comprehensive approach to understanding and strategizing IKS mechanisms, considering both the social and technical dimensions for effective knowledge sharing with diverse characteristics.

Additionally, the alignment between specific IKS mechanisms and various forms of knowledge sharing remains unclear. Existing literature indicates that the efficiency of IKS mechanisms is intricately linked to the tacitness of knowledge. Social mechanisms are well-suited for the sharing of tacit knowledge across organizations (Aaltonen and Turkulainen, 2018; Lawson et al., 2009; Vijver et al., 2011), whereas technical mechanisms facilitate the sharing of explicit knowledge (Le Dain et al., 2020; Naeem, 2019; Oesterreich and Teuteberg, 2019). However, within the context of projects, each type of knowledge outlined in the framework above possesses multidimensional characteristics. Relying solely on the tacitness of knowledge to choose an optimal IKS mechanism may prove insufficient. Moreover, in practical applications, a configuration that integrates multiple IKS mechanisms could outperform a singular mechanism in facilitating knowledge sharing. For instance, combining interdisciplinary technology workshops with document sharing mechanisms may enhance the promotion of new technology applications in megaprojects. Therefore, there is a need to establish configurations that integrate multiple IKS mechanisms to assist MSOs in identifying suitable IKS mechanisms for fostering collaborative knowledge sharing.

1.2.3 Facilitating IKS: lack of understanding of antecedents of IKS in megaprojects

MSOs encounter unparalleled and acute coordination obstacles due to the transient and intricate nature of megaprojects, the presence of interlinked tasks, and the usual involvements of diverse MSOs. These organizations temporarily collaborated together to fulfill distinctive and intricate objectives, mostly focusing on a complex task within a confined timeframe. Over the course of decades, scholars in organizational research have increasingly come to acknowledge the significance of identifying and investigating various obstacles and facilitators of IKS (Abdelwhab Ali et al., 2019; Becerra et al., 2008; Carnahan et al., 2014; Iftikhar and Lions, 2022; Martin and Emptage, 2019; Ren et al., 2018; Van Wijk et al., 2008; Zhou et al., 2022). Overall, antecedents of IKS could be classified into three categories: factors related to knowledge characteristics, such as tacitness and complexity (Easterby-Smith et al., 2008; Kim et al., 2013; Milagres and Burcharth, 2019); factors related to organizational characteristics (i.e., knowledge donator and collector), such as absorptive and sharing capacity (Amoozad Mahdiraji et al., 2022; Iftikhar and Lions, 2022; Martin and Emptage, 2019); and factors related to context characteristics, such as project culture and information technology application (Bharati et al., 2015; Bosch-Sijtsema and Postma, 2010; Chen et al., 2023; Zhao et al., 2015).

Although the qualitative and quantitative research, as mentioned above, identified and explored the effects of different antecedents, interrelationships between these factors are important but rarely revealed to form more comprehensive and dynamic driving mechanisms for enhancing IKS efficiency (Sun et al., 2023). Only a handful of studies have investigated the interrelationships among a very restricted set of factors concerning IKS through structural equation modeling (SEM) or other classic regression analysis techniques (Gil-Garcia and Sayogo, 2016; Philsoophian et al., 2022; Zhao et al., 2015). Nonetheless, techniques based on regression tend to overlook the intricate interdependencies among factors, and their application in cross-sectional datasets falls short in analyzing their causal relationships (Luo et al., 2020). SEM also exhibits limitations in terms of prediction, as it primarily assesses linear connections between variables and potentially results in the failure to detect crucial associations in cases where nonlinear relationships are present (Sun et al., 2023). Furthermore, SEM is unable to simultaneously propagate observations both forward and backward, which in turn imposes constraints on optimizing managerial decision-making processes (Gupta and Kim, 2008).

1.2.4 Facilitating IKS: lack of stakeholder synergy strategies

Megaprojects are delivered through a knowledge-intensive organization involving diverse MSOs with interdisciplinary specializations to jointly cope with complex problems (Davies et al., 2014; Worsnop et al., 2016). Maximal value creation from IKS could only be reached when all MSOs reciprocally implement IKS. However, MSOs are generally confused about how to collaborate with partners to reach the reciprocal goal.

Profits or benefits are the continuous motivation for MSOs conducting any actions. Another problem discouraging MSOs' IKS is that they have no way to directly perceive their gain or loss from IKS, as knowledge is more than a kind of invisible asset for both MSOs themselves and others. *Value-focused thinking* and *network-based perspective* provide a useful way to measure the perceived benefits for MSOs from IKS directly. Specifically, value, a good indicator for the organization to reflect how their desired goals are achieved, could be used to measure the direct benefits one MSO perceived from another's IKS (Eustace, 2003). *First*, by referring to *value-focused thinking* (Vuorinen and Martinsuo, 2019; Zheng et al., 2021), a knowledge value flow (KVF) through the interorganizational interaction is, therefore, understood to indicate "*whether a specific need of one MSO is met or whether the potential benefit has been obtained from another MSO through the IKS process"*. *Second*, IKS in megaprojects involves multiple MSOs. Joint value creation derived from multiple MSOs' IKS should be assessed through the search for and combination of various KVFs from a *network-based* perspective (Bendoly et al., 2021). Hence, an in-depth understanding of the IKS network feature from these two essential perspectives could help MSOs measure their benefits from IKS through a direct and quantified method, which greatly motivates their interest in IKS.

Collaborative advantage within the supply chain denotes the strategic advantages obtained over competitors in the market by engaging in partnerships and facilitating knowledge creation through collaboration with partners where these synergistic benefits are unattainable through independent actions (Lasker et al., 2001; Seo et al., 2016; Teng, 2003; Xin et al., 2023). Organization science scholars often utilize *stakeholder power* to describe the stakeholder's collaborative advantages and capability to influence the objectives and strategy-making of other stakeholders in the temporary stakeholder alliance network (Ackermann and Eden, 2011; Boaventura et al., 2020; McGahan, 2021; Wu, 2013). From the above value-focused thinking and network-based perspective, stakeholder power in the IKS network could be formed in two aspects. On the one hand, MSOs occupying essential knowledge resources that other MSOs' need would occupy a high level of stakeholder power (i.e., *value advantages*) (Boaventura et al., 2020; Savage et al., 1991). For example, the consultants provide valuable technical knowledge to help the contractor solve key technical challenges in megaprojects. On the other hand, MSOs centrally located in the IKS network also occupy a high level of stakeholder power (i.e., *exchange advantages*) (Boaventura et al., 2020; Rowley, 1997). For instance, the contractors play a knowledge-exchange-hub role in bridging all of the knowledge and information together from others, such as the owner, designers, and government, during the construction stage of megaprojects.

Traditional theories of value creation based on power depict that the gains of one stakeholder must be original from the losses of the others. However, new theories considering justice and reciprocity depict that a win-win relationship could be reached where the gains of one stakeholder may also increase the value creation of the others (Garcia-Castro and Aguilera, 2015). This phenomenon is labeled as *stakeholder synergy*, highlighting the upside value creation of the whole stakeholder network instead of the downside value appropriation by the partially powerful stakeholders (Tantalo and Priem, 2016). Powerful stakeholders could also keep their willingness to stay and contribute to the whole value creation system in this synergy situation because they could benefit more from a bigger value "pie" (Tantalo and Priem, 2016). These arguments change the focus from emphasizing bargaining stakeholder power to prioritizing stakeholder cooperation and power complementarity to contribute to total value creation (Bosse and Coughlan, 2016). Hence, a lack of stakeholder synergy strategies leads to a low efficient stakeholder collaboration to maximize value co-creation.

1.2.5 Applying IKS: lack of a link between IKS and innovation capability enhancement

Extant research depicted that IKS benefits innovation performance in megaprojects (Bacq and Aguilera, 2021; Brockmann et al., 2016; Sjödin, 2019), and promotes innovation capability enhancement, which describes MSOs' comprehensive capacity in integrating systematic resources, coping with complex and dynamic external environments, and creatively solving problems to obtain longer-term project benefits (Figueiredo et al., 2020; Yao et al., 2020). However, it remains unclear how IKS facilitates the enhancement of organizational innovation capability for MSOs in the megaproject innovation alliance.

Moreover, some specific problems affecting the progress of innovation capability enhancement by IKS should be solved. *First*, in this highly turbulent and uncertain era, volatility, uncertainty, complexity, and ambiguity (i.e., VUCA scenarios) are the features of the natural and social environment where the megaprojects are situated (Cousins, 2018; Troise et al., 2022). Volatility refers to large-scale, frequent changes without predictable patterns (Gao et al., 2021). Uncertainty indicates a lack of awareness about changes' frequency and importance (Bartscht, 2015). Complexity is the iteration of simple patterns and creates the potential for information overload in many interconnections (Bennett and Lemoine, 2014). Ambiguity refers to the lack of understanding of causality without precedent to predict (Wang et al., 2021). VUCA scenarios bring successful delivery of megaprojects with complex managerial and technical challenges (Li et al., 2019b; Lu et al., 2021). However, it remains unclear how VUCA sceneries influence the IKS process in megaprojects.

Second, most studies exploring IKS in megaprojects assumed that MSOs conducted IKS in a "point-to-point" pattern (Iftikhar and Lions, 2022). However, in practice, MSOs usually conduct the IKS in a dynamic way, and IKS activities are multiple and complementary (Chen et al., 2018; Jin et al., 2022; Qiu et al., 2019). Even when research is conducted on a single innovation topic, the innovation alliances still conduct a series of IKS activities (e.g., project inspection, interviews with experts, and lectures) (Balle et al., 2019).

Third, as the innovation process involves multidisciplinary knowledge integration, the design and construction of megaprojects often not only require the member organizations of the innovation alliance to cope with challenges but also require the owner to deal with management-level problems, such as resource integration and organizational coordination to create a favorable environment for IKS within the innovation alliance (Bereznoy et al., 2021; Jin et al., 2022). It remains unclear what role the megaproject owner plays in leading the IKS of the innovation alliance in different project stages.

1.3 Research Aims and Objectives

To sum up, to the best of my knowledge, the current practitioners and scholars has not solved these problems and need further exploration on mapping, facilitating, and applying IKS in the megaproject context. This research aims to develop an integrated framework for MSOs to identify and facilitate IKS and enhance innovation capability. The specific research objectives are established to achieve this aim, shown as follows:

1. To categorize knowledge shared in megaprojects based on different knowledge characteristics and map proper IKS mechanisms from Socio-technical perspectives

2. To explore complex interrelationships between factors and their joint effects on the IKS efficiency in megaproject

3. To identify the stakeholder power in megaprojects IKS network and propose stakeholder synergy strategies

4. To explore the evolution path of innovation capability enhancement by IKS in megaprojects

The relationship between the four research objectives is shown in Figure 1.5. Objective 1, described as "mapping IKS", aims to answer two research questions, including "What kind of knowledge is shared across MSOs in megaprojects" and "What kinds of IKS mechanisms are adopted by MSOs in megaprojects". Then, objectives 2 and 3 aim to explore how to "facilitate IKS" in megaprojects. Specifically, objective 2 identifies the most influential factors and their joint effects on the IKS efficiency from a knowledge-organization-context perspective. Based on the stakeholder synergy and value co-creation theory, objective 3 is designed to identify the different levels of stakeholder power of MSOs in megaprojects and form corresponding stakeholder synergy strategies. Finally, Objective 4 explores the interlink between IKS and innovation capability enhancement in megaprojects through a longitude case study, which is described as “applying IKS” in megaprojects.

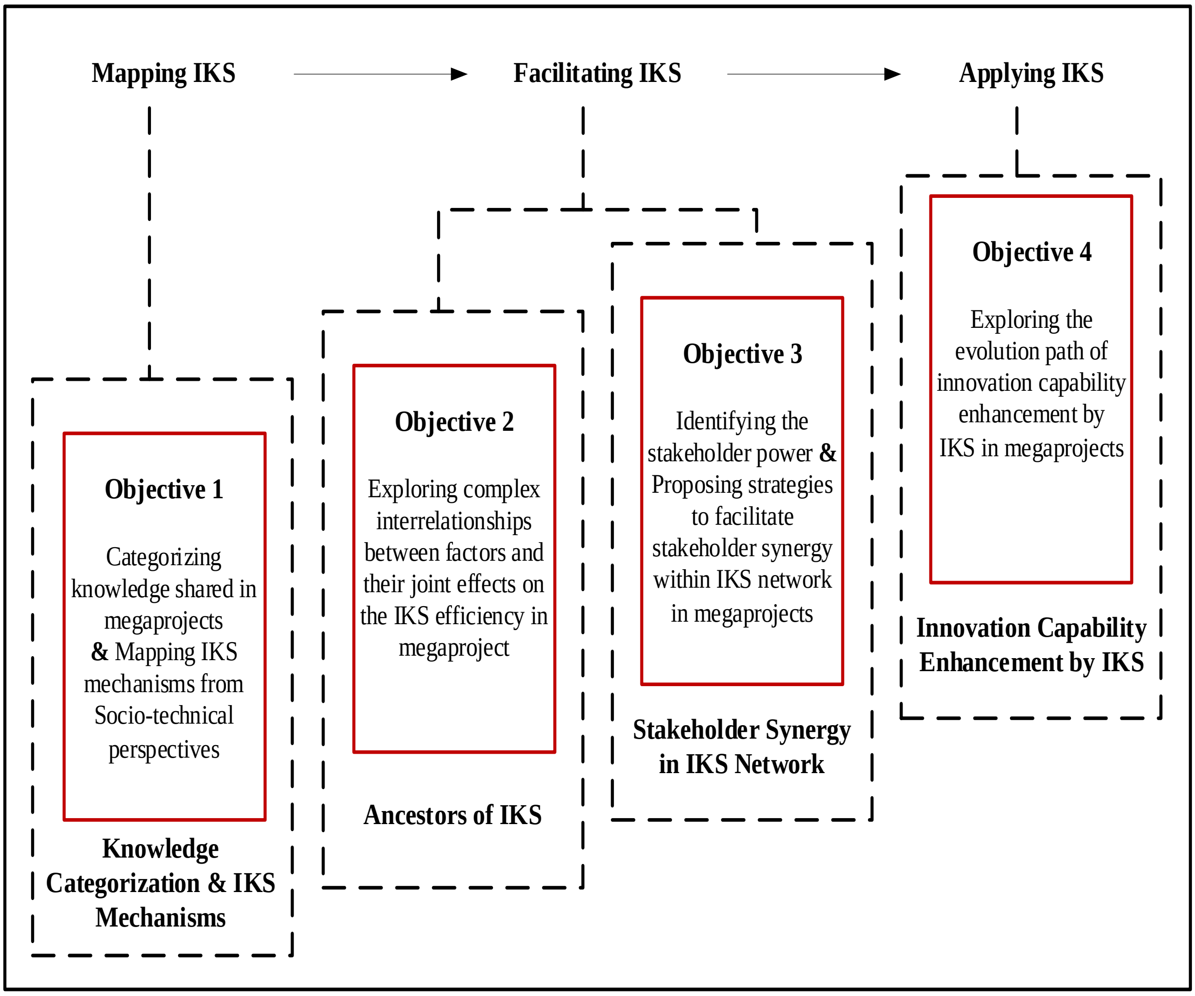
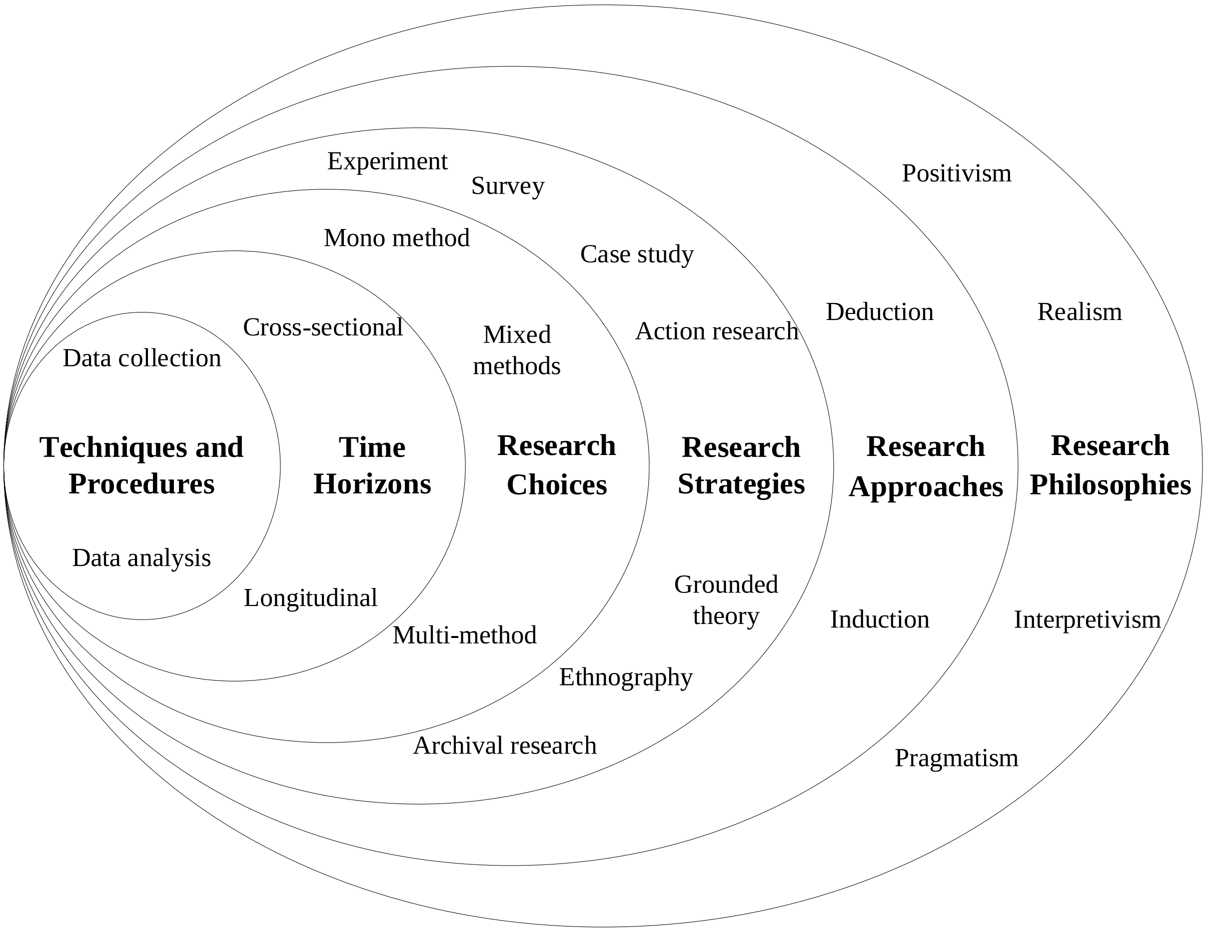


Figure 1.5 Structure of objectives

1.4 Research Methodology in Brief

Saunders et al. (1997) proposed the onion model, which outlines the process of research methodology in management fields from abstract to concrete, including six levels: research philosophy, research approach, research strategy, research choice, time horizons, and techniques and procedures, as shown in Figure 1.6. This paper draws on this model to design the research framework layer by layer, thereby deeply mapping, facilitating, and applying IKS in megaprojects. First, this study conducts relevant research based on the positivist philosophical stance, adhering to objective facts and value neutrality. It builds on socio-technical systems theory, stakeholder theory, and knowledge-based theory. This study also involves an in-depth investigation of the industrial practice of IKS in megaprojects and summarizes relevant literature, aiming for theoretical innovation research.



Note: The figure was revised based on Saunders et al. (1997)

Figure 1.6 The onion model of research methodology in management fields

Second, this paper follows a research logic that combines induction and deduction. On one hand, it inductively portrays the contours of IKS in megaprojects and the connotations of enhanced innovation capabilities through content analysis of expert interviews and actual cases. On the other hand, it quantifies and measures IKS through literature review and questionnaire surveys, deducing the motivations and facilitating strategies.

Additionally, this paper employs a variety of research strategies, including semi-structured interviews, questionnaire surveys, case studies, and grounded theory, to deeply explore how to form managerial and theoretical implication in mapping, facilitating, and applying IKS based on multi-source data.

Furthermore, this paper comprehensively applies a selection of research methods combining qualitative and quantitative approaches, including qualitative content analysis based on interviews and project text data, Bayesian network analysis and Stakeholder Value Network analysis based on literature review and questionnaire surveys.

In terms of time horizons, this paper simultaneously reflects both horizontal and vertical aspects. For example, the research objective 1 aims to analyze the net and joint effects of different factors under the knowledge-organization-contextual framework on IKS, and the interrelationship among them, which belongs to cross-sectional research. The research objective 4 involves a longitudinal single case analysis of the Hong Kong-Zhuhai-Macao Bridge where the time horizon should be longitudinal.

Last, this study involves different techniques and procedures (The details are shown in Section 3.2.2). Data collection methods include literature review of academic papers and project documents, semi-structured interviews, questionnaire surveys, and focus group discussion. Data analysis methods include grounded theory, Bayesian Network analysis, Stakeholder Value Network analysis, and longitudinal case study.

1.5 Structure of the Thesis

This section briefly introduces the overall research flowchart, as shown in Figure 1.7, including research phases, methods, research outputs, and the corresponding chapters. In this research, five phases are included to achieve the research aims and objectives.

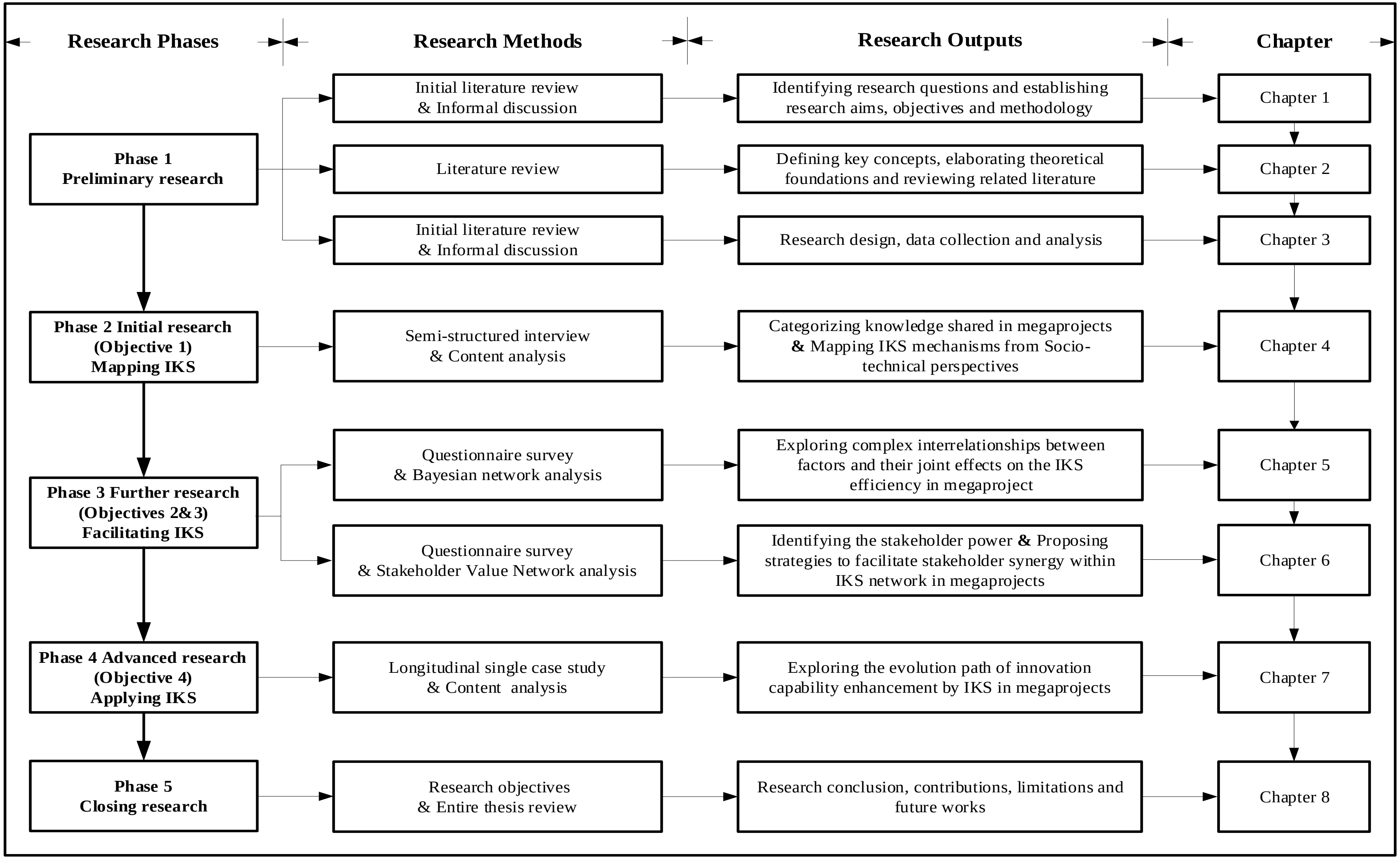


Figure 1.7 Flowchart of the entire study

Phase 1 is the preliminary research. The initial literature review and informal discussion are conducted in this phase to propose research aims, objectives, and framework. Besides, a further literature review was implemented to define key concepts, elaborate theoretical foundations, and related research progress, followed by research methodology describing the data collection and analysis process.

Phase 2 is the initial research that includes one chapter and achieves objective 1. From the Socio-technical perspectives, the categorization model of knowledge shared across MSOs and distinct IKS mechanisms in megaprojects are identified through grounded theory analysis in Chapter 4. Qualitative data were collected from both primary (e.g., semi-structured interviews) and secondary sources (e.g., published books and project documents) to triangulate the research findings.

Phase 3 is the further research that achieves research objectives 2 and 3. Chapter 5 identifies complex interrelationships between factors and their joint effects on the IKS efficiency in megaprojects using the Bayesian Network (BN) analysis method based on the data from semi-structured interviews and questionnaire surveys (Object 2). Then, based on the stakeholder synergy theory, three types of stakeholder powers of various MSOs were identified to form different synergy strategies through Stakeholder Value Network (SVN) analysis in Chapter 6 (Object 3). The data is also derived from semi-structured interviews and questionnaire surveys.

Phase 4 is the advanced research that contains one chapter and achieves research objectives 4. Chapter 7 conducts a longitudinal case study of the Hongkong-Zhuhai-Macau bridge project to explore the interrelationship between innovation capability enhancement and IKS and reveals the owner's role in IKS governance.

Phase 5 is the closing phase. Research conclusions are presented, and recommendations are provided at the end of this research.

More specifically, this thesis is expected to include 8 chapters. Brief introductions to each chapter are presented in the following.

Chapter 1 Introduction: This chapter introduces the research's background and problems. It outlines the research aims and objectives and briefly describes the research contributions.

Chapter 2 Literature review: This chapter presents a comprehensive literature review related to IKS in the megaproject context, including the definition of IKS, IKS mechanisms, antecedents of IKS, IKS network governance, and the relationship between IKS and innovation in megaprojects, and the theoretical foundation of this study, such as socio-technical theory and stakeholder synergy theory.

Chapter 3 Research methodology: This chapter presents the research methodology and introduces the research methods involved in this research, including the overall research design and specific data collection and analysis techniques.

Chapter 4 Knowledge categorization and IKS mechanism mapping in megaprojects: This chapter is designed to identify and categorize knowledge shared across MSOs according to knowledge characteristics and explore the relevant knowledge sharing mechanisms from the socio-technical perspective. Qualitative data were collected from both primary (e.g., semi-structured interviews) and secondary sources (e.g., published books and project documents) to triangulate the research findings.

Chapter 5: Exploring the antecedents of IKS through Bayesian network analysis: Despite extant qualitative and quantitative studies have widely identified and explored the effects of antecedent factors on IKS in megaprojects, the complex interrelationships between factors and their joint effects on the prediction of IKS efficiency still keeps vague. The Bayesian network analysis (BN) method was employed to establish an IKS-BN model to measure the effects of various factors related to knowledge, organizational, and context characteristics on IKS efficiency based on literature reviews, expert knowledge, and questionnaire surveys.

Chapter 6 Exploring stakeholder synergy in megaproject IKS network: From value-focused thinking and network-based perspective, knowledge value flows are formed by IKS. This chapter presents a novel approach derived from the stakeholder value network (SVN) to identify crucial KVFs across MSOs within the IKS network, quantify the stakeholder power, and propose strategies to facilitate IKS in megaprojects.

Chapter 7: Exploring the evolution path of IKS and innovation capability enhancement in megaprojects: This chapter conducted a longitudinal case study of the HZMB project to explore the evolutional path of IKS sceneries, IKS strategies, innovation capability enhancement, and the owner's role in leading IKS.

Chapter 8: Conclusion: This chapter concludes the main research results, contributions, and implications of this research. The research limitations are discussed, and recommendations for future research are provided.

1.6 Research Significance

Although many studies have been devoted to IKS research, not much has been done about the empirical study to promote IKS in the context of megaprojects. This research contributes to understanding IKS in megaprojects and its effect on innovation capability enhancement and provides practical implications to the industry. The research significance of this study contains the following aspects:

- This research developed the knowledge management theories by proposing a knowledge categorization model and corresponding IKS mechanisms from the Socio-technical perspectives;
- This research constructed a comprehensive nomological network quantifying the interrelationships among factors to predict IKS efficiency and propose corresponding governance strategies;
- This research developed the stakeholder synergy and value co-creation theory in the field

of megaproject knowledge management;

- This research explored the effects of IKS on organizational innovation capability and found out the dynamic roles of megaproject owners in leading IKS;
- The findings can provide an insightful reference for practitioners in identifying efficient approaches to facilitate IKS and improve MSOs' innovation capabilities and the overall megaproject performance.

1.7 Chapter Summary

This chapter aims to briefly introduce this study, including the research background, scope, research problem, aim and objectives, methodology framework, and other relevant parts. An overview of this study is presented in this chapter.

CHAPTER 2 LITERATURE REVIEW

This chapter presents a systematic description of the literature on IKS in megaprojects. First, organizational behavior and basic knowledge management concepts in the project context were introduced. Then, the literature review focused on the relevant IKS studies in the megaproject context. The research gaps from the literature review were finally summarized at the end of this chapter.

2.1 Introduction of Organizational Behavior and IKS Research in Megaprojects

2.1.1 Overview of megaproject management

The definition of megaprojects lacks a universally accepted standard. However, they are generally characterized by four features (Flyvbjerg et al., 2018; Flyvbjerg and Dan Gardner, 2023; Flyvbjerg and Turner, 2018; Pollack et al., 2018): 1) large size and high investment over USD 1 billion; 2) involvement of numerous MSOs with varying interests, complex institutional structures, and diverse cultures and expectations; 3)significant public and social integration that attract extensive public attention and participation; and 4) with high political sensitivity that often serve as symbols of national or global ambition, with a significant political and economic mission. These characteristics collectively contribute to the substantial complexity and high risks of megaprojects in technological, organizational, environmental, cultural, and financial aspects and also distinguish megaprojects from single “large projects” (Li et al., 2019a; Xue et al., 2020).

Despite playing a crucial role in regional and national development, driving technological innovation, and meeting the growing demand for economic growth, megaprojects have encountered numerous challenges and dilemmas (Flyvbjerg et al., 2003). Particularly, the outcomes and performance of megaprojects have often fallen short of expectations, with many experiencing issues such as cost overruns, schedule delays, and benefit shortfalls (Davies et al., 2009; Flyvbjerg, 2014b; Locatelli et al., 2017; Söderlund, 2017). Project delivery failures and low efficiency during implementation are widespread (Flyvbjerg and Dan Gardner, 2023). Consequently, the management of megaprojects is of paramount importance and comes with significant challenges. Traditional project management strategies frequently prove inadequate in addressing the unique demands and complexities of megaprojects (Pollack et al., 2018; Söderlund et al., 2017). Indeed, managing megaprojects is a complex and interdisciplinary endeavor (Brookes et al., 2017). The inherent characteristics of megaprojects, including technological challenges, unpredictable behaviors, and intricate decision-making processes, make these projects challenging to comprehend, forecast, and control.

Recent research has delved into the reasons behind failures in megaproject management, shedding light on the mechanisms that influence megaproject performance and the factors that impact megaproject success (Caldas and Gupta, 2017; Flyvbjerg, 2014b; Flyvbjerg et al., 2018; He et al., 2021; Hu et al., 2015; Lopez del Puerto and Shane, 2014; Shenhar and Holzmann, 2017; Wang et al., 2019a). Flyvbjerg, a pioneer in this field, introduced four sublimes that drive megaproject development: political, technological, economic, and aesthetic (Flyvbjerg, 2014b). He also highlighted five practices resolving megaproject cost overrun, including giving consistent definitions and measurement of overrun, conducting data collection that includes all valid and reliable data, recognizing that cost overrun is systemically fat-tailed rather than error and randomness, acknowledging that the root cause of cost overrun is behavioral bias, and doing de-biasing cost estimates with reference class forecasting or similar methods based in behavioral science (Flyvbjerg et al., 2018).

Those explorations mostly focus on the external questions of the black boxes and do not pay attention to the internal issues (Pollack et al., 2018). For example, why do these projects frequently exceed their budgets? Why do paradoxical situations emerge? Why decision makers tend to be optimistic about megaprojects? Exploring organizational issues and behavior in megaprojects is the key to internal issues (Li et al., 2019b). Redefining megaprojects from the organization theory perspective has been considered an important direction in rethinking megaproject management (Li et al., 2019b).

2.1.2 Organizational behavior research in megaprojects

Organizational behavior is a field of study that examines how individuals, groups, and structures influence human behavior in the context of organizations. The primary objective of organizational behavior research is to leverage this knowledge to enhance effectiveness and efficiency within organizational settings (Kreitner et al., 1989). In the realm of organizational behavior research, various analytical perspectives are employed. One prevalent approach categorizes organizational behavior into three levels: individual, group, and organizational systems, as illustrated in Table 2.1 (Schermerhorn Jr et al., 2011).

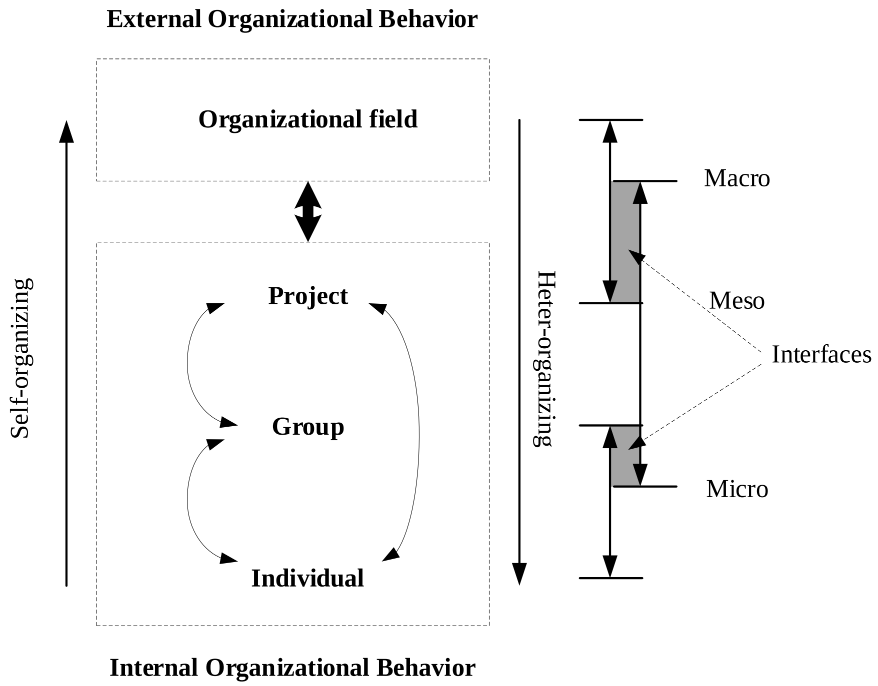
Table 2.1 Analytic hierarchies and research topics of organizational behavior

Focus	Origin	Topic
Organizations	Sociology, political science, anthropology, and economics	Formal organization theory, organizational change/culture, goal-setting, creativity, organization environment
Groups	Communication, social psychology, interactionist sociology, plus the origins of the two subfields	Size, composition, structure, communication, group processes, power, conflict, intergroup behavior
Individuals	Experimental, clinical, and organizational psychology	Motivation, personality, emotions, perception, values, commitment, leadership effectiveness, job satisfaction, individual decision making

Note: The table was revised based on Li et al. (2019b)

The individual level of analysis explores the impact of personality, values, perceptions, decision-making, attitudes, and motivation on individual behavior. Group-level analysis delves into topics, such as enhancing team performance, communication, and group decision-making processes, and addresses issues related to leadership, power, conflict, and negotiation. At the organizational level, the focus shifts to how organizational structure and culture influence behavior and how managers utilize measures to facilitate organizational changes and innovations. It is worth noting that these hierarchical levels of analysis are interconnected and dynamically influence one another. As a result, cross-level research has gained prominence in organizational behavior, encompassing topics such as decision-making, performance, interorganizational processes, multinational and cross-national issues, and more.

In the context of megaprojects, related organizational behavior studies extend the classic three-level framework by considering the project as a temporary organization and recognizing the multiorganizational nature of megaprojects (Li et al., 2019b). In addition, it introduces the concept of external organizational behavior, which pertains to the broader organizational field in which the megaproject operates and is closely related to its dynamics. This expanded framework is designed to better align with the complex interorganizational contexts of megaprojects, as illustrated in Figure 2.1.



Note: The figure was revised based on Li et al. (2019b)

Figure 2.1 Multilevel research framework of organizational behavior in megaprojects

This framework denotes a dynamic interaction between external and internal organizational behavior in megaprojects (Li et al., 2019b). The individual, group, and project-level organizational behaviors constituting an organization's internal activities can significantly impact each other. It is important to note that these levels of behavior are interconnected, and no clear boundaries separate them. When viewed through the lens of complex systems, megaprojects demonstrate a combination of bottom-up behavior emergence, characterized by self-organization from lower internal levels to higher external levels, and top-down behavior control, involving influence and direction from higher external levels to lower internal levels. This interplay results in a complex and ever-evolving ecosystem within megaprojects. Li et al. (2019b) summarized diverse and varied research topics and methodologies employed at different levels of organizational behavior in megaprojects, as illustrated in Table 2.2.

Table 2.2 Topics and methodologies of organizational behavior studies in megaproject

Subfield	Research topic	Cross-level research topic	Main research methodology
Organizational field	Institutions, politics, culture, social conflict, stakeholder, external cooperation, social responsibility, citizenship behavior		Case study, survey, interview
Project	Organizational structure, organization network, governance mechanism, governance system, governability, project culture	Stakeholder, leadership, culture, cooperation, ethics, decision making, social responsibility, citizenship behavior	Case study, social network analysis, interview, phronetic and abductive theory building
Group	Communication, collaboration, teamwork, innovation, team decision making, relationship behavior, cross-culture, conflict, team culture, organizational learning		Case study, survey, review, phronetic and abductive theory building,
Individual	Manager leadership, roles, trust, ethics, psychology		Survey, interview, narrative analysis

Note: The table was revised based on Li et al. (2019b)

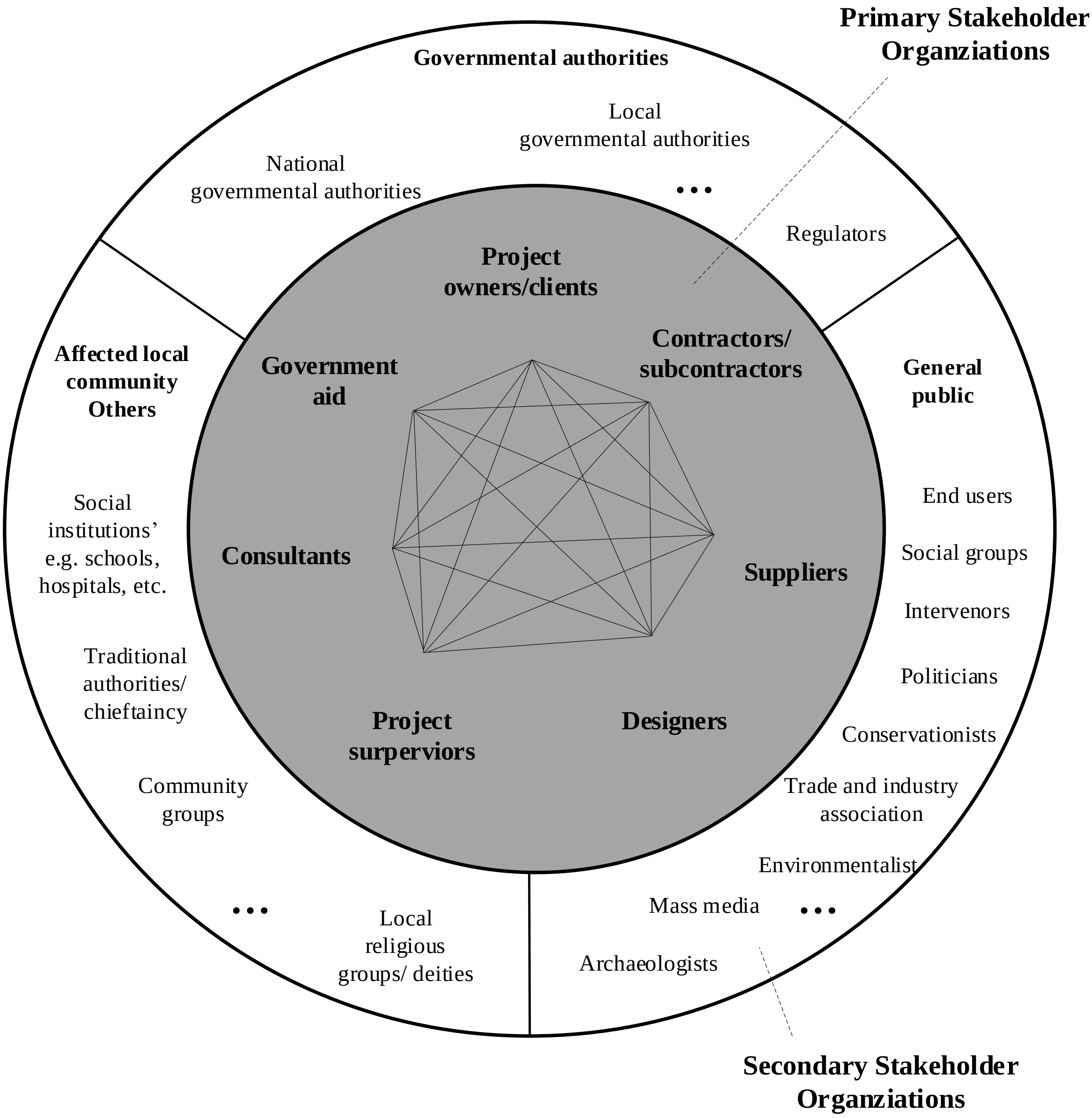
Table 2.2 demonstrates the interconnectedness and complex dynamics of organizational behavior in the context of megaprojects. These dynamics often involve behaviors that span multiple levels and interact in intricate ways. Here are some key observations:

1. **Cross-Level Behaviors**: Many behaviors and interactions do not adhere to specific levels but cross over them. For example, knowledge sharing behavior may involve individual, group, and cross-organizational interactions. The multifaceted nature of megaprojects necessitates cross-level interactions.

2. **Complex Networks**: Organizational networks extend beyond the boundaries of teams and projects. They encompass larger-scale networks at the organizational, business, and industrial levels. The study of these networks requires a comprehensive view that transcends traditional levels.

3. **Diverse Stakeholder organizations**: The development of megaprojects garners extensive attention due to the multitude of individuals and groups that can influence or be impacted by these projects. MSOs are entities that can influence or be influenced by an organization's pursuit of its goals and objectives (Freeman, 2010, 1983). Therefore, MSOs represent the diverse interests that arise in the process of organizations striving to achieve their objectives, which greatly influence their organizational behaviors. Stakeholder management research utilizes various models for categorizing construction MSOs.

The stakeholder concept originated in the 1960s and was formally introduced by Freeman as a novel theory of strategic management (Freeman, 1983; Laplume et al., 2008). Stakeholder theory has been applied across various business domains, including business ethics, finance, accounting, marketing, and management (Lehtinen and Aaltonen, 2020). This theory aims to generate value for various groups and individuals within organizations to achieve success. A stakeholder is most accurately defined as "any group or individual capable of influencing or being influenced by an organization's goals" (Ho, 2010; Tampio et al., 2022). Freeman underscored the significance of relationships between an organization and its stakeholders, considering them the central focus and starting point for stakeholder research (Freeman et al., 2010; Yang et al., 2014). In project management, stakeholder management has become a fundamental knowledge area for ensuring the success of projects. The fundamental concept of project stakeholder management is that the project owner can enhance the likelihood of project success by influencing and forming collaboration relationship with stakeholders (Li et al., 2013).



Note: The figure was revised based on Chan and Oppong (2017), Mok et al. (2015), and Olander and Atkin (2009)

Figure 2.2. MSOs involved in megaproject delivery

The most widely adopted classification model is based on the differentiation between internal (primary) and external (secondary) stakeholders, as depicted in Figure 2.2. Primary stakeholders comprise participants forming the project coalition or providing financial support, such as project owners, designers, contractors/subcontractors, consultants, project supervisors, governmental entities, and suppliers (Olander and Atkin, 2009; Zheng et al., 2021, 2019b), while secondary stakeholders are those significantly affected by the projects (Chan and Oppong, 2017), encompassing local and national government authorities, social organizations, political entities, local communities, the general public, environmentalists, trade and industry associations, the media, traditional authorities, and traditional spiritual and religious groups (Mok et al., 2015; Ninan et al., 2019). Therefore, the successful delivery of megaprojects typically involves a wide spectrum of MSOs, and comprehending their roles, organizational behaviors, and interactions is imperative for effective project governance.

4. **Multilevel Governance**: The intricate, contextual, and indeterminate nature of cross-level organizational behaviors necessitates adaptive project governance strategies. These strategies should account for the multilevel, dynamic, and evolving nature of megaprojects.

5. **Research Methods**: Research methods vary by level. Individual-level research often relies on surveys and interviews, which are suitable for examining personal motivations, attitudes, and behaviors. At higher levels (group, project, or organizational), richer research methods, such as social network analysis and case studies, are employed to capture the complexity of group dynamics, project interactions, and organizational behavior.

Knowledge is multidimensional and multivalent, which involves propositional, performative, experiential, and epistemological contents and engages with truth in various ways (Nonaka and Krogh, 2009). In complex megaprojects, knowledge is an increasingly valuable resource (Bercovitz and Tyler, 2014; Salvador et al., 2021) that is crucial for making appropriate and timely decisions (Mishra et al., 2020; Ramasesh and Browning, 2014). As an essential type of organizational behavior, knowledge sharing at different levels in megaprojects will be introduced hereafter.

2.1.3 Knowledge sharing at different levels in megaprojects

A series of basic concepts were reviewed in this section, including the difference between data, information, and knowledge; the definitions of knowledge sharing, donating, collecting, and knowledge flow; different types of knowledge sharing in the project context; and the significance of IKS for successful megaproject delivery.

2.1.3.1 Data, information, and knowledge

Human action is not conceivable without knowledge. In the context of KM, knowledge is often defined by comparing or relating it to data and information (Grundstein, 2013). Knowledge is seen as an entity at a higher level and with a higher authority than data and information (Tan et al., 2018). Data is described as a set of discrete facts about events, while information is "relevant and organized data" that can be created by adding value to data through contextualization, categorization, computation, correction, and compression (Thangamani et al., 2018). Knowledge can also be described as "actionable information", which "confers the ability to act and make value-creating decisions" (Athanassopoulos and Curram, 1996; Jiao et al., 2013). However, in the real world, it is not always possible to distinguish between data, information, and knowledge, as their differences are only a matter of degree. Depending on the different relevance of the knowledge and the knowledge base of the individual or organization, knowledge can be interpreted as information for one and vice versa. In the construction projects or megaproject context, the content of accumulated knowledge will be specifically introduced and reviewed in section 2.2.1.

2.1.3.2 Knowledge sharing, donating, collecting, and flows

Knowledge management is increasingly essential due to accelerating market changes and technological competition (Ma et al., 2008). Knowledge sharing is one of the key processes of knowledge management (Loebbecke et al., 2016; Mishra and Bhaskar, 2011), and is defined as the activities of a person, group, or organization to disseminate or sharing knowledge with another (Lee, 2001) or transferring knowledge from the place it is created or stored to where it needs to be applied (Ardichvili et al., 2003). Two typical views explore knowledge sharing: knowledge as possession and knowledge as process. From the knowledge-as-possession view, similar to information, knowledge is regarded as some objective and independent asset possessed by organizations (Newell et al., 2006). From the knowledge-as-process view, organizational knowledge is original from organizational cognitive and social interactions where ideas and expertise are progressively formed, shared, justified, and articulated (Apetrei et al., 2021; Kakihara and Sørensen, 2002). There is no definitive measurement of knowledge sharing. Previous studies have primarily measured knowledge sharing behaviors in two ways: counting knowledge sharing activities, such as counting the number of instances of communication instances like emails (Yi, 2009) or patents collaboration (Smojver et al., 2020), and subjective evaluation using survey items measured on Likert scales (Pian et al., 2019).

Knowledge sharing generally includes two main actions: knowledge donation and knowledge collection (Afsar et al., 2019; Ali et al., 2018). Knowledge donating refers to transferring intellectual capital from one organization to another (Le and Hui, 2018), while knowledge collecting involves consulting other organizations to acquire needed intellectual capital (Ba et al., 2018). These processes are dynamic and interconvertible (Hooff and Ridder, 2004). The knowledge motion from the donator to the collector is termed knowledge flow (Appleyard, 1996; Lai et al., 2020).

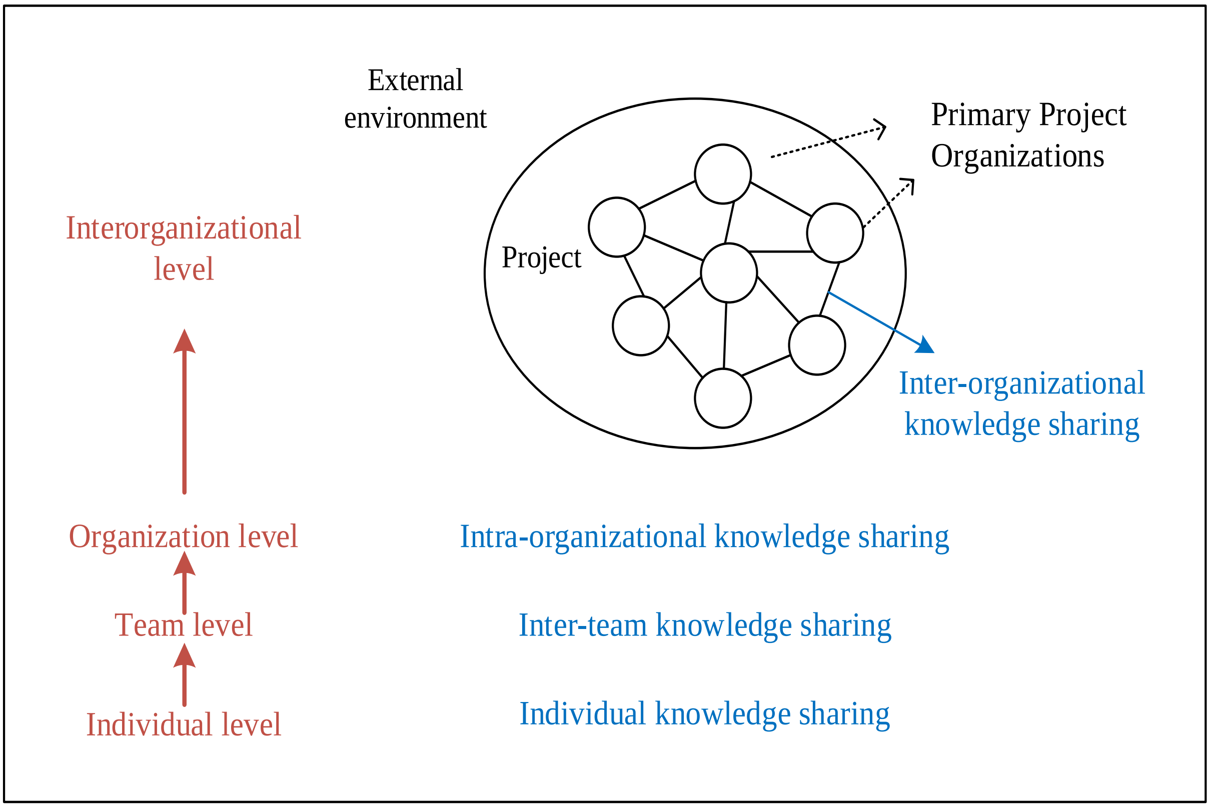
Notions of knowledge flow in the literature vary to some degree. Some studies have indicated that knowledge flow is a kind of movement related to knowledge from one node to another, with two important attributes: direction and content (Palanivelan and Anand, 2013;

Zhuge, 2002). Others have characterized knowledge flow as a strategy for making, passing on, and stratifying knowledge among distinct MSOs (Loebbecke et al., 2016; Palanivelan and Anand, 2013). Some have even investigated knowledge flows as a multistage process involving initiation, implementation, “ramp-up,” and integration (Appleyard, 1996; Szulanski, 1996). This study adopts the first of these definitions and conceptualizes knowledge flows as the transfer of aggregate experience and expertise of technical know-how or managerial skills as shared among the MSOs in megaprojects, including flows of information or materials (Gupta and Govindarajan, 1991). Knowledge flow moves from knowledge donor to knowledge collector, and its details are summarized in interviews. For example, the government may share building information model (BIM)-related policies and regulations with the project owner, where the direction of knowledge flow is from the government to the owner.

It is worth mentioning that knowledge flow differs from information flow. Zhuge (2006, 2002) proposed that the difference between knowledge and information flow lies in the value assigned to the nodes (i.e., knowledge collector in this research). This is knowledge flow if the information leads the node to understand, interpret, and use further incoming information (i.e., processing procedures and interpretation models). Conversely, suppose the information has no value to the node, and the node processes all incoming signals (inputs) and gives a reaction (outputs). In that case, this is to be characterized as information flow. Knowledge flows determine where nodes can obtain the processes they need to do their job and how to do them (Johansson and Jonsson, 2012). By contrast, like workflows, information flows are used to find the information needed for a process (information demand) and to organize work to focus on what to do and where to obtain resources.

2.1.3.3 Knowledge sharing in the megaproject context

In the project context, knowledge sharing happens at four levels: between individuals, teams, within organizations, and across organizations (Iftikhar and Ahola, 2022; Yi, 2009) to enhance individual, team, or organization's capacity to define a situation or problem, and act and to solve the problem (Möller and Svahn, 2006), as shown in Figure 2.3.



Note: The figure was created by the author.

Figure 2.3 Knowledge sharing at different levels in megaprojects

At the individual or team level, knowledge sharing requires team members to be motivated to actively communicate with, consult, and learn from their colleagues in the same departments (i.e., individual and inter-team knowledge sharing). At the organizational level, teams from different departments capture, organize, utilize, and disseminate interdisciplinary knowledge embedded in the organization (i.e., intro-organizational knowledge sharing). (Sáenz et al., 2012).

Interorganizational knowledge sharing (IKS) is defined as the transfer of useful know-how or information across organizational boundaries to develop new capabilities and opportunities for effective actions (Appleyard, 1996; Loebbecke et al., 2016), which requires multiple temporal or more permanent agreements among these organizations. IKS is a strategic necessity for achieving a competitive and collaborative advantage in rapidly changing business environments (Cao and Zhang, 2011; Morgan and Hunt, 1994; Shih et al., 2012). Effective IKS allows supply chain partners to streamline the flow of information across organizational boundaries, improving the supply chain's agility, adaptability, and predictability (Chen et al., 2014; Shih et al., 2012). For example, the consultants share project management expertise, such as risk control experience, with the contractors to avoid unexpected accidents due to terrible natural conditions.

2.1.3.4 Significances of IKS in megaprojects

From a single organization perspective, IKS in megaprojects involves both internal knowledge, which is generated within the organization and generally controlled by the organization itself, and external knowledge, which originates from the interaction among MSOs, such as the owner, contractors, consultants, and suppliers (Brookes et al., 2017; Invernizzi et al., 2019; Wu et al., 2018b). The continuous exchange of internal and external knowledge is necessary for successful megaproject delivery (Eriksson et al., 2017a). Organizations cannot focus on creating internal knowledge alone; they must also seek complementary knowledge from outside the organization (Hartmann and Dorée, 2015; Prencipe and Tell, 2001; Ren et al., 2018).

From an interorganizational project perspective, megaprojects are large interorganizational construction projects in which multiple organizations temporarily work together on a shared activity to coordinate and realize complex project delivery tasks (Greiman, 2013). These organizations consist of an interorganizational network, which is also named innovation alliance by innovation research scholars, to work together to pool various resources and types of expertise to complete the project successfully (Delhi, 2019; Harryson et al., 2008; Nielsen and Nielsen, 2009; Tian et al., 2022). An interorganizational network is a form of aggregated structure where a set of organizations are linked to each other through multiple interconnected relationships. These relationships are the key building blocks of networks. It is typical for an organization to have relationships with different types of actors which usually share common interests and, hence, motivate them to establish and engage in network relationships with each other for their mutual benefit (Oliveira and Lumineau, 2017). Such relationships are a common means of enlarging the scarce resource base of the organizations through the exchange of different kinds of resources such as money, goods, services, and knowledge to cope with the tasks required in a complex project (Nodari et al., 2016). For example, several studies denoted that sharing project management knowledge across organizations in the organizing, scope, schedule, cost, risk, quality, change, and technology is essential for successful project delivery (H. Liu et al., 2020; Williams et al., 2015; Zheng et al., 2017).

Moreover, the interorganizational network or innovation alliance consisting of MSOs should also search for external knowledge resources from similar projects. Unlike permanent enterprise organizations, MSOs present mixed “heterogeneity and dynamics” organizational characteristics (Liu et al., 2021; Liu et al., 2022). For example, the HZMB project integrates global resources and seeks the most professional and experienced organizations worldwide to participate in different stages of the megaproject. In such cases, the project innovation alliance is under special arrangements and always led by an “architect” (i.e., mostly the owner of megaprojects) to conduct their IKS activities. The “architect” is the key organization responsible for designing the overall system, setting common goals, and coordinating the actions to integrate knowledge in different professional fields (Chen et al., 2021; Denicol et al., 2021). The HZMB project integrated multiple forces such as expert groups, international consultants, design and construction consortia, and scientific research organizations, who are highly involved in prior similar megaprojects to solve similar challenges.

2.2 Overview of IKS Research in Megaprojects

Hereafter, a series of literature reviews were conducted on IKS research in megaprojects to extract research gaps in theory, including categorization of shared knowledge and IKS mechanisms, antecedents of IKS, IKS network governance, and the link between IKS and innovation capability enhancement in megaprojects.

2.2.1 Review of knowledge categorization and IKS mechanisms in megaproject

2.2.1.1 Knowledge categorization in megaprojects

Knowledge categorization is a long-standing research topic in the realm of knowledge management and project management, which helps manage and reuse knowledge in subsequent stages of the same project or other projects to avoid the reinvention of the same knowledge, prevent the recurrence of the same mistakes, and for continuous improvement.

Existing literature revealed that various types of knowledge in the project context were initially identified from the generic perspective, not focusing on any industries. Table 2.3 illustrates some available varieties according to different scopes and natures. For example, the knowledge was first classified into explicit and tacit (Nonaka and Krogh, 2009; Nonaka and Lewin, 1994). However, this classification was unsuitable for identifying reusable project knowledge, as most (if not all) of the knowledge was covered under the wide umbrella of tacit and explicit knowledge.

Another typology was proposed (Bhatt, 2001; Blackler et al., 1993), including five types. *Embraided knowledge* related to individuals' conceptual skills and cognitive abilities; *embodied knowledge* was action-oriented and rooted in specific contexts; *encultured knowledge* referred to the process of achieving shared understanding; *embedded knowledge* was the knowledge that resides in systematic routines; *encoded knowledge* was information conveyed by signs and symbols. The types of knowledge identified by Ruggles (2009) and KPMG (1998) covered more potential areas for knowledge classification. However, the scope might also be too broad to capture reusable project knowledge. For instance, 'cultural knowledge' is managed at an organizational rather than a project level. A too wide scope result in unnecessary knowledge overload and affect the knowledge capture and reuse processes.

Table 2.3 Classifications of knowledge for general projects and construction projects

Authors	**Classification of knowledge**	
(a) Generic perspective		
(Nonaka and Krogh, 2009; Nonaka and Lewin, 1994)	• Tacit knowledge	• Explicit knowledge
(Bhatt, 2001)	• Foreground knowledge	• Background knowledge
(Blackler et al., 1993)	• Embraided knowledge • Embodied knowledge • Encultured knowledge	• Embedded knowledge • Encoded knowledge
(Rollett, 2003)	• Core knowledge • Innovative knowledge	• Advanced knowledge
(Ruggles, 2009)	• Process • Factual	• Cultural • Catalogue
(KPMG, 1998)	• Methods and processes • Company's own markets • Company's own products and services	• Regulatory environments • Customers • Competitors • Employee skills
(b) Construction-domain-specific perspective		
(McLoughlin et al., 2000)	• Know-how • Know where/when	• Know why • Know what
(Robertson et al., 2001)	• Process • People	• Product
(Kamara et al., 2002)	• Organizational processes and procedures • Client's business • How to predict outcomes, manage teams, and focus on clients and motivate others	• Technical/domain knowledge • Know-who
(Wetherill, 2003)	• Project • Organizational	• Domain
(Tan et al., 2010)	• Process knowledge • Knowledge about the client • Costing knowledge • Knowledge of legal and statutory requirements • Knowledge of reusable details	• Knowledge of best practices and lessons learned • Knowledge of the supplier's performance • Knowledge of who knows what • Other types of knowledge

Note: The table was revised based on the study of Tan et al. (2010).

Next, the various types of knowledge were gradually grouped by scholars in construction management applied to general construction projects (Mentzas et al., 2006). From the construction-domain-specific perspective, McLoughlin et al. (2000) proposed four types of knowledge to be managed in long-term engineering projects: know-how, know where/when, know why, and know what. Still, they were less helpful in identifying the exact types of reusable project knowledge. Robertson et al. (2001) revealed that knowledge within the construction domain could be grouped into three context-based factors: *process, product*, and *people*. The three context-based factors related to the issues of what was produced (*products*), how it is produced (*processes*), and by whom (*people*). Then, a more complex five-dimensional knowledge classification model was identified by Kamara et al. (2002) and served as a useful guide to the various types of knowledge. However, Wetherill (2003) noted that knowledge was strongly interlinked in that any amendment introduced to one category was very likely to have a critical impact on the others and proposed a three-dimensional framework (i.e., organizational, domain, and project knowledge). Still, it must be noted that these classifications were solely based on the perspective of a single construction organization.

From a comprehensive project perspective, the exact classification models for construction project knowledge should be identified from case studies, by which Tan et al. (2010) identified a wide spectrum of reusable project knowledge in construction projects.

1) Process knowledge: This is the knowledge about executing various stages of a construction project. This category of reusable project knowledge includes design, tendering and estimating, planning, construction methods and techniques, and operation and maintenance knowledge. These knowledge types are sometimes captured in standard procedures (e.g., design manual for design knowledge) but mostly remain tacit. *2) Knowledge about clients*: This covers clients' specific requirements, internal procedures, and business. This knowledge may exist in the form of standard procedures compiled based on the experience of dealing with clients. It may also remain tacit and is usually shared through interactions between people. *3) Costing knowledge*: This knowledge is about the costs of alternative forms of construction and the whole life cost (WLC) of a facility. This knowledge may remain tacit (in the heads of estimators) or be illustrated and captured in custom-designed software. *4) Knowledge about legal and statutory requirements*: Regulatory requirements change over time. This knowledge covers the requirements and responsibilities imposed by regulations, codes of practice, and the best practices to address these requirements. This knowledge is available through subscription to the relevant Web services and in the form of CDs. It may also be held in people's heads through experience or attending specific courses. 5) *Knowledge about reusable details*: Reusable details comprise standard design details, specifications, and method statements. These details may be reused with adaptations. They help avoid recreating similar details from scratch and lead to time and cost savings. 6) *Knowledge of best practices and lessons learned*: These are the proven ways of working that contribute to project success and the mistakes that must be avoided in future projects. This knowledge is often explicated and compiled as best practice guides and codes of practice. 7) *Knowledge of the performance of suppliers*: The suppliers referred to are consultants, contractors, subcontractors, material suppliers, and others who contribute services or goods to a project. The capture of this knowledge facilitates a better selection of suppliers for future projects. This knowledge is explicit in nature. It is often captured in a custom-designed database accessible through the intranet. 8) *Knowledge of who knows what*: This is the knowledge of each staff member's skills, experience, and expertise. It helps to locate the right people with the right knowledge to share, particularly the tacit knowledge that is difficult to codify. This knowledge is captured in the organization's staff profile or skills yellow pages. 9) *Other types of knowledge*: This category includes key knowledge about competitors, risk management, key performance indicators, and other sector-specific knowledge.

In the realm of interorganizational projects, the question Brenner (2007) posed in the editorial of a special issue on “local knowledge resources and knowledge flows”—specifically, the inquiry into the categories of knowledge shared—has spurred scholarly efforts to address this gap. Various researchers have attempted to categorize knowledge in projects into different types, focusing on distinct knowledge characteristics such as tacitness *(e.g., explicit and tacit knowledge)* and heterogeneity *(e.g., managerial, technical, and market knowledge)*, as illustrated in Table 2.4.

Knowledge tacitness. In the analysis of knowledge within oil/gas projects and metro infrastructure projects, Olaniran (2017) and Iftikhar (2020) employ a classification based on codification or stickiness levels, dividing knowledge into explicit and tacit categories. Explicit knowledge pertains to tangible, documented, or publicly available information in project management, presented in a structured, externalized, and fixed-content form (Park and Gabbard, 2018). In contrast, tacit knowledge encompasses the intangible thoughts, evaluations, and repository skills of MSOs, reflecting their understanding, capabilities, and past experiences (Nonaka et al., 2014, 2000). Tacit knowledge is characterized by its flexibility and dynamism, surpassing explicit knowledge, and it plays a crucial role in mitigating project risks, fostering innovation, improving quality, and streamlining the construction process (Saini et al., 2019).

Knowledge heterogeneity. Sammarra and Biggiero (2008) and Kolloch and Reck (2017) have classified knowledge based on its heterogeneity and proposed three primary types: managerial, technological, and market knowledge. Additionally, Li et al. (2022) have expanded this categorization by introducing three more knowledge domains: knowledge of business value, procedural knowledge, and experienced expert knowledge, also based on knowledge heterogeneity. In the specific context of interorganizational construction projects, Ma (2008) has established a categorization criterion that includes auxiliary, field, and technical knowledge. While delivering complex projects, organizations are encouraged to integrate and utilize these diverse categories of knowledge (Sammarra and Biggiero, 2008).

Table 2.4 Knowledge categorization in interorganizational projects

Concepts	Description	Reference
Knowledge tacitness		
• Explicit knowledge	• Explicit knowledge refers to specifiable concepts, information, and insights that can be easily codified and conveyed in written documents such as reports, technical drawings, manuals, and operating procedures. • Explicit knowledge can be written down, while tacit knowledge cannot. "We employ a senior and a young assistant... Both these people have the same work to do, but the benefit is that the junior is gaining knowledge from the experience of the senior, and he is learning from him how to get the work done. So, this is how we try to share experience-based knowledge."	(Iftikhar and Ahola, 2022; Olaniran, 2017)
• Tacit knowledge	• Tacit knowledge refers to less specifiable insights and skills 'embedded' in individuals or an organizational context that can be gained through learning by doing, including the cognitive and technical aspects. • "We have taken documents from other organizations... like we required some third-party validation, some database, some reports, some cases that other organizations had worked on."	
Knowledge heterogeneity		
• Managerial knowledge	• Managerial knowledge refers to competencies and know-how necessary to efficiently and effectively coordinate and supervise organizational resources and processes.	(Kolloch and Reck, 2017; Sammarra and Biggiero, 2008)
• Technological knowledge	• Technological knowledge helps organizations rapidly adapt to the fast-changing technological environment and react accurately, referring to know-how and scientific knowledge.	
• Market knowledge	• Market knowledge refers to structured market information, such as customers' preferences and characteristics.	
• Knowledge of business value	• Knowledge of business value shapes project directions and leads to short-term and long-term project goals.	(Li et al., 2023)
• Procedural knowledge	• Procedural knowledge is embedded within the project processes and provides the project organization optimal path to avoid resource waste.	
• Experienced expert knowledge	• Experienced expert knowledge is linked to organizational best practices and experience to trigger new ideas.	
• Auxiliary knowledge	• Auxiliary knowledge refers to explicit documents assisting the production of interorganizational construction projects, including organizational rules and policies, technique documents, financial and accounting reports, operational procedures, instruction manuals, and human resources data, whether from internal or external sources.	(Ma et al., 2008)
• Field knowledge	• Field knowledge relates to explicit managerial or technological documents on interorganizational construction projects, including work schedules, contracts, analytical reports of other projects, project proposals, and budget documents.	
• Technical knowledge	• Technical knowledge consists of tacit managerial expertise and technological know-how that organizations accumulate through multiple years of experience.	

Despite numerous studies introducing frameworks that categorize knowledge based on single characteristics such as tacitness or heterogeneity, a comprehensive and systematic framework that incorporates multiple characteristics remains scarce. The process of using IKS mechanisms to facilitate knowledge sharing based on distinct knowledge characteristics remains unclear in the existing literature (Cegarra-navarro et al., 2021; Guo et al., 2020; Sammarra and Biggiero, 2008).

2.2.1.2 IKS mechanisms in megaprojects

IKS is a complex phenomenon with various obstacles arising from distinct knowledge characteristics (Ahokangas et al., 2022). Existing studies have put forth several effective mechanisms to overcome these challenges to fulfill the requirement of sharing different types of knowledge across organizational boundaries (Zeng et al., 2018), as illustrated in Table 2.5.

Drawing from the knowledge-based theory, Iftikhar (2020) and Mahura (2021) categorize all knowledge-sharing mechanisms into two types: formal and informal mechanisms. Formal knowledge-sharing mechanisms are structured activities endorsed by the organization, often pre-defined or embedded into various organizational artifacts or routines (Boh, 2007). Examples include training sessions, scheduled meetings, and apprenticeships. For instance, Iftikhar (2020) highlights learning through coordinating and consulting as a crucial formal mechanism in the Islamabad–Rawalpindi metro bus project, involving interorganizational cooperation on specific tasks to generate new insights and ensure more effective project execution. On the other hand, informal knowledge-sharing mechanisms encompass activities displayed in standardized forms, such as informal seminars, coffee break conversations, and interactions on social media. While not specifically designed, these informal mechanisms effectively facilitate knowledge sharing (Nahyan et al., 2018).

Table 2.5 IKS mechanisms

Concepts	Description	Authors
• Formal tools • Informal tools	• Formal knowledge sharing comprises resources, services, and activities that the organization carries out to share knowledge with each other. • · Informal knowledge sharing tools facilitate smooth knowledge exchange within and between organizations not only face-to-face but also over the telephone, by e-mail, and via WhatsApp, short message service, etc	(Iftikhar and Ahola, 2022)
• Formal practices • Informal practices	• Formal mechanisms are practices established by the organization to disseminate and share knowledge, including producing and sharing official documents, sharing lessons learned, using and producing project management written procedures, etc. • Informal mechanisms are based on project members' autonomy and motivation for knowledge sharing, including exploiting personal networking, mentoring, peer training sessions, etc.	(Mahura and Birollo, 2021)
• Learning through coordinating and consulting	• Organizations directly and indirectly involved in a project work together to increase awareness of the issues experienced in the project, resolve the issues, and ensure more effective project execution.	(Iftikhar and Wiewiora, 2020)
• Structural mechanisms • Procedural mechanisms • Technical mechanisms • Social mechanisms	• The structural mechanism relies on hierarchy, team structure, and liaison and is beneficial when there is an increased risk of opportunistic behavior; • The procedural mechanism includes commitments to professional standards for dealing with sensitive information, such as standards and contracts, which are appropriate for explicit, specifiable knowledge; • The technical mechanism applies if the knowledge is put in systems that grant different levels of controlled access and is useful for explicit, public, private, and component knowledge; • The social mechanisms include relational contracting, personal relationships, team working, and trust-building.	(Loebbecke et al., 2016)
• Market-based mechanisms • Trust-based mechanisms • Reciprocity-based mechanisms • Norm-based mechanisms	• The market-based mechanisms set prices as high-powered incentives that encourage to transform of knowledge into saleable explicit products; • The trust-based mechanism is a way to control and coordinate to build trust between partners for facilitating knowledge transfer through long-term and frequent interaction between parties; • The reciprocity-based mechanism is a way to control and coordinate to build reciprocal relationships between partners for knowledge sharing; • Norm-based mechanism builds social bonds between partners to facilitate knowledge transfer, where norms can guide members of organizations in their behavior, thinking, judgment-making, and perceptions of the world.	(Fang et al., 2013)

Building on organizational collaboration and control theory, Loebbecke et al. (2016) propose a concurrent configuration of four categories of IKS mechanisms: structural, procedural, technical, and social. Each mechanism is assigned an initial mission. Procedural and structural mechanisms take precedence in explicit knowledge sharing, while social mechanisms primarily involve tacit knowledge. Leveraging its advantages in facilitating detailed, fast, and interactive communication across time and geography, the technical mechanism is employed to modify the roles of other mechanisms. For instance, social networks play a significant role in bridging together multiple organizations (Senaratne et al., 2021).

Furthermore, an additional framework of IKS mechanisms, derived from the information-processing theory, was established by Fang (2013). This framework encompasses market-based, trust-based, reciprocity-based, and norm-based mechanisms. Firstly, market-based mechanisms utilize efficient pricing tools as high-powered incentives to encourage MSOs to acquire tacit knowledge services through explicit and saleable products. Secondly, norm-based mechanisms guide MSOs in various aspects, such as process, thinking, judgment-making, and code of conduct, aiming to standardize their IKS behaviors. While the former two mechanisms are technical, the latter two are more socialized. Thirdly, trust-based mechanisms encourage frequent, long-term, and amicable interorganizational interactions to establish trusting relationships, thereby facilitating knowledge sharing among partners. Lastly, reciprocity-based mechanisms seek to gather partner MSOs through rewards and reciprocal relationships, creating positive feedback chains to attract more IKS engagement in the future.

2.2.1.3 Socio-technical theory

The Socio-technical theory, originally proposed by Bostrom and Heinen (1977), is a framework for understanding and analyzing organizations by considering both the social and technological aspects that shape their performance (Y. Liu et al., 2020). The social aspect focuses on a more human perspective, emphasizing human attributes (such as values, attitudes, and skills), relationships, power structures, and reward systems (Roy et al., 2023; M. Zhang et al., 2022; Zhang et al., 2019). In contrast, the technical aspect centers on its technical competencies, emphasizing the tasks, technologies, and processes needed to improve organizational performance by transforming inputs into outputs (Cao et al., 2021; Ezeabasili et al., 2015; Pan and Scarbrough, 1998; Xiao et al., 2019). The Socio-Technical Theory posits that these two aspects are intricately interconnected and should not be studied in isolation. Successful organizations can effectively align and integrate their social and technical elements, creating a harmonious work environment that optimizes performance and productivity. By considering both aspects, organizations can better understand the complex dynamics that underlie their operations and make informed decisions to improve overall performance (Roy et al., 2023).

As a useful analytical framework, the socio-technical systems approach has been applied to a stream of organizational issue research to verify the crucial role of the combination of digital technology and social activities to lead positive outcomes in different disciplines, such as e-commerce (M. Zhang et al., 2022), solar energy research (Carbajo and Cabeza, 2022), manufacturing (Münch et al., 2022), and healthy (Grover et al., 2018). For example, drawing on the resource-based view and sociotechnical theory, Liu et al. (2020) identified technical attributes (i.e., technology readiness, security concerns, cloud computing context, rapid responsiveness, dynamic scalability, and on-demand self-service) and social attributes (i.e., socio-environmental competitive pressure and social relationships) of cloud computing and explores their effects on organizational performance. Li et al. (2021) respectively examined the effects of technical factors (i.e., synchronicity and vicarious expression) and social factors (i.e., interaction and identification) on emotional attachment to streamers and platform attachment, as well as their joint effects on user stickiness.

In the domain of knowledge management, traditional studies considered their technology infrastructure to be the most important component for successful knowledge management, which leads to a tendency to focus on only the technological factors of the system when introducing knowledge management systems (Davenport et al., 1998). However, because users' knowledge sharing behavior in the system occurs in a social process, implementing knowledge management technology without considering other social and environmental factors might cause a serious failure in knowledge projects. Current studies have reconsidered realizing highly efficient knowledge management from the socio-technical perspective (Cao et al., 2021; Chai and Kim, 2012; Hong et al., 2017; Lin and Lee, 2006; Owusu, 2023). For instance, Chai and Kim (2012) discussed the roles of social system factors (i.e., ethical culture, social tie, and a sense of belonging in online social networks) and technical system factors (i.e., structural assurance) by employing a socio-technical approach, and examed their effects on users' knowledge contribution behavior. Cao et al. (2021) explained how integrating social and technological factors can increase knowledge creation and team performance.

The choice of the socio-technical theory over other theories as a framework for understanding and integrating IKS mechanisms is based on some reasons. 1) The socio-technical theory offers a holistic perspective that considers both social and technical factors. It recognizes that organizational efficiency is not solely determined by technical systems but is also influenced by social structures, relationships, and human factors. In the context of IKS, where both technological tools and social interactions play crucial roles, the socio-technical perspective provides a comprehensive framework. 2) The socio-technical theory is inherently interdisciplinary, integrating insights from sociology, psychology, and engineering. This interdisciplinary nature makes it suitable for studying complex phenomena like IKS, which involves both technical systems and social interactions among individuals and organizations. 3) The theory emphasizes the interaction between social and technical elements within an organization. This is particularly relevant in the context of IKS, where effective IKS requires a balance between technical tools that facilitate information exchange and social dynamics that foster collaboration and motivation. 4) The socio-technical theory is adaptable and can be applied to various organizational contexts. It allows for the consideration of different mechanisms and interventions to improve both technical and social aspects of IKS, making it versatile for understanding and addressing challenges.

Besides, extant studies also revealed that the socio-technical theory provides a useful framework to help us understand how new technologies are adopted and used in an organization to facilitate knowledge sharing behavior at different levels (Handzic, 2011). Utilizing a socio-technical approach, Xiao et al. (2019) investigated how social aspects (i.e., social comparison, social interaction overload, social surveillance, and social information overload) affect users' knowledge sharing practices through social networking websites along with the consideration of technical factors (i.e., system complexity and system pace of change). In the construction projects, Alashwal and Abdul-Rahman (2014) emphasized the socio-technical perspective of learning and contributed to developing a hierarchical measurement model of learning involving social (e.g., openness, collaboration support, face-to-face communication and asking others) and technical (e.g., efficient project solving, new technology method, work delegation, and role of ITC) factor.

2.2.2 Antecedents of IKS in megaprojects

In today's rapidly evolving business landscape, organizational knowledge resources have become increasingly critical for attaining strategic competitive advantage. IKS encompasses the procedures for exchanging practical information, know-how, and expertise across organizational boundaries based on temporary or enduring interorganizational agreements (He et al., 2023). Efficient IKS is pivotal in overcoming information barriers stemming from organizational boundaries and enhancing project adaptability, agility, and resilience (Milagres and Burcharth, 2019). As an essential part of knowledge management, IKS has triggered many organization research scholars' attention, where exploring the antecedents of IKS was one of the hot topics (Ren et al., 2020). Literature reviews on the antecedents of IKS are summarized in Table 2.6. By referring to extant research (Easterby-Smith et al., 2008; H. Liu et al., 2020; Van Wijk et al., 2008; Zhou et al., 2022), the antecedents of IKS could be divided into three types: knowledge, organization, and context characteristics.

2.2.2.1 Knowledge characteristics

As depicted in Table 2.6, scholars have consistently highlighted four distinct categories of factors within this dimension. These encompass knowledge tacitness, ambiguity, complexity, and heterogeneity. *First*, knowledge tacitness pertains to the extent to which knowledge is concealed and challenging to articulate (Mciver et al., 2019), which can impede IKS to a certain degree (Easterby-Smith et al., 2008; Lim et al., 2015; Milagres and Burcharth, 2019). *Second*, knowledge ambiguity gauges the level of inherent and unresolvable uncertainty regarding the exact nature of underlying knowledge components and their interactions, which is detrimental to the facilitation of IKS (Van Wijk et al., 2008). *Subsequently*, the impacts of knowledge complexity on the IKS are twofold. On the one hand, knowledge with high complexity hinders the coding process, diminishes the efficiency of the boundary spanner structure for IKS, and elevates the sharing costs (Carnahan et al., 2010). On the other hand, knowledge complexity has the potential to enhance organizations' inclination to share knowledge by amplifying the benefits derived from IKS, as complex knowledge is used to provide more comprehensive information and experience (Duan et al., 2022). *Lastly*, the knowledge resource held by one organization in megaprojects significantly differs from others due to professional divisions. For example, the owner is usually unfamiliar with the design and construction procedures and methods from the designers or contractors. This type of knowledge heterogeneity similarly influences the efficiency of IKS (Guo, 2018).

Table 2.6 The antecedents of IKS from the literature review

Types	**Factors**	**Definitions**	(Iftikhar and Lions, 2022)	(Amoozad Mahdiraji et al., 2022)	(Lim et al., 2015)	(Milagres and Burchharth, 2019)	(Easterby-Smith et al., 2008)	(Becerra et al., 2008)	(Foss et al., 2010)	(Khamseh and Jolly, 2014)	(Van Wijk et al., 2008)	(Montazemi et al., 2012)	(Martin and Emptage, 2019)	(Kim and Shim, 2019)	(Jenke and Pretzsch, 2021)	(Zhou et al., 2022)	(Cheng et al., 2008)	(H. Liu et al., 2020)	(Abdelwahab Ali et al., 2019)	(Ren et al., 2020)	(Lawson and Potter, 2012)	(Bosch-Sijtsema and Postma, 2010)
Knowledge Characteristics	Tacitness	The extent to which knowledge is not easily observed or expressed (Mciver et al., 2019)			√	√	√	√	√		√					√						
	Ambiguity	The extent of inherent and unavoidable uncertainty regarding the exact nature of underlying knowledge components and their interactions (Van Wijk et al., 2008)		√	√	√	√		√	√	√					√		√			√	
	Complexity	The extent to which the knowledge involves the combination and integration of diverse and intricate information that may be difficult to comprehend (Duan et al., 2022)		√	√	√	√									√		√				
	Heterogeneity	The extent to which the knowledge possessed is unique or distinct from other organizations in megaprojects (Guo, 2018)			√	√																√
Organizational Characteristics (Knowledge donator and collector)	Absorptive capacity	The capacity of the collectors to acquire, assess, and incorporate the shared knowledge (Lawson and Potter, 2012)	√	√	√	√	√	√	√	√	√	√	√	√		√		√			√	
	Sharing capability	The capability of the knowledge donators to share knowledge after a thorough evaluation of the donators' needs and capabilities (H. Liu et al., 2020)	√	√	√	√	√	√	√	√	√	√	√	√		√	√	√				
	Reciprocity	The prevalent social norm fostering the commitment to reciprocate assistance when receiving help from others (Ren et al., 2020)	√		√	√	√	√	√	√	√			√	√	√			√	√	√	√
	Interorganizational trust	The beliefs, feelings, or expectations concerning exchange partners originating from their expertise, reliability, intentions, honesty, and benevolence (Cheng et al., 2008)	√	√	√	√	√	√		√	√	√	√	√	√	√	√	√	√	√		√

Types	Factors	Definitions	(Iftikhar and Lions, 2022)	(Amoozad Mahdiraji et al., 2022)	(Lim et al., 2015)	(Milagres and Burcharth, 2019)	(Easterby-Smith et al., 2008)	(Becerra et al., 2008)	(Foss et al., 2010)	(Khamseh and Jolly, 2014)	(Van Wijk et al., 2008)	(Montazemi et al., 2012)	(Martin and Emptage, 2019)	(Kim and Shim, 2019)	(Jenke and Pretzsch, 2021)	(Zhou et al., 2022)	(Cheng et al., 2008)	(H. Liu et al., 2020)	(Abdelwahab Ali et al., 2019)	(Ren et al., 2020)	(Lawson and Potter, 2012)	(Bosch-Sijtsema and Postma, 2010)
	Geographical distances	The geographical separation between the knowledge donator and collector resulting in challenges like varying time zones, extended communication channels, and potential language differences (Ambos and Ambos, 2009)	√			√	√			√	√				√	√		√				
	Organizational distance	The organizational separation between the knowledge donator and collector in terms of regulations, organizational structure, and power dynamics (Zhou et al., 2022)	√		√	√	√	√		√	√	√	√	√	√	√	√	√	√			
Context Characteristics	Project temporary nature	The short-term focus nature of projects, with defined start and end points, leading to the transient nature and instability of project organizations (Ren et al., 2018)			√	√		√	√							√						
	Project time constraints	The pressure experienced by project organizations to accomplish project tasks within a designated timeframe. (Iftikhar and Lions, 2022)	√		√	√										√						
	Project culture	The attitudes and values of project organizations being open to sharing information and knowledge with others (Ren et al., 2020)	√	√	√	√	√		√			√	√	√		√			√	√		
	Project incentive mechanisms	The reward system aimed at promoting IKS, encompassing both financial rewards and non-financial incentives (Wang and Shi, 2019)	√			√	√		√				√	√	√	√			√	√		√
	Communication infrastructure	The widespread utilization of social and technical tools to overcome communication obstacles between organizations (Zhou et al., 2022)	√	√	√	√	√		√	√				√	√	√	√		√	√		√
	Market competition	The extent of competitive rivalry presented within an industry (Harmancioglu et al., 2020)				√										√						

2.2.2.2 Organizational characteristics

The second type of influencing factor of IKS in megaprojects relates to organizational characteristics, referring to knowledge donators and collectors. *First*, organizational absorptive and sharing capabilities are the most typical factors. The former aspect pertains to the collector's capacity to acquire, assess, and assimilate the knowledge that has been transferred (Lawson and Potter, 2012), while the latter pertains to the knowledge donator's competence in transmitting information after effectively evaluating the collector's requirements and capabilities (H. Liu et al., 2020). High absorptive and sharing capabilities were believed to be necessary to facilitate IKS efficiency (Kim and Shim, 2019; Martin and Emptage, 2019). *Then*, the reciprocity among MSOs, defined as a shared social norm that encourages individuals to reciprocate when receiving assistance from others (Ren et al., 2020), has also been found to positively enhance IKS performance (Iftikhar and Lions, 2022). *Next*, interorganizational trust between project-participating organizations plays a pivotal role in facilitating IKS, which involves a belief, sentiment, or expectation about an exchange partner arising from factors such as the partner's intentionality, expertise, honesty, dependability, and benevolence (Cheng et al., 2008). *Moreover*, geographical distances, which quantify the separation between the knowledge donator and collector across locations, were identified as a deterrent to IKS in megaprojects. Longer distances introduce obstacles such as extended communication channels, varying time zones, and even potential language barriers (Ambos and Ambos, 2009). *Similarly*, extant research also uncovers that organizational distance between the knowledge donator and collector in terms of regulation, organizational structure, and power relations also influences the IKS outcome (Jenke and Pretzsch, 2021; Vesperi et al., 2021; Zhou et al., 2022).

2.2.2.3 Context characteristics

Some factors related to the IKS context also greatly influence the efficiency of IKS in megaprojects. *First of all*, the project's temporary nature makes the largest difference between corporate organizations and MSOs as projects are often short-term oriented and have a beginning and an end, causing the liquidity and instability of MSOs (Ren et al., 2018; Sun et al., 2019). Undoubtedly, the project's temporariness does not help the formation of channels for IKS. *Similarly*, project time constraints bring MSOs time pressure to complete project tasks within a specific time (Iftikhar and Lions, 2022). Lack of abundant time would decrease the IKS's willingness (Lim et al., 2015). Different types of project culture cultivate different kinds of organizational behaviors. Organizations in a supportive project culture encouraging reciprocity and value co-creation could play a positive role in enriching the practice of IKS (Abdelwhab Ali et al., 2019).

Besides, proper project incentive mechanisms, including economic rewards (e.g., salary raise and bonus) and non-economic rewards (e.g., reputation, promotion, and honor), were found to take efforts in enhancing the quality and quantity of IKS in megaprojects (Abdelwhab Ali et al., 2019; Decker et al., 2009; Wang and Shi, 2019). Communication infrastructure is another frequently explored factor in prior research. The wide application of social and technical tools, such as blockchain technology (Philsoophian et al., 2022), can help overcome communication barriers, thus enhancing the efficiency of IKS (Balle et al., 2019; He et al., 2023). *Lastly*, market competition also affects the organizational willingness of IKS as a high level of competitive intensity brings knowledge protection (Harmancioglu et al., 2020; Wu, 2012). Gast et al. (2019) unveiled some common strategies for organizations about how to balance knowledge sharing and protection in practice, involving in sharing general and project-specific knowledge while safeguarding core knowledge related to their companies and clients.

2.2.3 IKS network governance in megaprojects

Although imperial studies have verified the benefits of IKS for improving megaproject performance and proposed different approaches to facilitate MSOs' IKS efficiency (Fang et al., 2013; Haas and Hansen, 2005; Iftikhar and Ahola, 2022; Szulanski et al., 2016), it keeps vague about how MSOs maximize their value creation by stakeholder synergy.

2.2.3.1 Value co-creation by stakeholder synergy in project management

Considerable research efforts have been dedicated to comprehending the nature of value and its creation within projects and organizations (Liu et al., 2019; Smyth et al., 2018; Tóth et al., 2018). Due to the distinct characteristics of each project, the definition of value can vary across financial dimensions (such as project worth and investment return), organizational aspects (including impact on organizations), and social considerations (such as influence on society) (Vuorinen and Martinsuo, 2019). Despite the absence of a universally agreed-upon definition, the concept of project value encompasses three fundamental principles. *First*, project value is multifaceted, encompassing various types of values, such as financial or technical values, as well as long-term or short-term values (Fuentes et al., 2019). These diverse values may be sought across projects or within a single project. *Second,* project value is subjectively perceived by stakeholders (Chi et al., 2022). A comprehensive understanding of project value necessitates consideration of different stakeholders' perspectives—defining what value is and for whom—and acknowledgment of specific contexts, such as project types. *Third*, given that projects are value creation vehicles for organizations, the creation of project value should be an integral part of project performance evaluation (Bonamigo et al., 2022; Nudurupati et al., 2015; Zhang et al., 2011). The fundamental concept of project stakeholder management is that the project owner can enhance the likelihood of project success by influencing and forming collaboration relationship with stakeholders, such as suppliers, contractors, consultants, project supervisors, designers, and government entities (Chan and Oppong, 2017).

Numerous scholars have adopted a process perspective to explore the creation of project value in organizations. Some propose a sequential series of steps, including identification, prioritization, formulation, and realization (Breese, 2012), while others concentrate on enhancing practices within specific steps or phases of project value creation. For instance, Zwikael and Meredith (2018) have devised a conceptual framework and scale for evaluating the quality of target benefits. Critical activities promoting project value creation in front-end planning and execution phases have been identified by scholars (Artto et al., 2016; Vuorinen and Martinsuo, 2019). Despite differing research objectives and stakeholder perspectives, these process-oriented studies consistently characterize value creation as a dynamic process involving ongoing interactions among diverse project stakeholders (Smyth et al., 2018). These interactions, involving information, communication, and relations, contribute to establishing the project's scope and expectations in advance and fostering mutual learning throughout the process (Chi et al., 2022; Eriksson et al., 2017a). Such interactions are believed to enhance project value creation. The increasing emphasis on interactions among project stakeholders is reflected in the growing use of the prefix "co"—as in value co-creation—in the literature on project value creation.

Value co-creation theory. According to the literature, co-creation is inherent in service businesses where market offerings (quantity, quality, attributes) are created in the service encounter (Vargo and Lusch, 2004). Value co-creation is typically defined as a process where suppliers and customers create value together (Galvagno and Dalli, 2014; Saha et al., 2022). However, in the context of project and construction management, there are different definitions for value co-creation. for instance, Eriksson et al. (2017a) characterized value co-creation in a construction project as the collaborative practice where various project stakeholders pool and integrate their resources to collectively generate value during the design and production stages. Chi et al. (2022) illustrated that value co-creation in interorganizational projects could be described as an interactive process in which project participating organizations work together and influence each other, combine, and integrate their resources to create opportunities for synergy, interactions to promote joint value-in-use and benefits in different project stages, including monetary and non-monetary value (Chih et al., 2019; Liu et al., 2019).

Recently, the service-dominant logic theory has been employed in the examination of value co-creation within project management. Former conceptualizations of services, in the plural form, regarded services as outputs or supplementary components to the primary production process, such as maintenance or customer service. In this perspective, services were perceived as external to the generation of value outcomes. However, based on the service-dominant logic theory in marketing literature, which defines service as “the application of competencies (knowledge and skills) for the benefit of another entity or the entity itself ” (Ranjan and Read, 2016), value co-creation involves interactive processes throughout the project lifecycle, providing a platform for relevant actors to collaborate and enhance the functionality of value outcomes (Smyth et al., 2018). Chih et al. (2019) utilized the service-dominant logic theory to theorize how value is perceived and jointly created by service providers and clients in professional service projects. Additionally, Fuentes et al. (2019) proposed a definition of value co-creation as a simultaneous, collaborative, and interactive process aimed at enhancing project outcomes by leveraging both static and dynamic resources.

In the marketing, service, and manufacturing industries, a series of antecedent factors were revealed in recent studies influencing the implementation of value co-creation, such as resource complementarity, goal alignment, top-level and operating-level cooperation (Wang et al., 2023), complexity (Ruoslahti, 2020), conflicts, and the process of resolving them (Candel et al., 2021; Mele, 2011), social capital, trust, and shared vision (He et al., 2022), motivation to interact (He et al., 2022), value compatibility, geographical proximity (Bonamigo et al., 2020), AI technology (Leone et al., 2021) and interorganizational network centralization and density (Matinheikki et al., 2016; Zhao et al., 2023), resource scarcity, constant changes and the plurality of actors’ views (Niesten and Stefan, 2019), ideology and inquiry (Kier et al., 2023), reputation, creativity, flexibility, and negotiation (Pera et al., 2016). Extant research illustrated the process of value co-creation involves dialogue, access, risk assessment, and transparency (Xu et al., 2022), open communication, joint problem solving, and end-user involvement (Sjödin, 2019), coordination, consultation, and compromise (Reypens et al., 2016), co-ideation, co-valuation, and co-diagnosing, co-testing, co-design, co-launching co-solving problems, co-learning with internal and external stakeholders, co-developing a service with agility, and embedding (Fuentes et al., 2019; Marcos-Cuevas et al., 2016).

Besides, in the project and megaproject context, extant studies also explored what value co-creation is and how to realize value co-creation, as shown in Table 2.7. For example, Liu et al. (2019) explored stakeholder engagement in co-creation sessions at the front end of a Dutch infrastructure development program through a qualitative action research approach and found three-dimensional value co-creation in megaprojects: commercial value-in-use (including awareness of future work opportunities, understanding of each other's interests, and exchanging knowledge), intellectual value-in-use (including complementary to each other, increased mutual understanding, and continuation of advancing knowledge), and collaborative value-in-use (including increasing mutual trust and reassembling of partners in innovative networks). The dynamism of value co-creation was also considered as Takahashi and Takahashi (2022) characterized three phases of dynamic evolution in stakeholder relationships for value co-creation, including formation, strengthening, and integration. Some antecedents were identified and verified, such as relational engagement, collaboration, and innovativeness (Heredia Rojas et al., 2018), shared vision, requirements risk and dysfunctional competition (Chi et al., 2022), lack of competence, contractual incentives and trust (Eriksson et al., 2017a). Good implementation of value co-creation was revealed, promoting the project's success, innovativeness (Chang et al., 2013; Heredia Rojas et al., 2018), and satisfaction of the project's stakeholders (Asiedu and Iddris, 2022).

Table 2.7 Empirical studies on value co-creation in the project contexts

No	Reference	Industries	Methods	Empirical results
1	(Chang et al., 2013)	Infrastructure megaproject	Qualitative research through interview	• Values are subjective and dynamic; • Value needs to be "co-created" by engaging stakeholders in continuous value creation and capture process.
2	(Liu et al., 2014)	Infrastructure megaproject	Qualitative single case study	• Early contractor involvement promotes value co-creation; • The change in the client's attitudes promotes value co-creation.
3	(Näsholm and Blomquist, 2015)	European Capital of Culture program	Case study research	• Co-creation allows for creative cultural projects to emerge, but the program becomes reliant on the different actors involved. • Balancing dilemmas of multiple stakeholders and maintaining control while enabling the emergence of ideas is key
4	(Eriksson et al., 2017a)	Large construction projects.	Qualitative case study	• Proactive joint development • Reactive Join-problem solving • Lack of competence hinders co-creation • Lack of contractual incentives hinders co-creation • Lack of trust hinders co-creation
5	(Smyth et al., 2018)	Infrastructure megaproject	Qualitative case study	• Long-term value is overlooked in the decision-making process at the front-end; • Short-term value is highlighted: time-cost-quality/ scope.
6	(Heredia Rojas et al., 2018)	Construction project	PLS-SEM	• Value co-creation process underpinned through relational engagement, collaboration, and innovativeness positively influences project performance • Project's requirements uncertainty moderates the relationship
7	(Liu et al., 2019)	Infrastructure development program	Qualitative action research approach	• Commercial value-in-use: Awareness of future work opportunities, Understanding of each other's interests, Exchanging knowledge • Intellectual value-in-use: Complementary to each other, Increased mutual understanding, Continuation of advancing knowledge • Collaborative value-in-use: Increasing mutual trust, Reassembling partners in innovative networks

No	Reference	Industries	Methods	Empirical results
8	(Fuentes et al., 2019)	Public sector	Qualitative case study	• Eight managerial value interactions, • Five value outcomes from a client perspective in the medium- and long-term
9	(Chih et al., 2019)	Professional service projects	Qualitative interviews and quantitative surveys	• Highlight the importance of reciprocal interactions between service providers and their clients in co-creating value; • Service providers' professional knowledge and competence and the clients' levels of professional knowledge and motivation influence their interactions.
10	(Chi et al., 2022)	Infrastructure megaproject	PLS-SEM	• Shared vision can improve value co-creation, and its influence is moderated by requirements risk and dysfunctional competition; • For main contractors, requirements risk strengthens the positive effect of shared vision and value co-creation, whereas dysfunctional competition mitigates it. • For clients, dysfunctional competition attenuates this relationship, while requirements risk exerts no significant moderating effect.
11	(Asiedu and Iddris, 2022)	Construction projects	PLS-SEM	• Value-co-creation promotes stakeholder satisfaction and project success; • Project success mediates the relationship.
12	(Toukola et al., 2023)	Urban development projects	Qualitative case study	The co-creation of value by public and private actors in the front end of urban development projects includes four steps: • Zoning. Creation of requirements and standards for possible projects • Exploring. Exploring the feasibility of projects • Procuring. Procurement of possible project partners • Negotiating. Reaching a common understanding before proceeding to the next project phase
13	(Takahashi and Takahashi, 2022)	Consulting projects	Qualitative narrative literature review	• Evolution in the relationships among stakeholders: formation, strengthening, and integration; • Evolution in value capture: sharing of perceptions, ideas and experiences, self-reflection, and vision and solution.

Collaborative advantage. Classic literature on supply chain and operations management suggests that supply chain collaboration is grounded in the paradigm of collaborative advantage (Dyer and Singh, 1998; Kanter, 1994; Lasker et al., 2001). According to this collaborative paradigm, a supply chain is conceived as a sequence or network of interdependent relationships fostered through strategic alliances and collaboration (Cao and Zhang, 2013, 2011). Collaborative advantage within the supply chain denotes the strategic advantages obtained over competitors in the market by engaging in partnerships and facilitating knowledge creation through collaboration with partners where these synergistic benefits are unattainable through independent actions (Lasker et al., 2001; Seo et al., 2016; Teng, 2003; Xin et al., 2023). In the context of collaborative advantage, relational rents are derived, resulting in mutual benefits from cooperative rent-seeking behaviors. This stands in contrast to competitive advantage, which promotes individual rent-seeking behaviors aimed at maximizing an organization's own benefits (Cao and Zhang, 2010). The concept of collaborative advantage allows partners to perceive collaboration as a positive-sum game, in contrast to a zero-sum game. This perspective encourages a cooperative approach, emphasizing mutual benefits and shared value creation.

The literature on supply chain collaboration encompasses various perspectives, as shown in Table 2.8, reflecting the complex dynamics and multifaceted nature of collaborative endeavors within supply chains (Camarinha-Matos and Abreu, 2007; Deken et al., 2018; Verweij and Satheesh, 2023). The research conceptualizes supply chain collaborative advantage as the five dimensions, including process efficiency, offering flexibility, business synergy, quality, and innovation (Cao and Zhang, 2011, 2010). Collaborative advantage and firm performance are positively influenced by supply chain collaboration, where collaborative advantage serves as an intermediate variable facilitating synergies and contributing to superior performance among supply chain partners (Cao and Zhang, 2011; Liu et al., 2023; Seo et al., 2016; Um and Kim, 2019).

Table 2.8 Empirical studies on collaborative advantage

No	Reference	Methods	Research aim	Empirical results
1	(Cao and Zhang, 2010)	Structured interview and Q-sort	Uncover the nature and characteristics of supply chain collaborative advantage	The research conceptualizes supply chain collaborative advantage as the five dimensions: • Process efficiency, • Offering flexibility, • Business synergy, • Quality • Innovation.
2	(Cao and Zhang, 2011)	PLS-SEM	Uncover the nature of supply chain collaboration and explore its impact on firm performance based on a paradigm of collaborative advantage	• Supply chain collaboration improves collaborative advantage and indeed has a bottom-line influence on firm performance, • Collaborative advantage is an intermediate variable that enables supply chain partners to achieve synergies and create superior performance.
3	(Vangen and Huxham, 2003)	Qualitative action research	Investigate how leadership influences collaboration activity to enable collaborative advantage	• The main categories of activities split into two opposing perspectives on leadership. • Collaborative leadership involves the management of a tension between ideology and pragmatism.
4	(Liu et al., 2023)	PLS-SEM	Explored how supply chain collaboration can enhance firm performance and the roles of collaborative advantage and government subsidies in that process	• Supply chain collaboration is fundamental in shaping collaborative advantage and firm performance, while collaborative advantage is crucial in enhancing firm performance • Government support in the form of subsidies acts as a catalyst, further enhancing the positive outcomes of supply chain collaboration and ultimately benefiting firm performance

No	Reference	Methods	Research aim	Empirical results
5	(Lasker et al., 2001)	Conceptual research	Explore how to realize partnership synergy to strengthen the collaborative advantage	Determinants of Partnership Synergy: • Resources; • Partner characteristics • Relationships among partners • Partnership characteristics • External environment
6	(Camarinha-Matos and Abreu, 2007)	Game theory	Measure the benefits of collaboration and effects on enhancing collaborative advantage	• Share costs • Share risks • Decrease the dependence level in relation to third-party • Increase the innovation capacity • Defend a position in the market • Increase flexibility • Increase agility • Increase specialization • Establish proper regulations • Share social responsibilities
7	(Um and Kim, 2019)	Hierarchical regression analysis	Identify underlying factors that constitute collaboration and transaction cost advantage	• Supply chain collaboration leads to better firm performance and transaction cost advantage • Firm performance with contractual governance yields a better transaction cost advantage
8	(Paulraj et al., 2008)	SEM	Investigate the antecedents and performance outcomes of inter-organizational communication	• A long-term relationship orientation can increase collaborative communication between supply chain partners; • Network governance fosters inter-organizational communication, leading to sustainable competitive advantage for supply chain partners.
9	(Seo et al., 2016)	SEM	Investigate the association between SCC, collaborative advantage, and port performance in a maritime logistics context.	• Supply chain collaboration positively impacts collaborative advantage, which in turn helps improve port performance. • Collaborative advantage has a full mediation effect on the link supply chain collaboration-port performance.

Stakeholder power. From the supply chain and operation management, the project is a typical carrier where project organizations need to collaborate with each other to reach a common goal (e.g., jointly delivering a successful project). Besides, the distribution of resources among different organizations is rarely uniform, leading to an uneven collaborative advantage (Cao and Zhang, 2013, 2011). The uneven distribution of resources and collaborative advantage can influence others' decision-making processes, the direction of the whole project, and relationships among its members (Ninan et al., 2020), which could be measured by power (Bridoux and Vishwanathan, 2020). The power an organization holds over another arises from its dependence on the other to access resources necessary for achieving specific outcomes.

Various types of power are rooted in different resources of an organization (Roome and Wijen, 2006). For example, operational power is associated with the ability to influence the implementation (or non-implementation) of decisions, execute or obstruct actions. Informational power arises from possessing valuable knowledge that other organizations lack. This type of power is derived from organization members being experts in a specific domain or having access to critical information. Economic power is closely tied to financial or other economic resources. Organizations with control over financial assets, budgets, or economic resources wield this kind of power. Social power is rooted in the influence of social norms, values, respect, influence, and relationships.

Extant research supports a positive association between the absolute power of external stakeholders and organizational performance (Michalski et al., 2018, 2017). Moreover, the organization's perceptions of the relative importance of different stakeholders in influencing their organizational performance vary considerably (Michalski et al., 2017). As the power of external stakeholders is not uniform, organizations adopt diverse strategies to address these stakeholders, categorized as reactive, defensive, accommodative, and proactive (Walker and Laplume, 2014), or threats, punishment, rewards, and assistance (Cao and Zhang, 2013).

Stakeholder synergy. Project organizations must recognize and manage their collaborative advantage and power to ensure fairness and effective collaboration (Bridoux and Vishwanathan, 2020). In theories that revolve around the creation and distribution of value-driven by power dynamics, it's often the case that when one stakeholder gains, it typically implies losses for another stakeholder (Cao and Zhang, 2011; Frooman, 1999). This zero-sum perspective suggests that the benefits accrued by one party come at the expense of another (Hendry, 2005; Liu et al., 2007). However, from an alternative reciprocity viewpoint, it's possible to establish win-win relationships wherein the value distributed to one group of stakeholders can simultaneously enhance the well-being or utility of another group (Ninan et al., 2020; Roome and Wijen, 2006). This approach highlights the potential for creating positive value within the stakeholder network rather than focusing solely on the downside risks associated with powerful stakeholders appropriating value from others. In essence, this perspective encourages a more cooperative and equitable approach to value creation and distribution, where stakeholders collaborate to maximize overall value rather than engaging in a competitive struggle for a limited share of the pie. It underscores the potential for synergy and mutual benefit within the stakeholder ecosystem rather than the downside risks of value appropriation by powerful stakeholders (Jotaworn and Nitivattananon, 2023; Loban et al., 2021; Tapaninaho and Heikkinen, 2022). Tantalo and Priem (2016) label this phenomenon as stakeholder synergy.

Synergy is the idea of two organizations working together while preserving existing characteristics and behaviors to make the ultimate impact greater. A synergistic approach to value distribution increases the size of the value "pie" available for important stakeholders, increasing their willingness to stay and contribute to the firm's value creation system because they understand the complementarity of their contributions to the firm. Tantalo and Priem (2016) developed the "stakeholder synergy" perspective to identify new value creation opportunities where a single strategic action could simultaneously increase different types of value for two or more essential stakeholder groups and does not reduce the value already received by any other essential stakeholder group. These arguments change the focus from value distribution decisions emphasizing bargaining power criteria to decisions that place more weight on stakeholders' ability to contribute to total value creation (Feng et al., 2013; Lindsey et al., 2021; Loban et al., 2021; McGahan, 2021; Zvaigzne et al., 2023).

2.2.3.2 IKS governance by value co-creation in megaprojects

Building upon the literature review, value co-creation in megaprojects can be defined as an interactional creation process across stages of megaprojects, from design to delivery, prompting stakeholders to produce valued outcomes that all participating stakeholders find beneficial through their resource sharing and effective interactions (Chi et al., 2022). Specifically, two features of value co-creation in megaprojects could be summarized. *First*, value is realized in its use, signifying that the specific value derived depends on the involved stakeholders (Eriksson et al., 2017a; Fuentes et al., 2019; Vuorinen and Martinsuo, 2019). In value co-creation within megaprojects, a diverse array of stakeholders plays integral roles, encompassing owners, contractors, designers, consultants, suppliers, government entities, and others. For instance, the value co-creation of the owner pertains to the participatory actions that enhance project value, focusing on the value-in-use contributing to the overall project's success. On the other hand, the value co-creation of contractors involves their active participation in the co-creation process to obtain both monetary and non-monetary values, such as increased revenue, bolstered reputation, and enhanced collaborative advantages. These contributions contribute to the overall success of the megaproject. *Second*, the concept of value in megaprojects is subjectively perceived and multifaceted (Chih et al., 2019; Toukola et al., 2023). Stakeholders perceive the derived value differently due to their diverse (and often conflicting) interests and goals (Bahadorestani et al., 2020). For instance, the client focuses on the megaproject fulfilling its overall functional promises, while main contractors prioritize the profit incentive and monetary value of their services. *Third,* the service-dominant logic theory conceptualizes co-creation as a process (Näsholm and Blomquist, 2015). Value co-creation is described as an interactive process where stakeholders collaborate and influence each other, creating opportunities for synergy and transcending conventional "production", "exchange", and "use" activities. In essence, the process involves interactions and joint action among various stakeholders across stages, leveraging their distinct knowledge sets, which constitute the core of co-creation in megaprojects. This implies that the outcome of a co-creation process is the creation of something tangible, namely value in megaprojects.

Megaprojects provide great organization and technology platforms for value co-creation, especially in knowledge management (Lehtinen et al., 2019). Studying the governance of knowledge sharing, a key part of knowledge management, at the cross-organizational level continues to be among the most relevant topics in organization and management studies (Roehrich et al., 2020). Bonamigo et al. (2021) identified four subsequent knowledge management strategies for value co-creation in industries, including the adoption of information systems, external knowledge acquisition, social interaction among actors, and participation of knowledge intermediaries. Zhang et al. (2023) identified three processes of knowledge co-creation and found that organizations engage their stakeholders in knowledge sharing by building and maintaining trust, knowledge integration process through the owner's openness, and knowledge application process by mutual learning. Kazadi et al. (2016) proposed four stakeholder co-creation capabilities for generating valuable knowledge: networking capability, competence mapping, relational capability, and knowledge management capability.

Value-focused thinking and *network-based perspective* could be used to understand this relationship to realize value co-creation. The concept of value is widely utilized across various fields, from psychology to project management (Gray et al., 2020). In the context of the relationship between a project and its stakeholders, values are characterized as attributes that hold significance for both the project and the stakeholders (Bahadorestani et al., 2020). In contemporary project management, the value paradigm has transitioned from solely managing value creation from an individual perspective to understanding how stakeholders co-create value from a network perspective (Jin et al., 2022; Saha et al., 2022; Shi et al., 2023). It shows a vital shift from underscoring the importance of imposing value judgments on single stakeholder priorities to appreciating the total value co-creation by all stakeholders and forming synergy among them.

Table 2.9 Definition of relevant constructs

	Constructs	Definition	References
Value-focused thinking	Business value	Benefits for gaining tangible, valuable returns and meeting a business need.	Roehrich et al. (2020), Shaheen and Azadegan (2020), and Cropper et al. (2008)
	Social value	Benefits for gaining intangible valuable return, such as perceiving psychological satisfaction.	
network-based perspective	Restricted exchange	Dyadic and direct exchange between two organizations (e.g., A→B→A).	Zheng et al. (2021), Roehrich et al. (2020), Clark and Aragón (2013), and Shaheen and Azadegan (2020)
	Generalized exchange	Multiple and indirect exchanges among at least three organizations (e.g., A→B→C→A).	

First, by referring to *value-focused thinking* (Gaimon and Ramachandran, 2021; Vuorinen and Martinsuo, 2019; Zheng et al., 2021), a KVF through the inter-organizational interaction is, therefore, understood to indicate "*whether a specific need of one project participating stakeholder is met or whether the potential benefit has been obtained from another stakeholder during the IKS process*". Moreover, value is a multi-dimensional and relatively subjective concept (Sánchez-Fernández and Iniesta-Bonillo, 2007), as shown in Table 2.9. Business value usually relates to tangible benefit return embedding in goods, capital, and services, while social value usually relates to intangible benefits return, such as obtaining tacit experience, support, satisfaction, and approval (Gaimon and Ramachandran, 2021; Narasimhan et al., 2009). In the realm of projects, discussions of value refer to various outputs, outcomes, and impacts for delivering projects involving both business and social aspects (Control et al., 2008). Extant research describes social and business value as *satisfaction with the exchange process of receiving resources* (Griffith et al., 2006; Narasimhan et al., 2009) and *the importance of the resource for meeting a need* (Edwards, 1977). Furthermore, the value could be quantified by the *utility* through the lens of neoclassical economics, which is a comprehensive and aggregated indicator to assess the level of each kind of value by the recipient stakeholder (Kahneman and Thaler, 2006; Sampson, 2015).

Second, inter-organizational projects face arduous governance challenges to coordinate interactive value co-creation deriving from inter-organizational behaviors (e.g., IKS) (Gil et al., 2021) from the *network-based* view (Bridoux and Stoelhorst, 2022). Projects pervade organizations (Maylor et al., 2018; Zerjav, 2021). The inter-organizational projects manifest as a network of several organizations (Cropper et al., 2008). Several large industries (e.g., construction and information technology) typically function through inter-organizational projects involving temporary organizational networks (Oliveira and Lumineau, 2017). From the *network-based* view, as shown in Table 2.9, not only direct dyadic exchanges between two stakeholders, which are also defined as *restricted exchanges*, should be considered (Das and Teng, 2002), but also indirect multiple exchanges among more stakeholders, which are conceptualized as *generalized exchanges*, also deserve attention (Caldwell et al., 2017). The importance of *generalized exchanges* is even more pronounced due to the prevalence of indirect approaches in the network, where one stakeholder repays the favor gained from another to a third stakeholder in the network. However, the theoretical underpinnings of twofold exchanges in delivering projects have remained unexplored (Roehrich et al., 2020), particularly in the megaproject context with massive stakeholders.

2.2.3.3 Stakeholder synergy among MSOs for IKS

As introduced before, power is usually used to describe one organization's capability to influence the objectives and strategy-making of others in an inter-organizational network (Ackermann and Eden 2011; McGahan 2021; Wu 2013). An organization's power in occupying knowledge resources could be formed in two aspects. First, an organization with essential knowledge resources that others need has a high level of power (i.e., *value advantages*) (Boaventura et al., 2020; Savage et al., 1991). For example, a consultant provides essential knowledge to support contractors in solving key technical challenges. Second, an organization's position in a network of KVFs (e.g., in the center) also has greater power (i.e., *flow advantages*) (Boaventura et al., 2020; Rowley, 1997). For example, the contractor acts as a knowledge-flow hub, bringing together the knowledge of others such as the owner, designers, and government in megaprojects.

A win-win inter-organizational *synergy* could be reached for governing IKS in megaprojects, highlighting the upside value creation of the whole inter-organizational network instead of the downside value appropriation by powerful stakeholders (Garcia-Castro and Aguilera, 2015). Powerful stakeholders could also keep their willingness to stay and contribute to the value of the network as a whole, as they could benefit more from a bigger value "pie" in the synergy situation (Tantalo and Priem, 2016). These arguments change the focus from bargaining one organization's power to inter-organizational cooperation and power complementarity to contribute to the overall value (Bosse and Coughlan, 2016).

2.2.4 IKS and innovation capability enhancement in megaprojects

Considering the heterogeneity of knowledge, different MSOs have different resource reserves and knowledge interaction needs, which provides an opportunity for IKS based on project cooperation networks (Routhe et al., 2021). That valuable knowledge or experience could greatly improve the overall innovation capability and decision-making efficiency to cope with challenges and problems in the current megaprojects. According to the knowledge-based theory, effective IKS is an important guarantee and prerequisite for megaproject innovations and innovation capability enhancement of MSOs (Zhou et al., 2022).

2.2.4.1 Knowledge-Based Theory

To address the enduring question in business: how an organization can achieve greater profitability, improve its efficiency, or attain sustainable competitive and collaborative advantage through a scientific management approach or a systems approach, Wenerfelt (1984) initially defined resource as "a strength or weakness of a given organization", and originally introduced the Resource-Based View (RBV) as a framework for assessing an organizational strategic positioning with its competitors, specifically concerning markets and products. RBV emphasizes that differences in organizational performance stem primarily from the heterogeneity of resources held or accessible by an organization (Barney, 1991). In simpler terms, RBV underscores the importance of variations among organizations regarding the resources they possess and their ability to creatively manage and utilize these resources to exploit environmental opportunities (Pereira and Bamel, 2021). Organizations possessing resource heterogeneity and the competence to innovatively manage these resources are more likely to gain a competitive advantage (Martin and Javalgi, 2019; Nickerson and Zenger, 2004; Paiva et al., 2008). Barney (1991) identified three categories of strategic resources that enhance organizational competitiveness: physical capital resources, human capital resources, and organizational capital resources.

Knowledge stands out as a crucial factor of strategic resources influencing long-term organizational performance (Martin and Javalgi, 2019). Grant (1996, 2006) suggests that knowledge encompasses elements like transferability, aggregation capacity, and appropriability. The transferability of knowledge within an organization is a key determinant of its competitive advantage. The efficiency of knowledge transfer largely relies on its potential for aggregation. Appropriation of knowledge can be understood as the resource owner's ability to derive returns from the knowledge resource. These three aspects provide a rationale for regarding knowledge as a strategic resource for organizations, which gave rise to the development of the Knowledge-Based View (KBV), as proposed by Grant (1996, 2006). Hence, the KBV can be seen as an outgrowth of the RBV, expanding the range of resources within an organization to encompass knowledge-based resources. These knowledge-based resources, which consist of organization-specific knowledge, are primarily cultivated internally or within the organizational boundaries, making them challenging for competitors to replicate or imitate. Consequently, they serve as a foundation for sustainable differentiation. KBV puts forth the idea that a diverse knowledge base and capabilities, which are an organization's intangible assets, are the principal determinants of organizational performance in a knowledge-based economy. Grant (1996, 2006) characterizes organizational knowledge as the "preeminent productive resource of strategic significance." KBV posits that an organization can establish and maintain a competitive advantage as long as it has the capacity to "access and integrate the specialized knowledge of its members".

Scholars have explored how to enhance organizational competitive advantage from the perspectives of KBV in various contexts. For instance, Herden (2020) contributes to this body of research by presenting a theory-based explanation for establishing sustainable competitive advantage through the fusion of organizational knowledge and the application of analytics to generate solutions and make decisions. Similarly, Kong et al. (2020) adopted the KBV within the context of a green supply chain initiative aimed at achieving innovations in both green product development and green processes. Their findings support the idea that knowledge creation plays a crucial role in forming an organizational ability to innovate and sustain its operations.

Expanding the field of innovation management within the RBV and KBV framework, Costello and Donnellan (2011) introduced the innovation-based view as an emerging theory. Innovation capability encompasses an organization's ability to create novel products, resources, operations, and systems, enabling it to adapt effectively to evolving markets, technology, and environmental conditions, ultimately leading to the establishment of a sustainable competitive advantage (Aas and Breunig, 2017; Le and Lei, 2019; Saunila and Ukko, 2012). Historically, research has segmented innovation into various categories, including exploitative and exploratory innovation (Yi et al., 2019), technical, product, process, and managerial innovation (H. Chen et al., 2021; Liao et al., 2007; Najafi-Tavani et al., 2018), as well as radical and incremental innovation (Berry, 2018; Harmancioglu et al., 2020; Worsnop et al., 2016).

According to the KBV, previous studies contend that both internal and external knowledge serves as critical primary sources of innovation capability and competitive advantage for organizations (Chang and Lee, 2008; Figueiredo et al., 2020; Lei et al., 2020; Liao et al., 2007; Sáenz et al., 2012, 2009; Yao et al., 2020). Specifically, an organization's ability to innovate is intricately tied to its internal competencies, which encompass its knowledge base, operational and technical foundations, and its proficiency in acquiring, assimilating, promoting, and leveraging knowledge generated within the organization (Martinez-Conesa et al., 2017; Obeso et al., 2020; Shehzad et al., 2022). Besides, the organization's interactions with its external environment, which involve internal and external knowledge, significantly shape its innovation capabilities (Migdadi, 2022; Shehzad et al., 2022). Following the "Scenario-Process-Outcome" framework based on the knowledge-based theory, this section elaborates on a comprehensive literature review on IKS and innovation capability enhancement in megaprojects

2.2.4.2 VUCA scenarios of IKS in megaprojects

IKS is one of the core strategies for MSOs to gain sustainable competitive advantage from external organizations to better adapt to the context in which it is embedded. Therefore, IKS is situational: different scenarios will trigger different organizational strategies and bring different effects. The “new normal” of VUCA scenario features presents new challenges for IKS (Cousins, 2018; Gao et al., 2021). Adapting to the “new normal requires a deep grasp of the characteristics of VUCA. MSOs urgently need to improve their ability to creatively foresee and solve problems through IKS to survive in an uncertain situation and even use this as a lever to leverage future development. Existing research on IKS and innovation generally examine the challenges posed by VUCA from a whole perspective but do not distinguish the characteristics of the four aspects of VUCA in detail (Cousins, 2018; Wang et al., 2021).

2.2.4.3 IKS process in megaprojects

IKS is a process in which subjects in an organization change their cognition and behavior, enhancing the organization’s competitive advantage and innovation capability. According to the difference in goal design, IKS can be divided into two aspects: *IKS in tactic* and *IKS in operation*.

First, *IKS in tactic* refers to a process in which an organization thinks and examines development vision, goals, and values, refines regular knowledge, and forms a strategic interpretation mechanism and development path planning (Crupi et al., 2020). MSOs should not only reflect on existing knowledge, which is the starting point for formulating organizational strategies, but also cultivate their intuition and insight into opportunities and threats in the external environment (Zhang et al., 2020). *IKS in tactic* will help MSOs generate richer knowledge, form an overall plan and guide, and reduce understanding ambiguity (Jackson et al., 2020; Yun et al., 2020). The successful delivery of megaprojects must remove obstacles at the cognitive level and build a clear vision and goals through *IKS in tactics.* The owner especially plays a special role in this aspect as an “architect”, forms a forward-looking development plan, designs the overall organizational system, coordinates the actions of other MSOs through goal setting, and then promotes the development of the entire organizational system (Liu et al., 2022).

Second, on the contrary, *IKS in operation* denotes a process in which an organization refines technical and management knowledge related to specific operational processes and details and helps MSOs improve operational efficiency, improve product quality, and reduce costs and risks through the construction of an integrated and standardized practice system (Al-Busaidi and Olfman, 2017; Balle et al., 2019; Wanberg et al., 2017). MSOs should also emphasize the coordination and combination of knowledge resources, which helps to reduce conflicts and differences in complex systems, and the process of solidifying organizational best practices and promoting the optimization and dissemination of organizational practices. The successful delivery of megaprojects requires the removal of barriers at the business and operation level and the formation of standard systems and best practices by integrating and solidifying practical knowledge of business processes and operational details (Eriksson et al., 2017a; Liu et al., 2021; Zheng et al., 2017). To sum up, the perspective of “*IKS in tactic vs. IKS in operation*” is helpful for a comprehensive understanding of the IKS process under the VUCA scenario.

2.2.4.4 IKS for enhancing innovation capability

Innovation is the process where an organization implements and creates new technologies and ideas by allocating organizational resources (Del Giudice and Della Peruta, 2016). Innovation is closely related to internal organizational resources support and external cooperation (Aggarwal et al., 2020). Innovation capability is a comprehensive concept that is not limited to an organization’s research and product development capabilities but is a comprehensive representation of an organization's creative problem-solving capabilities and system integration capability to better cope with complex changing scenarios (Mazzucchelli et al., 2021; Sáenz et al., 2012; Yao et al., 2020).

Knowledge resource is a key channel for coping with VUCA scenarios and improving innovation capabilities. Existing studies have unveiled two key reasons for the strong correlation between internal knowledge and innovation capability. *First*, internal knowledge is widely accessible, straightforward, less risky, and highly reliable. Although research and development activities are often associated with greater risk due to the higher likelihood of failure at various stages of projects, these endeavors frequently yield new insights that lead to product enhancements (Mao et al., 2016). *Second*, internal sources of knowledge are typically linked to the qualifications and competencies of the workforce. Research in established markets has shown that training programs to expand employees' knowledge and skill sets often result in product innovation (Brockmann et al., 2016).

External knowledge acquisition contributes to innovation capabilities in two primary ways (Shehzad et al., 2022). *First*, innovative products often result from reverse engineering and improvements to existing market items. Developing new products often requires accessing information not accessible within the organization. These unique products require innovative knowledge from external sources (Zhou et al., 2021). *Second*, acquiring knowledge from external sources is preferred because it creates a reservoir of information that can complement or supplement internal sources. MSOs that place a high value on publicly available sources of information tend to engage in more collaborative innovation endeavors (Bacq and Aguilera, 2021; Chen et al., 2018). Knowledge obtained through open-source communities of practices (Fauzi, 2020; Levitt et al., 2011) and collaboration networks (Zhang et al., 2022) can significantly contribute to the development of innovation capabilities

Extant studies specified innovation capability from distinct aspects. For example, Leiringer and Zhang (2021) denoted that innovation capability is related to learning, strategic management, research and development, resource support, manufacturing, marketing, and organizational capability. Stordy et al. (2021) linked innovation capability to the product, process, management, and technological innovation capability. Besides, innovation capability also involves the aspects of the market, institutional, business model, organization, and integration (Cantarelli and Genovese, 2021; Iddris, 2016; Najafi-Tavani et al., 2018; Saunila et al., 2012; Saunila and Ukko, 2012; Zawislak et al., 2012). At present, the dimensional division of innovation capabilities needs to be analyzed and refined in a contextualized manner in conjunction with the IKS practices in megaprojects.

2.2.4.5 The owner's role in megaproject IKS governance

As a typical complex giant project, the traditional innovation model (referring to a single organization) can no longer meet the challenges and needs of megaprojects (Sáenz et al., 2012). MSOs must implement effective IKS to improve innovation capability and achieve project goals (Azadegan et al., 2008; Najafi-Tavani et al., 2018). IKS activities in megaprojects involve owners, designers, contractors, consultants, universities, and scientific research institutions (Idrees et al., 2018; Moon et al., 2022; Qian et al., 2019). The problems and challenges in different project stages require different MSOs to work together to build a megaproject innovation alliance (MIA) with close multi-agent connections, find solutions, and avoid the 'island effect' caused by fragmentation due to professionalization. IKS in megaprojects should be considered from a multi-agent collaborative perspective (Bendoly et al., 2021; Dessaigne and Pardo, 2020; Diriker et al., 2022). Bridoux and Stoelhorst (2022) proposed collaborative models suitable for different situational characteristics, including *Hub-and-spoke, polycentric,* and *shared modes*. Among them, the *Hub-and-spoke mode* emphasizes the overall guiding role of key entities, the *polycentric mode* emphasizes the important driving role of key entities, and the *shared mode* emphasizes the platform support and advocacy role of key entities. The three proposed collaborative modes lay the foundation for exploring the stakeholder synergy of IKS in megaprojects (Bacq and Aguilera, 2021; Tantalo and Priem, 2016). Due to the one-off, unique, and dynamic characteristics of megaprojects, the goals of each MSO are inconsistent with the project's final construction and operation goals. Megaproject owners play the role of architects throughout the project's entire life cycle in the innovation ecosystem and promote different types of innovation (Winch and Leiringer, 2016). Therefore, the relationship between IKS in megaprojects, the improvement of multi-type innovation, and the role of architects played by owners in different project stages need to be further explored.

2.3 Research Gaps

Literature review shows that previous studies have explored IKS in megaprojects from different theoretical and managerial perspectives. There are several research gaps to be filled in this study.

1) Two theoretical gaps in the literature related to existing studies propose various frameworks for knowledge categorization and IKS mechanisms. *Firstly*, there is a lack of an integrated perspective to consolidate and summarize these mechanisms. Drawing on Malhotra et al. (2021), the socio-technical perspective could be employed. Originally constructed by Trist et al. (1963), this perspective aims to understand how social and technological factors influence organizational capability. Within this perspective, IKS mechanisms encompass two aspects: technical mechanisms are designed to optimize processes, tasks, and technologies to facilitate IKS, while social mechanisms focus on developing interorganizational relationships and reinforcing motivations for knowledge sharing. The socio-technical perspective offers a valuable framework for comprehending how different mechanisms are jointly adopted in IKS. *Secondly*, the existing literature has examined how single knowledge characteristics, such as knowledge tacitness or knowledge heterogeneity, influence the selection of IKS mechanisms. However, there is still a lack of clarity on how to effectively match combinations of multiple

knowledge characteristics (e.g., knowledge tacitness and knowledge heterogeneity) with IKS mechanisms. In the complex context of megaprojects, there is an urgent need for empirical research to explore these matching situations in practice (Loebbecke et al., 2016).

2) Concerning the literature review of exploring the antecedents of IKS, overall, previous research has presented certain frameworks for measuring the effects of different antecedent factors on IKS within a project context through qualitative and quantitative methodologies, such as the exploratory single case study approach (Iftikhar and Lions, 2022), meta-analytic review (Van Wijk et al., 2008), system dynamic approach (H. Liu et al., 2020), multi-layer decision-making approach (Amoozad Mahdiraji et al., 2022), set-theoretic approach (Bakker et al., 2011), analytic model and numerical analysis (Ma et al., 2020; Wang and Shi, 2019), and structural equation modeling analysis (Ren et al., 2018). Nonetheless, achieving a high level of IKS efficiency stems from the intricate interplay of numerous elements, necessitating a more comprehensive assessment of cause-and-effect relationships. *Moreover*, the existing models do not fully assess the effects of different antecedent factors under what-if scenarios (Zhou et al., 2022).

3) Each MSO owns a different initial knowledge repository and occupies a different structure position in the IKS network, leading to a unique stakeholder power in the whole IKS network (Bendoly et al., 2021). Based on the value co-creation and stakeholder synergy theory, the benefits of IKS can be achieved or maximized only when it is reciprocally implemented (Tantalo and Priem, 2016). Two main research gaps remain to be filled regarding IKS network governance in megaprojects. *First*, measuring the stakeholder power in the IKS network of megaprojects remains unclear. *Second*, after measuring the different levels of stakeholder power for MSOs, it should be further revealed what internal strategies could be adopted to improve stakeholder power and what external strategies MSOs should adopt to collaborate with others to facilitate stakeholder synergy for value co-creation.

4) Knowledge-based theory posits that MSOs must extract external knowledge resources to establish and maintain their competitive advantages and innovation capabilities through IKS (Herden, 2020; Kong et al., 2020). MSOs usually conduct IKS and form MIA to tackle technological and managerial challenges in the life-cycle project delivery. However, the internal mechanism of how IKS influences the innovation capability of the MIA remains vague. The IKS process of MIA and its effect on MIA's innovation capability of following a "Scenario-Process-Outcome" framework need to be explored. *Besides*, as the captain leading the megaproject delivery, the megaproject owner is essential in guiding MIA in conducting IKS at different project stages (i.e., preliminary, construction, and operation). Further research needs to clarify the owner's dynamic roles.

2.4 Chapter Summary

This chapter conducts a systematic description of the literature on IKS in megaprojects. *First*, organizational behavior and IKS research in megaproject management were reviewed. Basic concepts related to knowledge management in the project context were introduced. Knowledge is distinguished from data and information. Knowledge sharing at different levels was defined in the project context, including individual, team, and inter-organizational levels. *Second*, the literature review focused on the IKS in the megaproject context, including identifying knowledge categorization and IKS mechanisms in prior studies, modeling antecedents of IKS, reviewing network governance of IKS, and exploring the relationship between IKS and innovation capability enhancement. Finally, different knowledge gaps were summarized to provide an overview of the study.

CHAPTER 3 RESEARCH METHODOLOGY

3.1 Introduction

This chapter provides an overview of the research methodology applied in this study. It presents how the researcher systematically designs a study, guarantees valid and reliable results, and fulfills its aims and objectives. Although there is a brief introduction to the research methodology in the first chapter, this chapter aims to describe the research design and methods in more detail.

3.2 Research Design

The research methodology and the flowchart of the entire study have been introduced briefly in section 1.4. This section addresses the research frameworks of each part of the study.

3.2.1 Research Design and Process

This study addresses four major aspects, including the questions to study, the relevance of the data, the data collection methods, and the analyses of the collected data. The research methods are proposed to be conducted via various procedures, generally divided into qualitative, quantitative, or mixed methods. The qualitative methods include the interview, observation, and documented data (texts or images), whereas the quantitative ones feature instrument-based questions that include performance- and attitude-related information that will be further processed through statistical analyses. The mixed methods combine qualitative and quantitative methods, which allow the triangulation of the data sources to determine the convergence of both methods. This research adopted a mixed-method approach, comprising a literature review, semi-structured interviews, questionnaire survey, factor analysis, grounded theory analysis, Bayesian Network (BN) analysis, Stakeholder Value Network (SVN) analysis, and longitudinal case study. Figure 3.1 depicts the specific steps and flow of the research methods.

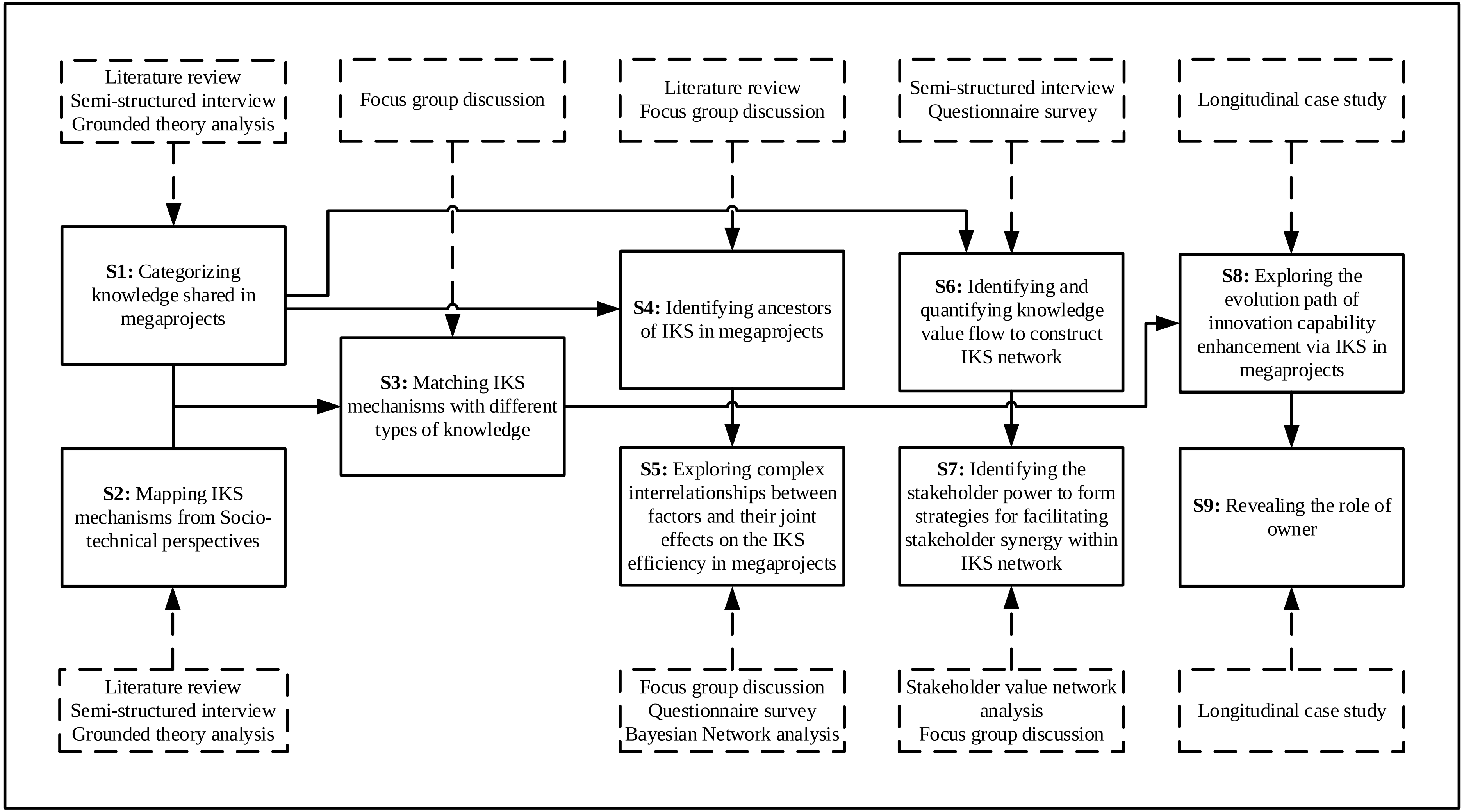


Figure 3.1 The research process and research methodology

Step 1: Categorizing knowledge shared in megaprojects. A comprehensive literature review, including academic publications and project documents, and semi-structured interviews are conducted to collect data to identify knowledge shared in megaprojects. Grounded theory analysis is used to provide an in-depth understanding to categorize knowledge based on different characteristics from extant studies.

Step 2: Mapping IKS mechanisms from Socio-technical perspectives. Simalrly, grounded theory analysis based on data from the literature review and semi-structured interview is employed to identify efficient IKS mechanisms in megaprojects and categorize them from the socio-technical perspective.

Step 3: Matching IKS mechanisms with different types of knowledge. Based on steps 1 and 2, focus group discussions are conducted in this step to form different matching strategies between knowledge characteristics and the identified IKS mechanism. The first research objective is reached by conducting steps 1 to 3.

Step 4: Identifying antecedents of IKS in megaprojects. The main research method in this step includes a literature review and focus group discussion. The factors were identified through a comprehensive literature review. The resulting list was subsequently submitted to experts for validation, a process carried out through focus group discussions.

Step 5: Exploring complex interrelationships between factors and their joint effects on the IKS efficiency in megaprojects. A combination of focus group discussion, questionnaire survey, and Bayesian Network (BN) analysis is used in this step. First, a questionnaire survey is conducted to measure IKS and its antecedents. Expert knowledge from focus group discussions is referred to identify the complex interrelationships between factors. Finally, Bayesian Network (BN) analysis is employed to analyze the joint effects of these factors on the IKS efficiency in megaprojects. The second research objective is reached by conducting steps 4 and 5.

Step 6: Identifying and quantifying knowledge value flows (KVFs) to construct the IKS network. This step uses semi-structured interviews and questionnaire surveys to construct the IKS network in megaprojects, including identifying MSOs (nodes) who participated in megaproject delivery and quantifying the value of IKS among MSOs (links), i.e., KVFs.

Step 7: Identifying the stakeholder power to form strategies for facilitating stakeholder synergy within the IKS network. Stakeholder value network analysis is used in this step to calculate the different types of power for different MSOs. Besides, a focus group discussion is conducted to triangulate the findings. The third research objective is reached by conducting steps 6 and 7.

Step 8: Exploring the evolution path of innovation capability enhancement via IKS in megaprojects. This step is a longitudinal single case study using ground theory analysis based on multi-source data (Glaser and Strauss, 2017), including primary data (e.g., interviews, industry forums, and knowledge Salon minutes) and secondary data (e.g., research reports, internal management documents, monographs, the HZMB project magazine) for cross-validation (Yin, 2009).

Step 9: Revealing the role of the owner in promoting innovation capability enhancement via IKS. Similarly, this step conducts a longitudinal single case study based on the multi-source qualitative data. Lastly, the fourth research objective could be obtained after steps 8 and 9 are finished.

3.2.2 Overview of the research methods

All the research methods applied in this study and the corresponding research objectives are shown in Table 3.1. The data collection methods include literature review, semi-structured interviews, questionnaire survey, and focus group discussion. The data analysis methods include grounded theory analysis, Bayesian Network (BN) analysis, Stakeholder Value Network (SVN) analysis, and longitudinal case study.

Table 3.1 Research objectives and corresponding research methods

	Research objectives	Objective 1	Objective 2	Objective 3	Objective 4
Data collection methods	Literature review (Academic papers and project documents)	√	√	√	√
	Semi-structured interviews	√		√	√
	Questionnaire survey		√	√	
	Focus group discussion	√	√	√	√
Data analysis methods	Grounded theory	√			√
	Bayesian Network (BN) analysis		√		
	Stakeholder Value Network (SVN) analysis			√	
	Case study				√

3.3 Data Collection Methods

3.3.1 Literature review

The literature review provides a solid foundation for developing the knowledge base in a particular research area. The review in this study is not only about reviewing the relevant publications but also identifying critiques and research gaps of the existing works in a particular research area (Yeung, 2007).

3.3.1.1 Review of academic papers

The objectives of the literature review are as follows: (1) to determine the research gaps in the research on IKS in the megaproject context to identify the research problems, (2) to develop an overall research framework for the research problems, (3) to identify knowledge categorization in megaproject and different IKS mechanisms, (4) to identify the potential antecedent factors influencing the efficiency of IKS in megaprojects, (5) to identify the primary MSOs involved in IKS network and potential knowledge value flows (KVFs) among them, (6) to elaborate the definition and construction of innovation capability for MSOs, (7) to provide a basis for conducting interviews and questionnaire survey, and (8) to provide a theoretical foundation for the entire study. The literature reviews are summarised, analyzed, and reported in Chapter 2.

3.3.1.2 Review of practical documents

1) Identify knowledge categorization and IKS mechanisms

I collected project-specific documents for data triangulation and further analysis with the results of semi-structured interviews (Yang et al., 2022). These project documents were comprehensively searched and gathered from public websites and corporate profiles, referring to project and knowledge management in megaprojects, such as the Beijing Daxing International Airport, Hong Kong-Zhuhai-Macao Bridge, Wuhan Metro Line 4, Westbound Media Port Area in Xuhui District, Haiwen Bridge, Shanghai Disney Resort, Shanghai Pudong International Airport. A total of 48 documents were collected after screening out and eliminating the irrelevant files, involving published papers and books on related projects, magazines, internal handbooks, logs, minutes of meetings, and emails among MSOs.

2) Explore the mechanism enhancing innovation capability via IKS

A case study of the Hong Kong-Zhuai-Macau Bridge project was conducted to explore how IKS enhances the MSOs' innovation capability. Following the suggestion put forward by Glaser and Strauss (2017), multi-source data should be integrated, including primary data (e.g., semi-structured interviews, focus group discussion, industry forums, and knowledge Salon minutes) and secondary data (e.g., research reports, internal management documents, monographs, HZMB project magazine) for cross-validation (Yin, 2009), to avoid retrospective sense-making and impression management brought by only primary data analysis (Eisenhardt and Graebner, 2007; Pettigrew, 1990). A series of practical documents regarding knowledge and innovation management of the Hong Kong-Zhuai-Macau Bridge project were collected from September 2019 to May 2020. The detailed data sources are shown in Table 3.2.

Table 3.2 Multi-source data for case study (secondary data part)

Data Sources	Descriptions	Source code
Internal document	Report on Steel Box Girder Manufacturing Technology (2011/07, Japan)	PR01
	Research Report in the US and Canada (2011/09)	PR02
	Report on visiting NCC company in Japan (2012/09, Japan)	PR03
	Report on Bidding for Bridge Deck Pavement Construction (2013/07-08, Turkey, Germany, Switzerland, UK)	PR04
	Report on Bridge Deck Pavement Construction technology (2014/07, Japan)	PR05
	Report on Tunnel Operation Management and Fire Rescue Technology (2015/11, Japan and Korea)	PR06
	Report on Preparation for Operation Management (2015/11-12, Canada and US)	PR07
	Guidelines for Design Technical Specifications in the HZMB Project (2007/08)	PR08
	Salon Compilation I (2014)	PR09
	Salon Compilation II (2016)	PR10
Public document	Book: "China Bridge: The Road to the Dream of the HZMB Project" (Zeng Pingbiao)	PUB01
	Book: "Tiankai Haiyue Approaching the HZMB Project" (Yangtze River)	PUB02
	Book: "Integration and Development: Legal Practice in HZMB project" (Gao Xinglin)	PUB03
	Book: "Bidding Planning and Practice in HZMB project" (Gao Xinglin, Dai Jianbiao, Ruan Minghua)	PUB04
	Book: "Exploration and Practice of Island Tunnel Project Management in HZMB Project" (Lin Ming, Wang Mengjun, Luo Dong, Wang Qing'e)	PUB05
	Book: "Eternal Bridge in Heart: Apocalypse of China's HZMB project" (Yu Jixin)	PUB06
	Book: "A Rainbow over Lingding: the HZMB project" (Zhou Qiang)	PUB07
	Reports original from the official website of the HZMB Project and other media	NR01
	Academic paper related to the project management practices of the HZMB project	AL01
	HZMB Project Magazine (Issue1 - 44, from 2011/03 to 2018/12)	MG01
Industry Forum	The 7th International Forum on Project Management (2018/04/15)	IL01
	The 6th International Forum on Megaprojects (2018/10/25-26)	IL02
Seminars and lecture videos	Spark Project Lecture (Lecture1-18 from 2020/04/18 to 2020/12/19)	IL03
	Seminars in Tongji University (2021/07/25, Title: Project Management Innovation Practice and Thinking in HZMB Project)	IL04

3.3.2 Semi-structured interviews

An interview is a qualitative research method with the primary objective of uncovering the fundamental themes of the real world. It is achieved by recording and analyzing the underlying meanings conveyed by the interviewees in their statements (Bell et al., 2022; Chen et al., 2006; Green and Thorogood, 2018). This approach has gained widespread use in project and knowledge management research (Blake et al., 2020; Liu et al., 2022; Solli-Saether et al., 2015).

Interviews can take on various forms, typically falling into three categories: structured, semi-structured, and unstructured interviews. These structured interviews follow a standardized information-gathering format, with interviewees answering a predetermined set of questions. In contrast, semi-structured interviews provide a framework of open-ended questions, allowing for a degree of flexibility and depth in the responses. Unstructured interviews are characterized by their free-form nature, with interviewees encouraged to express their thoughts and experiences unrestrainedly. In this study, the semi-structured interview method was adopted in different sections, which combines the benefits of a flexible, open-ended framework while maintaining some level of structure, making it a versatile choice for qualitative research in diverse contexts (Invernizzi et al., 2019; Jotaworn and Nitivattananon, 2023; Mamédio and Meyer, 2020; Rodrigues and Lindhard, 2021).

3.3.2.1 Process and criteria for the expert selection

MSOs can be divided into internal and external organizations. In distinguishing between them, the criterion is the presence of a formal contractual relationship between stakeholders and their direct involvement in project implementation and decision-making (Olander and Landin, 2005; Yang and Shen, 2015). To mitigate bias in this study, a survey was conducted on seven crucial types of internal stakeholders. These stakeholders, including the owner, government, consultants, project supervisors, contractors, suppliers, and designers, played pivotal roles in facilitating IKS throughout the project implementation process (Newcombe, 2003; Yu et al., 2017).

Moreover, the selection of interview experts requires careful and objective consideration to ensure the study's validity and the quality of its results, as this process directly influences the outcomes (Tripathy and Eppinger, 2013). Typically, expert selection is guided by the disciplinary expertise relevant to the study's topic. Following a qualitative approach similar to Marshall (1996), this study employed a purposeful sampling technique. The two-step process began by sending official invitation letters to identify potential experts, seeking support from members of the Research Institute of Complex Engineering Management (http://ricem.tongji.edu.cn), which comprises one academician in China, over 30 industry researchers, and more than 50 postgraduates and Ph.D. students specializing in complex project management. Subsequently, these members were asked to nominate qualified practitioners, both within and outside the institute, based on predefined criteria outlined in the invitation letter.

The predefined criteria, outlined to ensure data representativeness, are as follows: 1) Individuals must possess a minimum of 10 years of working experience and a strong understanding of construction megaproject management, along with at least a bachelor's degree. 2) Candidates should have recent hands-on experience in at least one construction megaproject in China. 3) Individuals are required to have expertise in both knowledge management and megaproject management. This criteria-setting phase resulted in the identification of potential candidates for interviews. Subsequently, these targeted interviewees were contacted via email or telephone to gauge their willingness to participate in the study and to determine their availability for interviews. Following the interviews, each participant received a letter of thanks and a souvenir expressing gratitude for their valuable contribution to the study. In total, 63 potential interviewees were contacted, of whom 18 agreed to participate. This group included 3 owners ('O'), 3 consultants ('CS.'), 3 contractors ('C'), 3 project supervisors ('PS.'), 2 government officials ('G'), 2 designers ('D'), and 2 suppliers ('S'). Prior research supports the reliability of conducting 18 interviews, as it is anticipated that little “new” information would emerge from verbatim transcripts after interviewing individuals with such experience (Gao and Low, 2014; Yang et al., 2022).

3.3.2.2 Background information of the respondents

Specific background information of the 18 interviewees is shown in Table 3.3.

Table 3.3 Backgrounds of semi-structured interviewees

No	Roles	Gender	Position	Education background	Work experience	Involved megaprojects	Project location
1	Owner	Male	Project director	Doctor	13	Hong Kong-Zhuhai-Macao Bridge	Southeast China
2	Owner	Male	Department/operation manager	Master	15	Wuhan Metro Line 4	South Central China
3	Owner	Female	Project director	Master	10	Westbound Media Port Area in Xuhui District, Shanghai	East China
4	Consultant	Male	Project director	Doctor	16	Haiwen Bridge	Southeast China
5	Consultant	Male	Project manager	Doctor	10	Shanghai Disney Resort, Shanghai Pudong International Airport	East China
6	Consultant	Male	Professor	Doctor	32	Beijing Daxing International Airport	Northeast China
7	Contractor	Male	Department/operation manager	Master	14	National Exhibition and Convention Center（Shanghai）	East China
8	Contractor	Male	Project manager	Master	14	Zhengzhou Metro Line 2	Northeast China
9	Contractor	Male	Project manager	Master	13	Nanning Wuxu International Airport	Southwest China
10	Project supervisors	Male	Project director	Master	14	Shanghai Expo 2010	East China
11	Project supervisors	Male	Department/operation manager	Doctor	12	Shenzhen Ping'an International Financial Center	Southeast China
12	Project supervisors	Male	Project director	Master	14	Guangshen Expressway	Southeast China
13	Government	Male	Government official	Bachelor	21	Pudong International Airport Expansion	East China
14	Government	Male	Government official	Bachelor	17	Qiushi Expressway	South Central China
15	Designer	Female	Project director	Master	10	Guiyang North Railway Station	Southwest China
16	Designer	Male	Project manager	Doctor	10	Shenzhen Qianhai Cooperation Zone	Southeast China
17	Supplier	Male	Department/operation manager	Master	12	Hong Kong-Zhuhai-Macao Bridge	Southeast China
18	Supplier	Male	Department/operation manager	Master	15	Lanzhou Metro Line 2	Northwest China

3.3.2.3 Framework for semi-structured interviews

In this study, the semi-structured interview method was employed across various sections, with each interview comprising three parts: 1) Basic information inquiry: The initial part focused on gathering basic information about the interviewee, such as their involvement in megaprojects and their roles in megaproject management. Questions like “What megaprojects have they participated in?” and “What roles have they undertaken in megaproject management?” were posed. 2) Review of typical cases. Following the approach proposed by Belvedere et al. (2019), a research protocol method was implemented. Interviewees were asked to identify recent, typical cases where knowledge had been shared across MSOs in their involved projects. Upon a positive response, interviewees were then prompted to answer a series of open questions related to the surveyed topics. 3) Presentation of summarized statements. During the interviews, certain focal interviewees were presented with summarized statements from other participants. This approach, inspired by Nguyen et al. (2023), aimed to stimulate further thinking and elicit additional insights, contributing to the richness of the dataset. Based on this comprehensive framework, semi-structured interviews were conducted to achieve various research objectives, as outlined in Table 3.1, including:

1) Identifying knowledge categorization and IKS mechanisms;

2) Mapping the qualitative IKS network in megaprojects; and

3) Exploring mechanisms that enhance innovation capability through IKS.

The semi-structured interviews commenced in October 2019, concluded in May 2020, and were conducted through face-to-face or online meetings. Each interview, lasting approximately 1 hour, was recorded using a digital audio recorder and subsequently transcribed for further analysis.

1) Identify knowledge categorization and IKS mechanisms through semi-structured interviews

A series of semi-structured interviews with the above 18 experts were conducted to summarize the main knowledge categories and IKS mechanisms in megaprojects and the matching strategies. Typical interview questions were designed as shown in Table 3.4. It began with introductory questions about the knowledge categories and content, then a discussion of IKS mechanisms used in their daily works, and ended with a conclusion or recommendation of the matching strategies between different types of knowledge and IKS mechanisms.

Table 3.4 Questions asked in semi-structured interviews for Objective 1

No	Questions designed for semi-structured interviews
SECTION I: Introductory questions about the knowledge categories and content	
Q1	What kinds of knowledge are you willing to share with (donate to) other stakeholders in your involved projects?
Q2	What knowledge could you usually collect from other stakeholders in your involved projects?
Q3	Could you please give specific examples of interorganizational knowledge sharing in your involved projects?
Q4	What kinds of characteristics do you think this shared knowledge has?
SECTION II: Introductory questions about the IKS mechanisms	
Q5	Do you think your interorganizational knowledge sharing frequency is high in your involved projects? What are the main obstacles do you think impeding its occurrence?
Q6	What interorganizational knowledge sharing tools do you adopt in your involved projects?
Q7	Do you think proper tools are essential for facilitating interorganizational knowledge sharing in your involved projects? Please give some reasons to explain your answers.
SECTION III: Questions about the matching strategies	
Q8	How do you match these mechanisms with the sharing of different categories of knowledge?
Q9	Do you agree that people-related factors like trust, partnership, leadership, and culture are essential for facilitating interorganizational knowledge sharing? Why?
Q10	Do you agree that advanced technologies, such as BIM, VR/AR, and knowledge management systems, are essential for facilitating interorganizational knowledge sharing? Why?
Q11	Do you have more experience or ideas regarding interorganizational knowledge sharing and facilitating mechanisms?

2) Map qualitative IKS network in megaprojects through semi-structured interviews

Another semi-structured interview with the 18 experts was conducted to construct the qualitative IKS network among MSOs. Designed questions were shown in Table 3.5, aiming to introduce the IKS and value creation, involved MSOs, and main knowledge value flows.

Table 3.5 Questions designed in semi-structured interviews for objective 3

No	Questions designed for semi-structured interviews
SECTION I: Introductory questions about the IKS and value creation in megaprojects	
Q1	How do you view the knowledge-intensive characteristic of construction megaprojects?
Q2	Can you give a few examples?
SECTION II: Questions about the involved organizations in megaprojects	
Q3	What organizations do you think are involved in the knowledge-sharing process in your recently involved megaprojects?
Q4	What are the different roles these organizations play in the knowledge-sharing process?
Q5	What is your relationship status with other organizations in the knowledge-sharing process?
SECTION III: Questions about the shared knowledge in megaprojects	
Q6	What kinds of knowledge are frequently shared in your recently involved megaprojects? Please give some examples.
Q7	What benefits have you provided or received from the knowledge-sharing process? Please give some examples.
Q8	How do you evaluate these benefits?

3) Explore the mechanism enhancing innovation capability via IKS through semi-structured interviews

Similarly, the semistructured interview was adopted as an essential part of data collection for the HZMB project longitudinal case study on exploring how IKS enhances the MSOs' innovation capability to avoid retrospective sense-making and impression management brought by only primary data analysis (Eisenhardt and Graebner, 2007; Pettigrew, 1990). Ten senior managers who participated in the delivery of the HZMB project were invited to participate in the semistructured interview, as shown in Table 3.6.

Table 3.6 Backgrounds of the semi-structured interview in the case study

No	Roles	Gender	Position	Education background	Work experience	Involved megaprojects
1	Contractor	Male	Project director	Doctor	35	Hong Kong-Zhuhai-Macao Bridge
2	Owner	Male	Department/operation manager	Doctor	29	
3	Owner	Male	Department/operation manager	Master	30	
4	Consultant	Male	Professor	Doctor	21	
5	Designer	Female	Project manager	Master	17	
6	Consultant	Male	Project director	Master	19	
7	Project supervisor	Male	Project manager	Master	27	
8	Contractor	Male	Project manager	Master	39	
9	Government	Male	Government official	Master	16	
10	Supplier	Male	Department/operation manager	Master	35	

The open questions designed for the semi-structured interview involved four sections, including a description of IKS strategies and scenarios, an explanation of what innovation capability could be improved through IKS, as well as the understanding of the role of the owner (i.e., the Hong Kong-Zhuhai-Macao Bridge Authority) for this process, as shown in Table 3.7.

Table 3.7. Questions designed in semi-structured interviews in the case study

No	Questions designed for semi-structured interviews
SECTION I: Open questions about the IKS scenarios in the Hong Kong-Zhuhai-Macao Bridge project	
Q1	Do you have some experience conducting IKS behaviors in the HZMB project, such as attending seminars, lectures, and regular meetings to donate or collect necessary knowledge from other organizations? Please give specific examples.
Q2	What are the reasons your organizations conduct these kinds of IKS activities?
Q3	What are the biggest challenges you have ever met in the life-cycle delivery of the HZMB project? Do these challenges motivate your IKS behaviors?
SECTION II: Introductory questions about the IKS strategies in the Hong Kong-Zhuhai-Macao Bridge project	
Q4	What kinds of strategies do your organizations follow when you need to conduct IKS and collaborate with other organizations to solve some managerial or technical issues?
Q5	Is there any difference between individuals in your organizations conducting IKS activities, such as an engineer or a project manager?
SECTION III: Questions about the effects of IKS on innovation capability enhancement in the Hong Kong-Zhuhai-Macao Bridge project	
Q6	What do you think of the innovation capability of your organization? As an essential organization in the HZMB project, what kind of innovation capability does your organization need to develop?
Q7	Do you agree that IKS is vital to developing your organization's innovation capability? Please give your reasons.
SECTION IV: Questions about the role of the owner (i.e., the Hong Kong-Zhuhai-Macao Bridge Authority) in different project stages in leading IKS	
Q8	(For experts from the HZMB authority) As the owner, do you encourage IKS in the HZMB project? What efforts have you ever made? Please give some specific examples. (For experts from other MSOs) As an involved organization in the HZMB project, do you agree that the owner is important in facilitating IKS among MSOs? What efforts has the owner ever made? Please give some specific examples.
Q9	Do you agree that the owner plays a different role in diverse project stages in facilitating IKS for enhancing overall innovation capability?

3.3.3 Questionnaire survey

A questionnaire survey is a systematic approach for gathering data from a selected sample population, popularly used in construction, project, and knowledge management research. This approach has several advantages: quantifiability, objectivity, and cost-efficiency (Li et al., 2005). This method allows data to be rapidly collected while ensuring respondent anonymity and analyzed objectively by facilitating statistical analysis. Despite its advantages, it is important to acknowledge the potential drawbacks of the questionnaire survey method, such as the risk of bias and the possibility of a low response rate. However, researchers can overcome these limitations by taking appropriate measures to ensure the sample is representative and reasonably sized (Cavaliere and Lombardi, 2015; Modi and Mabert, 2007; Wang et al., 2019b; Wang and Hou, 2015). This method, with due diligence, offers researchers a valuable opportunity to provide quantitative descriptions of the perceptions and attitudes of the entire study population by examining only a sample of that population (Watson and Hewett, 2006; Xue et al., 2018; M. Zhang et al., 2022). In this study, this method was employed as a fundamental data collection method to

1). Measure the efficiency of IKS and antecedent factors in megaprojects;

2). Measure the identified knowledge value flows among MSOs.

3.3.3.1 Questionnaire development

The adequacy and readability of the designed questionnaire underwent testing through a pilot study involving the participation of five experts. Their valuable feedback was incorporated into the final questionnaire, which comprised two sections.

1) Background Information Section: The first section consisted of questions aimed at gathering respondents' background information, including their organization type (e.g., contractor), position (e.g., project manager), education background (e.g., bachelor’s degree), and years of work experience in megaproject management. Respondents were required to select

one construction megaproject they had recently been involved in, serving as a reference for answering the questionnaire. Additionally, details about the specific megaproject were requested, such as its name, commencement year, and the city where it is located. This background-related information enhances the quality of the data collected in the second section of the questionnaire (Zheng et al., 2017).

2) Evaluation Section: The second section was developed based on the initially identified 23 success criteria and 35 critical factors. To gather professionals' opinions, five-, seven-, and nine-point rating scales were considered. However, for this study, the five-point rating scale was selected due to its advantages in interpreting unambiguous results. In this section, respondents were required to rate each item on a five-point Likert scale (1 = strongly disagree; 2 = disagree; 3 = neutral; 4 = agree; 5 = strongly agree). The five-point Likert scale has been widely used in research on construction project management (Rafique et al., 2018).

Two sets of questionnaires were designed, one to measure the efficiency of IKS in megaprojects and its antecedent factors, and the other to measure the identified knowledge value flows, shown as follows.

1) Measure the efficiency of IKS and antecedent factors in megaprojects.

The designed questionnaire includes two parts. *First*, general information about participants, such as educational background, work experience, position, and organization type participated in megaprojects. Their involved projects, such as Project scale, property, and duration, were also surveyed. *Second*, the efficiency of IKS was measured. The measurement items were adapted from (Ren et al., 2020, 2018), including five items, such as "We enhanced work efficiency by knowledge sharing with other organizations" and "We often share managerial experience and technical expertise with other organizations." All scales used a five-point Likert scale: "1 = disagree, 2= rarely agree, 3= moderately agree, 4=highly agree, and 5 = extremely agree" (Luo et al., 2020). All of the measurements are shown in **Appendix A**.

Besides, 16 identified factors of IKS were measured by adopting extant studies, including tacitness (Guo, 2018), ambiguity (Lawson and Potter, 2012), complexity (Kim et al., 2013), heterogeneity (Guo, 2018), absorptive capacity (Lawson and Potter, 2012), sharing capability (Zhao et al., 2015), reciprocity (Ren et al., 2020), interorganizational trust (Ren et al., 2020), geographical distances (Ren et al., 2020), organizational distance (Hsiao et al., 2017), project temporary nature (Ren et al., 2018), project time constraints (Ren et al., 2020), project culture (Ren et al., 2020), project incentive mechanisms (Wang and Shi, 2019), communication infrastructure (Zhou et al., 2022), and market competition (Harmancioglu et al., 2020). All scales were also measured via a five-point Likert scale.

2) Measure identified knowledge value flows (KVFs)

To measure the utility of each KVF, the attributes of the KVFs were carefully established in questionnaire surveys. Few attributes will impact the model quality, whereas excessive attributes aggregate the burden on data collection and influence the reliability of the data. Previous SVN studies have suggested that using two attributes was suitable (Pereira et al., 2018; Sutherland, 2009). *Satisfaction with the exchange process in receiving resources* and *the importance of the resource for meeting a need* are the most frequently used attributes in utility measurement (Ferreira et al., 2019; Zheng et al., 2019b). In this study, *satisfaction with the IKS process* and *the importance of knowledge for meeting the project needs* were employed to measure each KVF's utility. Specifically, the former item characterized the KVF from the perspective of the business aspect, and the latter characterized the KVF through the lens of the social aspect. The details of the questionnaires are shown in **Appendix B**. Respondents were invited to check whether they could identify each KVF in their recent participated megaproject and, if so, to rate the two indicators, i.e., stakeholder's satisfaction, $U_f(\text{satisfaction})$, and the utility of the source importance meeting a specific need, $U_f(\text{importance})$ on a five-point scale.

3.3.3.2 Process description of the questionnaire surveys

Similarly, the process of the questionnaire surveys and background information of the respondents for the two sets of questionnaires were respectively introduced as follows.

1) Measure the efficiency of IKS and its antecedent factors in megaprojects.

To obtain quantitative data for BN analysis, a questionnaire survey in China was conducted to measure the efficiency of IKS in megaprojects and how the 16 identified factors interconnect to influence IKS. As the author participated in organizing one seminar and one workshop on the topic of "Enhancing project management capability in megaprojects", data was mainly collected by distributing hard copies or an online link and QR code via the Questionnaire Star platform (https://www.wjx.cn/) to the participated experts in the seminar or workshop. Besides, these participants are generally senior managers in companies, so they are asked to invite more qualified respondents to participate in the surveys based on their professional network. Careful control was exercised in selecting the respondents to maintain the representativeness and objectivity of the gathered expert opinions. The respondents were required to have more than five years of work experience in megaprojects and were asked to provide specific information regarding their most recently involved project (He et al., 2023; Luo et al., 2020; Sun et al., 2023).

The questionnaire survey was conducted from January 2023 to May 2023. A total of 359 questionnaires were distributed, and 240 valid questionnaires were ultimately collected, comprising 102 hard copies and 138 online submissions, yielding an effective recovery rate of 66.9%.

The demographic composition of the sample is presented in Table 3.8. The majority of respondents are contractors (20.8%), with a position of project manager (31.7%), holding a bachelor's degree (50.4%), and possessing 6-10 years of work experience (32.9%). The data predominantly originate from megaprojects on the municipal level (32.5%), with a project scale of 1 to 5 billion RMB (34.2%) and a duration between 36 and 60 months (40.0%).

Table 3.8 Demographics of surveyed respondents and involved projects

	Variables	Measurement	Frequency	Percentage
Respondent information	Organization type	Owners	32	13.3%
		Designers	45	18.8%
		Contractors	50	20.8%
		Consultants	44	18.3%
		Project supervisors	39	16.3%
		Suppliers	30	12.5%
	Position	Project manager	76	31.7%
		Department manager	62	25.8%
		Technical director	67	27.9%
		Chief engineer	13	5.4%
		Others	22	9.2%
	Education background	College or below	37	15.4%
		Bachelor	121	50.4%
		Master	63	26.3%
		Doctor	19	7.9%
	Work experience	Below 5 years	75	31.3%
		6-10 years	79	32.9%
		11-15 years	35	14.6%
		16-20 years	32	13.3%
		Above 20 years	19	7.9%
Project information	Project property	National five-year planning project	46	19.2%
		Provincial five-year planning project	55	22.9%
		Municipal planning project	78	32.5%
		Others	61	25.4%
	Project scale	Below ¥1 billion	59	24.60%
		¥1-5 billion	82	34.20%
		¥5-10 billion	58	24.20%
		Above ¥10 billion	41	17.10%
	Project duration	Below 36 months	65	27.1%
		36-60 months	96	40.0%
		Above 60 months	79	32.9%

2) Measure identified knowledge value flows (KVFs)

As the temporal separation between measurements is beneficial for controlling survey biases (Venkatesh et al., 2010), a two-wave survey was used to measure the *satisfaction* and *importance* of each KVF separately. The surveys were conducted between May and September 2020. Invitation letters were distributed to 19 projects in different regions of China (such as Shanghai, Beijing, and Shenzhen), explaining the purpose of the survey and seeking willingness to participate so that respondents who had worked on megaprojects with different characteristics (e.g., project types and geographic locations) were included to improve the sample's representativeness (Wang et al., 2017). Besides, by referring to Zheng et al. (2019), only megaprojects over one billion RMB (Chinese currency) in costs are considered. The selection process of questionnaire respondents was similar to that of selecting interviewees. Briefly speaking, the author sent the questionnaires to the megaproject project managers and asked them to help complete or distribute them to qualified respondents (Arellano et al., 2021). A total of 15 of these 19 were available and willing to participate in the survey.

A 21-day interval was designed between the two-time points (Serban et al., 2015) to counteract recall bias and avoid external environmental influence. The data was also collected by distributing hard copies or an online link and QR code via the Questionnaire Star platform (https://www.wjx.cn/) to the participating experts. 320 respondents that worked in different large inter-organizational construction projects (e.g., different project types and geographic locations) are involved in the survey to improve the sample's representativeness (Wang et al. 2017). In the first round of the survey (T1), 276 valid responses were received (initial response rate of 86%). In T2, the questionnaires were sent only to these 276 respondents, from whom 198 valid responses were ultimately received (see Table 3.9), resulting in a final response rate of 62%. The respondents' average working experience in mega projects was 7.3 years (SD = 3.22). The surveyed respondents included a range of organizations and roles, including owners (20.2%), consultants (19.2%), contractors (11.1%), project supervisors (12.6%), suppliers (13.1%), government officials (10.1%), and designers (13.7%).

Table 3.9 Demographics of surveyed respondents and their involved projects

	Variables	Categories	Number	Percentage
Respondent information	Gender	Male	145	72.1%
		Female	56	27.9%
	Education Background	Doctor	52	25.9%
		Master	99	49.3%
		Bachelor	50	24.9%
	Work experience in megaprojects (Years)	>10	66	32.8%
		5-10	111	55.2%
		<5	24	11.9%
	Position	Project directors	85	42.3%
		Project/team managers	65	32.3%
		Department/operation managers	51	25.4%
	Roles	Owner	35	17.4%
		Contractor	26	12.9%
		Consultant	35	17.4%
		Government	24	11.9%
		Designer	39	19.4%
		Project supervisor	22	10.9%
		Supplier	20	10.0%
Project information	Project region	Southeast China	24	11.9%
		Northeast China	31	15.4%
		East China	49	24.4%
		South Central China	34	16.9%
		Southwest China	36	17.9%
		Northwest China	27	13.4%
	Project type	Transportation hub	21	10.4%
		Road	25	12.4%
		Bridge	32	15.9%
		Tunnel	23	11.4%
		Railway	21	10.4%
		Highway	33	16.4%
		Airport	21	10.4%
		Skyscraper	10	5.0%
		Dam	8	4.0%
		Public Building Projects (such as event facilities)	7	3.5%

In the questionnaire surveys, respondents were asked to evaluate KVFs according to their experience in megaprojects in which they had recently been involved to avoid their preferential selection of most successful experiences (Wang et al., 2017). Therefore, the risk of socially desirable responses that influence respondents' evaluation (Milfont, 2009), was mitigated, and the respondents were more likely to give an objective assessment of KVFs by this means. This survey also adopted three measures to control response bias: anonymity, the promise of confidentiality, and a request for honesty (Nancarrow et al., 2001). *First*, no personal information, including the respondents' names, ages, and addresses, was obtained from the participants (Randall and Fernandes, 1991). *Second*, each respondent was informed of the academic purpose of the research and the confidentiality of the data before the survey was begun. *Third*, each respondent was asked to provide honest and sincere responses to the survey (Phillips and Clancy, 1972).

3.3.4 Focus group discussion

While sociologists and psychologists have employed focus groups for more than half a century, it's only in the past decade that this method has gained widespread popularity in social research. In its most basic form, a focus group constitutes an informal conversation among carefully chosen individuals centered around particular topics (Leung et al., 2014; Okhuysen and Eisenhardt, 2002).

Focus groups involve discussions among participants, with the degree of direction varying, often facilitated by a group moderator. These discussions are typically recorded through audio or video and later transcribed. The collected data are then subjected to typical qualitative analysis methods. Focus groups have been employed in three main ways within research (Rabiee, 2004; Wilkinson, 1998).

1). As an adjunct to other methods. In many instances, focus groups are used in conjunction with other research methods, forming part of a multi-method research design. Often, they complement quantitative research methods and provide a qualitative perspective that enhances the overall research.

2). As a primary research method: In some cases, focus groups are utilized as the primary research method in their own right. This is particularly common when conducting phenomenological research, which aims to explore and understand people's own perspectives and experiences.

3). As participatory action research: Focus groups are also used as a form of participatory action research, intending to empower participants and drive social and political change. In this context, focus groups serve as a means to actively engage participants in the research process and mobilize them toward collective action.

Each way has unique strengths and applications, making focus groups a versatile tool for researchers in various fields, from social science to psychology and beyond. Besides, focus group research can be approached from two distinct epistemological frameworks: essentialist and social constructionist (Rabiee, 2004; Wilkinson, 1998). Each framework holds unique assumptions about the nature of individual ideas and the process of understanding:

1) Essentialist epistemological framework. In an essentialist framework, the assumption is that individuals possess their own personal ideas, opinions, and understandings. Researchers within this paradigm view their role as accessing or eliciting these pre-existing ideas and understandings from individuals. In this context, the particular advantage of focus groups is their capacity to draw out individuals' views comprehensively. Focus group research within an essentialist framework focuses on revealing and capturing what is already inside participants' minds.

2) Social constructionist epistemological framework. In contrast, a social constructionist framework does not rely on the concept of pre-existing ideas and understandings within individuals. Instead, it presupposes that sense-making occurs collectively through social

interactions among people. In this framework, the particular advantage of focus groups lies in their ability to allow researchers to observe how people engage in collective sense-making. This includes how views are collectively constructed, expressed, defended, and sometimes modified within the context of discussions and debates with others. Focus group research within a social constructionist framework focuses on understanding how meaning and understanding are co-constructed in a social context.

The choice between these two epistemological frameworks influences the research focus and objectives, with essentialist perspectives concentrating on individual perspectives and social constructionist perspectives emphasizing the collective nature of meaning-making and understanding within a group context.

Here, the focus group discussion in this study follows the social constructionist epistemological framework by concluding professional views through conscious interactions. The focus group discussion in this study was specifically designed to

1) Explore the matching between IKS categories and IKS mechanisms in megaprojects;

2) Elaborate the interrelationship between antecedents of IKS; and

3) Triangulate the results of identified stakeholder power.

4) Triangulate the results of the case study

3.3.4.1 Background information of the experts in focus group discussion

The processes of the three focus group discussion sets were denoted as follows.

1) Explore the matching between IKS categories and IKS mechanisms

Focus group sessions were conducted to assess and validate the coding results derived from qualitative data obtained through literature review and semi-structured interviews. These sessions, involving 13 participants, were digitally audio recorded and comprised 2 owners, 2 consultants, 2 contractors, 2 project supervisors, 2 government officials, 2 designers, and 1 supplier, as detailed in Table 3.10. All participants possessed over 10 years of work experience in megaproject management, with their recently involved megaprojects also documented. On average, each of the three focus groups lasted 1 hour and 40 minutes. The groups were initially presented with the first-order concepts and subsequently queried about the suitability of the second-order dimensions. This approach allowed the focus groups to deliberate on the aggregated dimensions that emerged from the coding results.

Table 3.10 Profiles of experts who participated in the focus group discussion for objective 1

No	Roles	Position	Work experience	Recently involved megaprojects
1	Owner	Project director	13	Westbound Media Port Area in Xuhui District, Shanghai
2	Owner	Department/operation manager	15	Haiwen Bridge
3	Consultant	Project director	16	Shanghai Disney Resort, Shanghai Pudong International Airport
4	Consultant	Professor	32	Beijing Daxing International Airport
5	Contractor	Department/operation manager	14	National Exhibition and Convention Center （Shanghai）
6	Contractor	Project manager	13	Hong Kong-Zhuhai-Macao Bridge
7	Project supervisors	Department/operation manager	12	Haiwen Bridge
8	Project supervisors	Project director	14	Hong Kong-Zhuhai-Macao Bridge
9	Government	Project director	21	Haiwen Bridge
10	Government	Project manager	17	Hong Kong-Zhuhai-Macao Bridge
11	Designer	Project director	10	Westbound Media Port Area in Xuhui District, Shanghai
12	Designer	Project manager	10	Shenzhen Qianhai Cooperation Zone
13	Supplier	Department/operation manager	15	Hong Kong-Zhuhai-Macao Bridge

2) Elaborate the interrelationship between antecedents of IKS

Seven industry experts and two professors were invited to join the focus group discussion to form an in-depth understanding of the interrelationship between antecedents of IKS in megaprojects. All involved experts had taken different roles in managing or studying megaprojects with more than 10 years of work experience, as shown in Table 3.11. Based on the literature review and focus group discussion with experts, 16 factors of IKS were finally identified to construct the BN model.

Table 3.11 Profiles of experts participated in the focus group discussion for objective 2

NO	Roles	Position	Work experience	Recently involved megaprojects
1	Owner	Project Manager	20	Westbound Media Port Area in Xuhui District, Shanghai
2	Designer	Department Director	17	Shenzhen Qianhai Cooperation Zone
3	Consultant	Professor	18	Shanghai Disney Resort, Shanghai Pudong International Airport
4	Contractor	Site Safety Manager	10	Beijing Daxing International Airport
5	Contractor	Technical Director	14	Hong Kong-Zhuhai-Macao Bridge
6	Consultant	Professor	11	Hong Kong-Zhuhai-Macao Bridge
7	Supplier	Department Manager	12	Haiwen Bridge
8	Project supervisor	Project Manager	16	Hong Kong-Zhuhai-Macao Bridge
9	Government	Governmental Official in the Department of Housing and Urban-Rural Development	10	Haiwen Bridge

3) Triangulate the results of identified stakeholder power

Next, further focus group sessions were conducted with the previous 18 experts who participated in semi-structured interviews (See Table 3.3) to triangulate the findings (Deng et al., 2021; Wang et al., 2023). Workshops were conducted as a part of the research process to discuss and validate the findings obtained from the semi-structured interviews, specifically concerning essential MSOs and KVFs among them. These group discussions proved invaluable in uncovering insights and details that might not have surfaced during individual interviews. The results could be cross-verified and triangulated by incorporating various data sources, enhancing the research's overall robustness and credibility.

4) Triangulate the results of the case study

Similarly, The 10 experts involved in the HZMB project and participated in the semi-structured interviews, as shown in Table 3.6, were also invited to join in a focus discussion. An online workshop was organized to triangulate the results obtained from the longitudinal case study of the HZMB project. The sessions were recorded digitally through audio recording. In total, the two focus groups spanned a duration of 135 minutes.

3.3.4.2 Results of focus group discussion

The processes of the four focus group discussion sets were denoted as follows.

1) Explore the matching between IKS categories and IKS mechanisms

Table 3.12 shows the most relevant contributions provided by the focus group sessions. Focus groups I and II were designed to verify the second-order dimensions of "knowledge categorization" and " IKS mechanisms" and the features of each dimension. Focus group III was designed to identify the matching between "knowledge categorization" and " IKS mechanisms". During these discussions, the understanding of the emerging theory could be tested and expanded according to the previous steps.

Table 3.12 Description of the focus group session for Objective 1

Focus groups	**Members**	**Session's length**	**Contributions**
Focus group I	4	105 min	·Validation of " real-time project status", "innovative managerial experience", "cutting-edge technical skills", and "integrated technical guidance" as second-order dimensions ·There are different extant "knowledge heterogeneity" and "knowledge tacitness" for each kind of identified knowledge
Focus group II	4	85 min	·Validation of "Large-scale interorganizational events", "Small-scale offline interactions", "Instant online communication", and "Document synthesis and summarization" as second-order dimensions ·There are different extant "Socialization" and "technicalization" for each kind of identified interorganizational knowledge sharing strategies · Large-scale interorganizational events feature interactions of a larger number of people across organizations · Small-scale offline interactions feature direct human interaction among a few persons · Instant online communication features transferring knowledge in a quick and effective tools · Document synthesis and summarization is featured in explicit, written, well-defined, and systematic forms
Focus group III	5	110 min	·Validation of the matching between "real-time project status" and "Instant online communication" ·Validation of the matching between " innovative managerial experience" and "Small-scale offline interactions" ·Validation of the matching between "cutting-edge technical guidelines" and "Document synthesis and summarization" ·Validation of the matching between "technical skills" and "Large-scale interorganizational events"

2) Elaborate the interrelationship between antecedents of IKS

Table 3.13 shows the most relevant contributions the focus group sessions provided for research objective 2. Focus group I was designed to verify the interrelationship among different antecedents of IKS. Focus group II was designed to verify the effects of different antecedents on the efficiency of IKS.

Table 3.13 Description of the focus group session for Objective 2

Focus groups	Members	Session's length	Contributions
Focus group I	9	60 min	·Validation of the relationship among different antecedents of IKS
Focus group II	9	55 min	·Validation of the effects of different antecedents on the efficiency of IKS

3) Triangulate the results of identified stakeholder power

Table 3.14 shows the most relevant contributions provided by the focus group sessions. The sessions were digitally audio-recorded. The two focus groups totally lasted 175 min.

Focus group I was designed to verify the calculating results of the "value advantage", "flow advantage", and "integrated advantage" of each project organization. Focus group II was designed to identify the strategies designed for different project organizations with different levels of "value advantage", "flow advantage", and "integrated advantage". During these focus group sessions, the understanding of the emerging theory could be tested and expanded according to the previous steps (He et al., 2023).

Table 3.14 Description of the focus group session for Objective 3

Focus groups	**Members**	**Session's length**	**Contributions**
Focus group I	18	85 min	·Validating the calculating results of the "value advantage", "flow advantage", and "integrated advantage" of the owner; ·Validating the calculating results of the "value advantage", "flow advantage", and "integrated advantage" of the contractors; ·Validating the calculating results of the "value advantage", "flow advantage", and "integrated advantage" of the consultants; ·Validating the calculating results of the "value advantage", "flow advantage", and "integrated advantage" of the project supervisors; ·Validating the calculating results of the "value advantage", "flow advantage", and "integrated advantage" of the government; ·Validating the calculating results of the "value advantage", "flow advantage", and "integrated advantage" of the designers; ·Validating the calculating results of the "value advantage", "flow advantage", and "integrated advantage" of the suppliers;
Focus group II	18	90 min	·Validating the strategies designed for the owner; ·Validating the strategies designed for the contractors; ·Validating the strategies designed for the consultants; ·Validating the strategies designed for the project supervisors; ·Validating the strategies designed for the government; ·Validating the strategies designed for the designers; ·Validating the strategies designed for the suppliers;

4) Triangulate the results of the case study

Table 3.15 shows the most relevant contributions provided by the focus group sessions in triangulating the results of the case study. The sessions were also digitally audio-recorded. The two focus groups totally lasted 135 min. Focus group I was designed to verify the second-order dimensions of the “IKS scenarios”, “ IKS strategies”, and “innovation capability enhancement” and the features of each dimension. Focus group II was designed to identify the “role of the owner” in different project stages. During these focus group sessions, the understanding of the emerging theory could be tested and expanded according to the previous steps.

Table 3.15 Description of the focus group session for Objective 4

Focus groups	Members	Session’s length	Contributions
Focus group I	10	85 min	·Validation of “environmental variability”, “uncertainty of needs”, “complexity of objects”, and “cognitive ambiguity” as the second-order dimensions of “IKS scenarios”; ·Validation of “IKS in tactic” and “IKS in operation” as the second-order dimensions of “IKS strategies”; ·Validation of the second-order dimensions of “organizational innovation capabilities” in four aspects: institution, business, technology, and management.
Focus group II	10	50 min	·Validation of the “leader” role in facilitating IKS in the preliminary stage of megaproject delivery; ·Validation of the “coordinator” role in facilitating IKS in the construction stage of megaproject delivery; ·Validation of the “supporter” role in facilitating IKS in the operation stage of megaproject delivery.

3.4 Data Analysis Methods

3.4.1 Grounded theory analysis

3.4.1.1 Method selection

Grounded theory is a systematic research methodology widely employed in qualitative research by social scientists (Mac Donald et al., 2020). This approach involves creating hypotheses and theories by gathering and analyzing data (Corbin and Strauss, 1990). Grounded theory is characterized by the use of inductive reasoning, which enables researchers to construct a theoretical framework that captures the fundamental characteristics of a subject while anchoring the theory in empirical observations and data. In essence, it is a method for generating theory from the ground up, starting with the data and moving towards developing conceptual frameworks and hypotheses.

A study utilizing grounded theory typically commences with a question or the collection of qualitative data (Glaser and Strauss, 2017). As researchers review this data, their observations naturally generate ideas or concepts. These emerging ideas and concepts are tagged with *codes*, which serve as concise labels summarizing these emergent themes. Over time, as more data are collected and reviewed, these *codes* can be grouped into higher-level concepts and further organized into categories. These categories ultimately form the foundation for constructing hypotheses or a new theory. This approach contrasts significantly with the traditional scientific model of research, where researchers start with an existing theoretical framework, derive hypotheses from that framework, and then collect data to test the validity of these hypotheses (Glaser and Strauss, 2017). Hence, the grounded theory method stands in contrast to the hypothetico-deductive model frequently used in traditional scientific research, emphasizing the generation of theory from empirical data rather than the testing of preconceived hypotheses (Cao et al., 2019; Morkan et al., 2023; Rodríguez-Labajos et al., 2021).

The grounded theory in this study was specifically designed to form a framework for categorizing knowledge shared in megaprojects and IKS mechanisms. Several justifications underpin the choice of this method:

1) Theoretical Development: Grounded theory is particularly well-suited for studies that seek to develop new theoretical insights or expand upon existing theories. By employing this method, the research aims to construct a solid theoretical framework based on the collected data.

2) Open and Exploratory: Grounded theory is an open and exploratory approach to research. It allows for the emergence of concepts and theories from the data itself, making it suitable for investigations where the research questions are not entirely predetermined.

3) Data-Driven Analysis: Grounded theory emphasizes a data-driven approach, ensuring that the theories and concepts are firmly grounded in the empirical evidence collected during the study.

4) Rich and In-Depth Analysis: This method enables an in-depth analysis of the data, which is especially important when constructing new theoretical perspectives or delving into complex and multifaceted phenomena.

Overall, the choice of grounded theory in this chapter is driven by its suitability for developing theoretical constructs and its commitment to rigorous, data-driven analysis.

3.4.1.2 Data analysis process

This study adhered to grounded theory and coding procedures to discern patterns and themes that formed the foundation for the conceptual model of knowledge categorization and IKS mechanisms in megaprojects (Iftikhar et al., 2021). Qualitative data analysis was conducted using NVIVO 11 software. The data coding process encompassed three structural steps: open coding, axial coding, and selective coding, aligning with the research questions and objectives.

1) Open coding

In the open coding phase, the data underwent examination, comparison, conceptualization, and categorization. Both the first and third authors independently conducted the open coding step, allowing for subsequent comparison. From the transcribed interviews, a set of initial codes was generated, amounting to 30 double-spaced pages with over 10,000 words. Subsequently, these descriptive codes were amalgamated and summarized into significant statements.

2) Axial coding

Axial coding involves reassembling the data in novel ways by making connections between categories, essentially putting the broken-down information back together. The initial first-order statements obtained from open coding were condensed in this step. This was achieved by sorting codes into more analytical second-order dimensions, facilitating a deeper understanding and organization of the emerging patterns and relationships within the data.

3) Selective coding

Selective coding plays a crucial role in determining core categories by establishing relationships with other categories and validating existing connections. Second-order dimensions are further analyzed in this step and merged into broader aggregated dimensions. The focus is on identifying the core categories that form the central themes within the data, providing a comprehensive understanding of the underlying patterns and relationships in the context of knowledge categorization and IKS mechanisms in megaprojects.

After completing the threefold data coding process, each dimension of knowledge categorization and IKS mechanisms emerged from the practical insights of the interviewees and the analysis of secondary project documents, as detailed in the findings section. An extracted example is provided in the study to illustrate the derived dimensions, as shown in Figure 3.2.

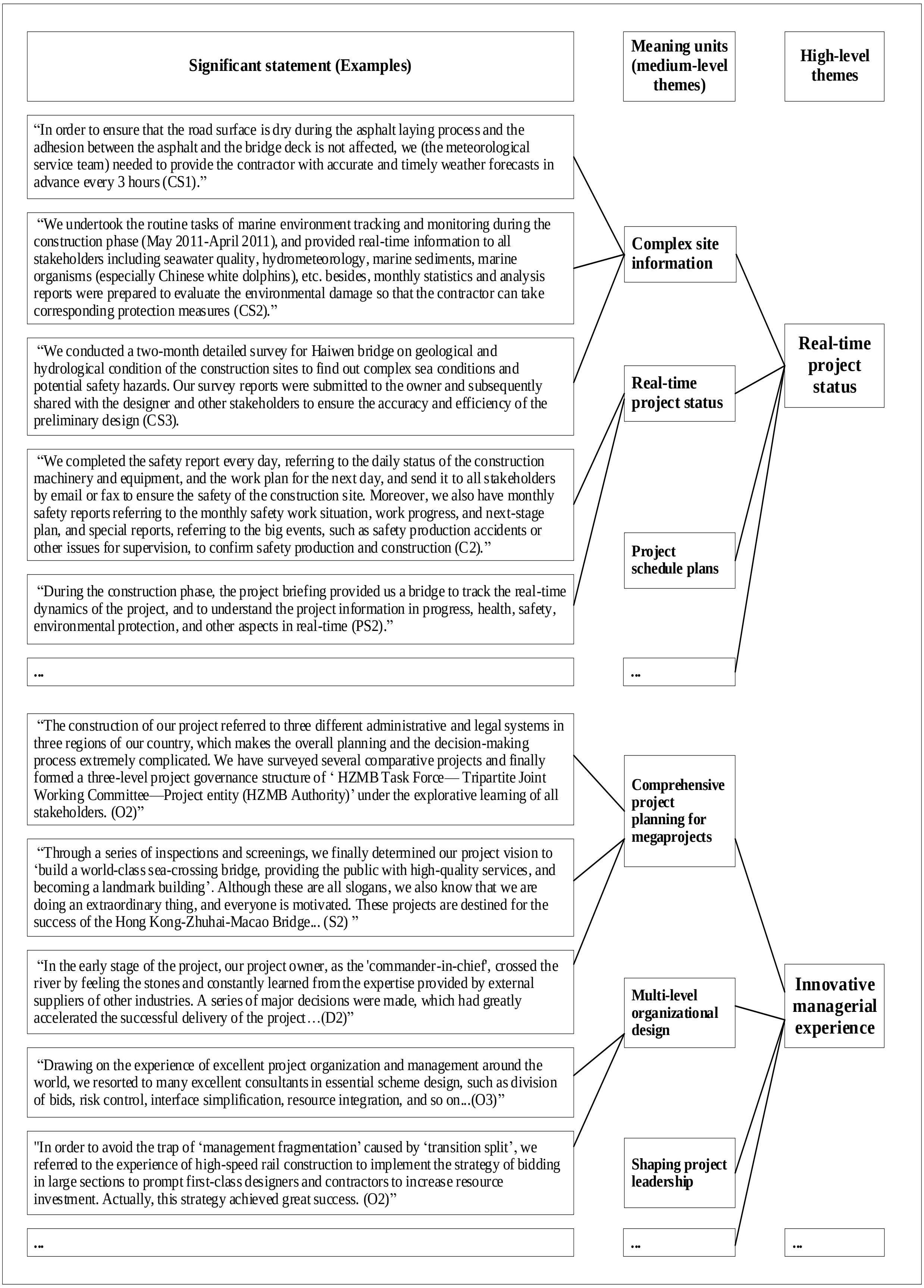


Figure 3.2 Data analysis process (extract)

3.4.1.3 Reliability and validity check

To ensure the validity and reliability of the research findings, this study adhered to the guidelines provided by Bell et al. (2022) and Curado et al. (2019), thereby upholding the constructivist principles of trustworthiness and authenticity.

1) Trustworthiness check

The trustworthiness of qualitative studies comprises four criteria: dependability (reliability), credibility (internal validity), transferability (external validity), and confirmability (objectivity). 1) To confirm the reliability of data collection, the interviewees consisted of key informants at the top-management level, each with over 10 years of work experience in megaprojects, ensuring comprehensive perspectives and extensive practical knowledge. 2) A rigorous protocol for selecting interviewees was established using a snowball sampling technique. Triangulation between different sources of evidence during the data analysis phase was employed to confirm the internal validity of data collection. 3) To ensure external validity, precise boundaries defined by the research questions were established for data generation. A rigorous coding process during data analysis was applied (Saldaña, 2021). 4) To ensure objectivity, various sources of evidence, including interviews, project-specific documents, and literature reviews, were utilized. An iterative process between these sources established a chain of evidence, allowing for adequate citations and cross-checking (Merriam and Tisdell, 2015).

2) Authenticity check

Within this research context, authenticity encompasses four criteria: ontological, educative, catalytic, and tactical authenticity. These criteria can be confirmed by the involvement of participants with diverse roles, genders, positions, educational backgrounds, and work experience (Guba and Lincoln, 2005). 1) Ontological authenticity is achieved through the author's proposal of a model that integrates knowledge categorization and IKS mechanisms for organizations. 2) Educative authenticity is ensured by merging contributions from various

MSOs, thereby integrating diverse perspectives on the phenomenon. 3) Catalytic authenticity is confirmed by providing feedback to the organizations participating in the research, reflecting on the consequences that emerged from the proposed model. 4) Tactical authenticity in this study is achieved by supporting organizations that seek to eliminate the matching rules between knowledge categorization and IKS mechanisms. This ensures that the proposed framework is not only theoretical but also practically applicable to the challenges in practice.

3.4.2 Bayesian Network (BN) analysis

3.4.2.1 Method selection

A Bayesian network is a probabilistic graphical model used to represent a collection of variables and their conditional dependencies. This modeling approach is valuable in various fields and applications (Chan et al., 2020; Sun et al., 2023). Bayesian networks are particularly useful for assessing the likelihood that a particular known cause contributed to an observed event. For instance, they can be employed to represent the probabilistic relationships between diseases and their associated symptoms. When presented with symptoms, a Bayesian network can calculate the probabilities of various diseases being present.

Efficient algorithms are available to facilitate both inference (making predictions or assessments based on the network) and learning (updating the network's parameters based on data). Furthermore, a more advanced form of Bayesian networks is known as influence diagrams. Influence diagrams generalize Bayesian networks and are designed to handle decision-making problems under conditions of uncertainty. These models are especially beneficial when addressing complex scenarios that predict outcomes and make decisions based on available information and uncertainty (Caimo and Lomi, 2015; Freire et al., 2018; Kaikkonen et al., 2021). In summary, the Bayesian network was an effective technique for searching out the most influential factors among several possible known factors and predicting the likelihood of occurrence (Chen et al., 2022; Varshney et al., 2017).

A typical Bayesian Network model consists of two main components: a directed acyclic graph (DAG) and a conditional probability table (CPT). The DAG consists of nodes (i.e., variables) and directed arcs/edges (representing connections between notes). The CPT showcases conditional probabilities of a single variable concerning the other variables (i.e., the probability of each potential value of one variable when the values of the other variables are known).

There are four main steps for applying this research method, as shown in Figure 3.3.

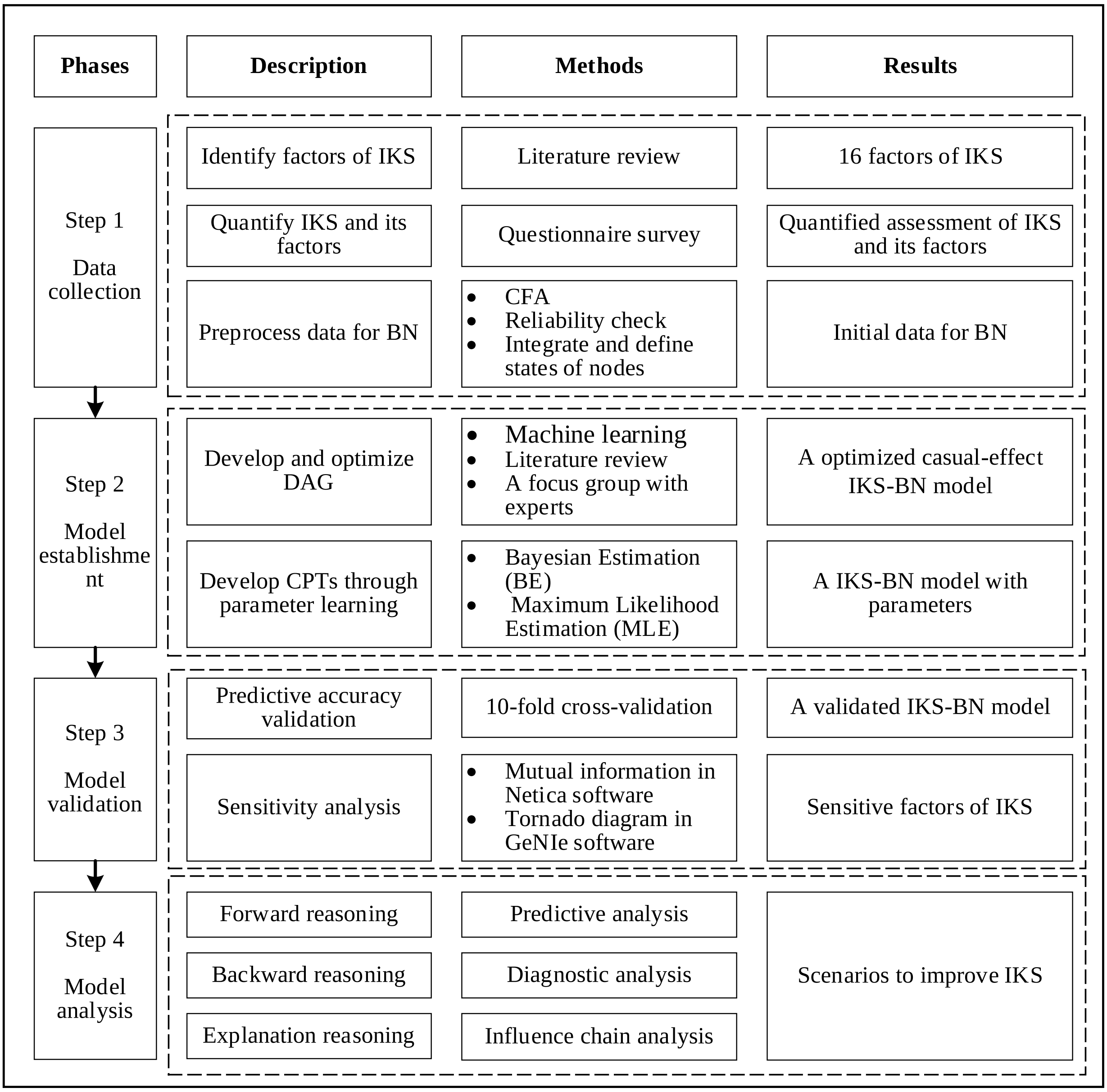


Figure 3.3 Research method framework

First, necessary data must be collected to construct the Bayesian network, including identifying and quantifying the factors of IKS. The second step is to develop a valid DAG and CPT based on the preprocessed data. The third step involves model validation, including 10-fold cross-validation and Sensitivity analysis. Last, the developed IKS-BN network is analyzed to form efficient scenarios to improve IKS, including forward reasoning (predictive analysis), backward reasoning (diagnostic analysis), and explanation reasoning (influence chain analysis). A detailed description of each step is provided as follows.

3.4.2.2 Data collection

1) Identify influencing factors of IKS

The initial step of data collection involves identifying the factors contributing to IKS through a combination of literature review and expert elicitation of parameters. The factors were identified through a comprehensive literature review (see section 3.3.1). The resulting list was subsequently submitted to experts for validation, a process carried out through focus group discussions (see section 3.3.4).

2) Quantify IKS and its factors

To obtain quantitative data for BN analysis, a questionnaire survey was conducted in China to measure the efficiency of IKS in megaprojects and how the 16 identified factors interconnect to influence IKS (see section 3.3.2).

3) Preprocess data for BN

After quantifying IKS and its factors, preliminary data analyses were conducted to prepare further Bayesian network analysis. *First*, the factor loadings were obtained for all variables. By referring to Sun et al. (2023), sub-items to measure each variable should not be assigned equal weights to explain the variable. Instead, the factor loadings for each item should be the valid weight for calculating the variable. The results are all demonstrated in **Appendix A**. *Second*, to test the efficiency of the one-factor congeneric measurement model (i.e., to what extent the several observed items measure the latent variable), confirmatory factor analyses (CFAs) were conducted for each variable and calculated a series of indicators to measure their goodness-of-fit indices, including Tucker–Lewis index (TLI), incremental fit index (IFI), standardized root mean square residual (SRMR), comparative fit index (CFI), and root mean square error of approximation (RMSEA). *Third*, the reliability and validity of each variable were also examined by calculating a series of indicators, including the average variance extracted (AVE), composite reliability (CR), and coefficient H, with the lowest acceptable threshold values of 0.5, 0.7, and 0.8, respectively. *Last*, by referring to extant research (De Oliveira et al., 2012), variables are usually measured in three states, including low (L), moderate (M), and high (H), to simplify the calculation process. Thus, The five-point Likert scales in the questionnaire were reformed to three-point ones. The states 'very good' and 'good' are combined as "High (H)". The state of 'neither good nor poor' is labelled as "Moderate (M)". The states 'poor and 'very poor' are integrated as "Low (L)". Each variable's weighted sum score was designed to range into these three equal segments.

3.4.2.3 Model establishment

1) Develop and optimize DAG

Multiple methods were integrated to develop and optimize the DAG, including structure learning, literature review, and a focus group discussion. *First*, the structure learning tool had a great capability to establish an intuitive causal model that aligns effectively with the available data. The author used the Peter and Clark (PC) algorithm and 240 samples to construct the initial IKS-BN network using the GeNIe 3.0 Academic software. *Second*, due to the limited data, unreasonable causal relationships among the factors will appear in the obtained model. The author further optimizes the IKS-BN model by referring to extant research (i.e., literature review) and experts' views (i.e., focus group discussion). Previously involved experts, as depicted in Table 3.11, were re-invited to join the focus group discussion for model validation.

A structure matrix was developed to help the researchers and experts clarify the logical relationship between factors during the literature review and focus group discussion, as shown in Table 3.16.

Table 3.16 The structure matrix used in the literature review and focus group discussion

Factors of IKS	Tacitness	Ambiguity	Complexity	…	Incentive mechanisms	IKS
Tacitness	N/A					
Ambiguity	-	N/A				
Complexity	-	-	N/A			
…	-	-	-	…		
Incentive mechanisms	-	-	-	-	N/A	

A BN network only allows unidirectional relationships between two nodes. By referring to Sun et al. (2023), the upper half of the matrix was solely utilized to gather expert input. Specifically, “1” denoted that the factor in the column influenced the factor in the row, while “-1” represented the opposite situation. “0” showed that there was no link between them. Referring to Chan et al. (2020) and Sun et al. (2023), an agreement was only considered valid when no less than 4 experts were convinced of the causality. The final result was also sent to all experts for confirmation.

2) Develop CPTs through parameter learning

After obtaining the optimized IKS-BN model, parameter learning was further conducted to calculate the CPT of each node variable in the GeNIe 3.0 Academic software. Specifically, this research employed the Maximum Likelihood Estimation (MLE) method due to its high computational efficiency and no need to define prior probabilities artificially. The MLE method's core principle involves establishing network parameters by maximizing the likelihood of both the sample data and the network parameters.

3.4.2.4 Model validation

1) Predictive accuracy validation

After establishing and optimizing the IKS-BN network, 10-fold cross-validation was used in GeNIe 3.0 Academic software to validate the model and evaluate its predictive accuracy. Specifically, the collected datasets were equally and roughly divided into k subsets, among which 9 subsets (216 samples) were designed as training sets and 1 as testing sets (24). The efficiency of IKS was selected as the predicted node for calculation. The model's predictive accuracy was evaluated by how the simulation value was consistent with the real value within the allowance error range (i.e., the rate of the times making accurate predictions to the total test times). Then, this process is repeated 10 times, with each subset being treated as test sets, to calculate a mean value as the predictive accuracy of the BN. The model can be regarded as effective once the validity is above 80% (Terán-Bustamante et al., 2021).

Following Sun et al. (2023), predictive accuracy was assessed using the confusion matrix, including the user's and producer's accuracy. The former is also defined as the reliability of the BN model, indicating how frequently the forecasted states of IKS accurately correspond to the actual states. On the contrary, the latter signifies how often the BN model correctly forecasts the actual states of IKS. To visualize the performance of the BN model, the receiver operating characteristic (ROC) curve is utilized. The area (i.e., ranging from 0 to 1) under the ROC curve (AUC) quantifies the quality of the BN. A higher AUC value indicates a more accurate prediction by the BN, with a threshold typically set at 0.5.

2) Sensitivity analysis

Additionally, **sensitivity analysis** was utilized to calculate the occurrence of some factors when the target node was set to figure out the most suspected factors, including sensitivity to findings and sensitivity to parameters (Sun et al., 2023). As for sensitivity to findings, mutual information (MI) could be employed to quantify the effect of each specific factor on the target node. As for sensitivity to parameters, a tornado diagram could be used to demonstrate the sensitivity of different parameters (i.e., conditional probabilities) for various levels of the target node. The efficiency of IKS was designed as the target node. The sensitivity analysis was conducted through two software tools, Netica 6.07 and GeNIe 3.0 Academic.

3.4.2.5 Model analysis

The BN model analysis involves calculating probabilities, including three types, according to the direction of reasoning.

1) Forward reasoning (predictive analysis)

This type of reasoning allows the BN to forecast future outcomes based on given evidence (Luo et al., 2020).

2) Backward reasoning (diagnostic analysis)

In this approach, the BN is used to diagnose possible influences by observing changes in the posterior probability of the target nodes (Anderson and Thomas Lenz, 2001). By analyzing the changes in probabilities, one can identify the likely causes of observed outcomes.

3) Explanation reasoning (influence chain analysis)

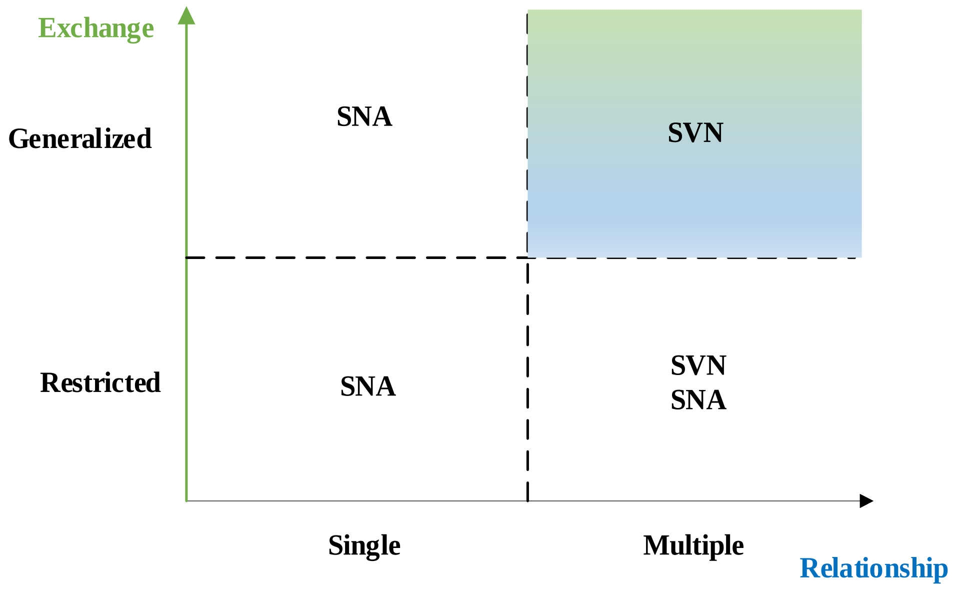
This type of reasoning aims to understand the degree of mutual influence between nodes in the BN, helping to identify the most probable pathways leading to a particular result (Luo et al., 2020). Sensitivity analysis examines the changes that input variables affect the output, while influence chain analysis studies the chain of influences that commonly lead to an outcome. By utilizing the developed IKS-BN model, more suggestions and recommendations can be proposed through the three types of model analysis to enhance the efficiency of IKS in megaprojects.

3.4.3 Stakeholder Value Network (SVN) analysis

3.4.3.1 Method selection

In the editorial of the special issue on "*Old Theories, New Contexts: Extending Operations Management Theories to Projects*", Maylor et al. (2018) suggested using the design structure matrix approach (Artto and Turkulainen, 2018) in contemporary project studies. The design structure matrix method is an effective tool using a matrix form to visualize, model, and analyze the interdependency within system elements (Tripathy and Eppinger, 2013). Eppinger (2017) has researched, applied, and extended design structure matrix methods into the broader social science and engineering research communities. A critical challenge for megaprojects is the multiple exchanges between and among MSOs. The SVN analysis, a multidisciplinary method developed from the design structure matrix tool (Ferreira et al., 2019; Zheng et al., 2021), is used in this chapter to enumerate, evaluate, and model MSOs' interactions. The following section illustrates the SVN analysis method, data collection process, and the procedure for data analysis.

Cameron et al. (2008) first developed the SVN analysis method that integrates both qualitative and quantitative analyses. Figure 3.4 compares SVN with traditional social network analysis (SNA). Value-type elements split the horizontal axis into two areas (*single vs. multiple)*, while the exchange types divide the vertical axis into two halves (*restricted vs. generalized)*. The *single* means that only one type of value (e.g., business or social value) could be considered in the network analysis each time; *multiple* means that multiple types of value (e.g., both business and social value) are explored simultaneously. Besides, the *restricted* and *generalized* exchange types represent distinct exchange patterns (direct and dyadic for *restricted* and indirect and multiple for *generalized*). Compared with SNA analysis, the SVN analysis method considers both business and social value co-creation between MSOs in the knowledge supply chain (Griffith et al., 2006; Narasimhan et al., 2009; Shaheen and Azadegan, 2020). Next, similar to SNA, the SVN analysis identifies restricted and generalized exchanges among MSOs to realize intangible and tangible value co-creation, which are assessed by utility analysis.



Note: The figure was revised based on the study of Feng (2013)

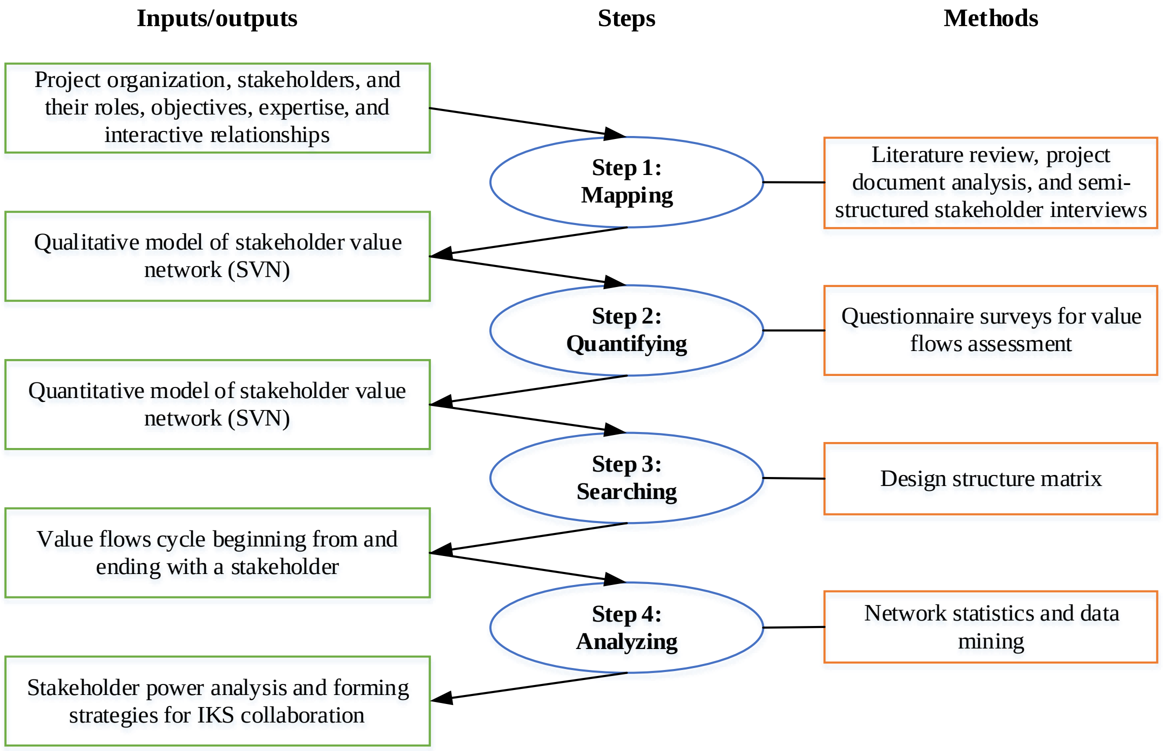
Figure 3.4 The network analysis approach

As a network-based method, the SVN analysis method involves four constructs (Table 3.17). The MSOs are presented as the nodes of the network. Benefits originally from the two MSOs' behaviors were defined as *value flows* (e.g., knowledge value) and measured by the utility perceived by the recipient stakeholder. The link between two nodes (sender and recipient) was defined as a value flow (e.g., KVF A→B). A loop of value flows beginning and ending with the same stakeholder is defined as a value flow cycle (e.g., KVF cycle A→B→C→A).

Table 3.17 Definitions of the SVN model constructs

Element in SVN	Legend	Definition
MSOs	$a, b, \cdots, m$	Any organization may directly or indirectly be involved in an exchange.
Value	$\Delta_1, \Delta_2, \cdots, \Delta_i$	Needs met due to other MSOs' actions or meeting others' needs via one's own action.
Value flow	$a \overset{\Delta_1}{\rightarrow} b$	The specific value Δ_1 is delivered from the sender stakeholder (a) to the recipient stakeholder (b).
Value flow cycle	$a \overset{\Delta_1}{\rightarrow} b \rightarrow \cdots \overset{\Delta_i}{\rightarrow} a$	A loop of value flows beginning from and ending with the same stakeholder.

This study analyzes inter-organizational knowledge flow value through SVN methods. The research framework is shown in Figure 3.5, which includes the following four steps:



Note: The figure was revised based on the study of Feng (2013)

Figure 3.5 Process of SVN analysis

- **Step 1: Mapping:** the boundary of the MSOs was first identified and defined. The roles, expertise, objectives, and interactive value flows of MSOs are derived from literature, project documents, and semi-structured interviews. Then, a qualitative SVN model could be constructed by mapping the IKS network.

- **Step 2: Quantifying**: the next step is to assess the value flows by the perceived utility of the recipient stakeholders through questionnaire surveys. The value utility theory indicates that value is based on how much *use* is obtained from the valued thing (Fishburn, 1968). It enables needs and preferences in numerically useful ways, allowing operations and supply chain management researchers to focus on and differentiate stakeholder-specific value flows (Ayvaci et al., 2018; Bai et al., 2021; Sodhi, 2015).

- **Step 3: Searching:** based on the quantified value flows, a quantitative SVN model is constructed to search for the value flow cycles through the design structure matrix approach (Eppinger, 2017; Tripathy and Eppinger, 2013).
- **Step 4: Analyzing:** the last step is to explore the implications of the SVN model for governing megaprojects by network measurements and statistics.

In the following sections, each step is presented in detail.

3.4.3.2 Mapping the IKS network

1) Identification of primary MSOs

The first step in this chapter was to identify MSOs and their KVFs. MSOs shape the boundaries and scopes of the SVN model. Megaprojects include large-scale infrastructure (e.g., bridges, highways, railways, tunnels, airports, and dams), usually commissioned by the government and delivered by private organizations (Caldwell et al., 2009; van Marrewijk et al., 2008). An increasing number of megaprojects are underway in emerging countries (e.g., China and Brazil) (Ansar et al., 2014; Wang et al., 2020, 2018), and the design-bid-build approach is the most prevalent delivery system (Zheng et al., 2019a), and hence, this chapter focuses on it.

In previous SVN studies (Ferreira et al., 2019; Zheng et al., 2021), one of the MSOs involved in the stakeholder network was chosen as the focal organization for further analysis. However, due to the relative intangibility of knowledge resources (Gaimon and Ramachandran, 2021) in combination with the complex nature of megaprojects (Pitsis et al., 2018), this rule was changed in this study. Each stakeholder involved in delivering a megaproject is considered a separate focal organization in the SVN analysis.

Here, MSOs are those who (1) have a direct or indirect influence on the knowledge management of megaprojects, (2) receive direct or indirect benefits from knowledge exchanges in megaprojects, or (3) possess a significant and legitimate interest in project knowledge resources. Primary MSOs were identified through a literature review of academic papers and project documents produced by different MSOs (see section 3.3.1) and semi-structured interviews (see section 3.3.2). In the SVN model, each node represents a type of stakeholder (Ferreira et al., 2019; Fu et al., 2011; Zheng et al., 2021).

2) Identification of KVFs among MSOs

After identifying the primary MSOs for the SVN model, the next step was determining the KVFs among different MSOs. Each stakeholder's role, objectives, and specific needs in delivering projects were identified. When another stakeholder's knowledge exchange met a specific need on the part of one stakeholder, a KVF was identified. The details of the data collected are shown in Table 3.18.

Table 3.18 Data collection

Objectives	Methods	Data Description
Identifying primary MSOs and related KVFs among them	Literature review and project document analysis (See section 3.3.1)	The literature includes journal papers, professional guidelines, and technical reports. The project documents describe the project management process in delivering megaprojects, such as minutes of project meetings and project implementation reports.
	Semi-structured interview (See section 3.3.2)	The surveyed 18 experts, including owners (3), consultants (3), contractors (3), project supervisors (3), government (2), designers (2), and suppliers (2).
Assessing each KVFs	Questionnaire surveys (See section 3.3.3)	The 198 surveyed experts include owners (20.2%), consultants (19.2%), contractors (11.1%), project supervisors (12.6%), suppliers (13.1%), government (10.1%), and designers (13.7%).
Verifying the assessment results	Focus group discussion (See section 3.3.4)	The surveyed 18 experts

3.4.3.3 Quantifying the IKS network

The second step of the SVN analysis was to quantify the qualitative SVN model in the following two sub-steps.

1) Measurements of each KVF

First, a score was set up to measure the utility of each KVF through questionnaire surveys.

To measure the utility of each KVF, the attributes of the KVFs were carefully established in questionnaire surveys. In this study, *satisfaction with the IKS process,* $U_f(\text{satisfaction})$, and *the importance of knowledge for meeting the project needs,* $U_f(\text{importance})$, were employed to measure the utility of each KVF on a five-point scale (see section 3.3.3).

2) Measurements of each KVF cycle

Second, a propagation rule was set to measure the score of each KVF cycle (Ferreira et al., 2019; Pereira et al., 2018; Zheng et al., 2019b). By applying the multi-attribute utility theory (Keeney, 2002; Kidd et al., 1977; Mitra et al., 1979; Zheng et al., 2019b), the utility of KVF (U_f) could be quantified by integrating the utilities of its two-dimensional attributes, i.e., $U_f(\text{satisfaction})$ and $U_f(\text{importance})$, through multiplicative utility function, as shown in Equation (1). By referring to Ferreira (2019) and Sutherland (2012), the five-point scale for $U_f(\text{satisfaction})$ and $U_f(\text{importance})$ are adjusted to scores of 0.2, 0.4, 0.6, 0.8, and 1.0 to make the utility of each KVF U_f ranging from 0 and 1 ($0<U_f<1$).

$$U_f = U_f(\text{satisfaction}) \times U_f(\text{importance}) \qquad \text{Equation (1)}$$

However, the different utility score U_f could be obtained from different respondents for each KVF. With reference to Tripathy and Eppinger (2013), the Delphi method was used to reach an agreement on the final utility score of each KVF. The coefficient of variation, cv_j, as shown in Equation (2), was used to assess the relative degree of dispersion of experts' score on *j* KVF and judge whether re-evaluation should be conducted. The smaller the cv_j, the greater the degree of coordination of the experts on the *j* KVF. By referring to Meijering (2013) and Strasser (2019), $cv_j < 0.2$ is generally acceptable.

$$cv_j = \frac{\sqrt{\frac{1}{m_j-1}\sum_{i=1}^{m_j}(c_{ij}-\overline{x}_{ij})^2}}{\overline{x}_i} \qquad \text{Equation (2)}$$

where cv_j represents the coefficient of variation of the experts' score on the *j* KVF; $\overline{x}_i$ represents the average value of the score obtained by the *j* KVF; m_j represents the number of experts participating in the j KVF score; c_{ij} represents the score value given by the i expert to the j KVF.

The mean value of the evaluation results was used to reflect each KVF when the coefficient of variation, cv_j, is smaller than 0.2 (Zhang and Xi, 2021). If the coefficient of variation is not acceptable (V>0.2), further online meetings with the respondents to pursue re-evaluation were held until an acceptable result was generated (Yu et al., 2017). After two rounds of re-evaluation, an agreed result for the evaluation of each KVF was reached.

3.4.3.4 Searching for KVF cycles

The third step of the SVN analysis was to search all KVF cycles using a design structure matrix based on the multiplication method (i.e., Danielson algorithm) (Zheng et al., 2019b).

1) Design structure matrix and Danielson's algorithm

A design structure matrix is a square matrix designed to model the structure of complex systems or interactions among multiple system elements, where the diagonal cells typically represent the elements, and the off-diagonal cells are interactions between the elements (Browning, 2016). Danielson's (1968) algorithm was adopted in the SVN analysis method as the multiplication method for a design structure matrix (Hein et al., 2017). This study employed the design structure matrix combined with Danielson's algorithm to search all KVF cycles among MSOs. The specific process of how to search the KVF cycles through the design structure matrix method is shown in **Appendix C**.

2) Propagation rule for calculating KVF cycles

Then, a multiplicative propagation rule was set to calculate the utility score of a given KVF cycle (Ferreira et al., 2019; Hein et al., 2017; Zheng et al., 2021). The score of a given KVF cycle equals the product of the scores of all KVFs in that cycle, as shown in Equation (3).

$$U_c = \prod_{n=1}^{x} U_{f(n)}, x \in z \qquad \text{Equation (3)}$$

where U_f (n) is the utility score of the $n\text{-}th$ KVF in the KVF cycle. x is the total number of KVFs in the KVF cycle. In KVF cycles, x is greater than 2 and not greater than m because the focal organization is linked twice.

This propagation rule has three advantages. First, the utility score for each KVF cycle remains in the range of [0, 1]. Second, longer KVF cycles may receive lower utility scores, which conforms to the reality that engaging MSOs is increasingly difficult as the KVF cycles lengthen. Using a design structure matrix method that combined Danielson's algorithm and the multiplicative propagation rule, KVF cycle distribution among the seven MSOs could be revealed and ranked in terms of utility scores.

3.4.3.5 Analyzing the SVN model

A KVF could be measured from two aspects: the value and the exchange aspect. Accordingly, the maximum stakeholder's co-creation depends on its value, exchange, or integrated advantages (which combine value and exchange advantages). After searching for all KVF cycles, three types of statistical indicators reflect the value co-creation status of different MSOs, according to which corresponding governance strategies could be formed to promote MSOs' stakeholder synergy and value co-creation.

1) Value advantage analysis

The indicator of value advantages was calculated to quantify the value-adhesion capability of a specific type of stakeholder (e.g., stakeholder k) across the value chain. This indicator was calculated using the ratio of the score of the KVFs related to stakeholder k and the score sum of all of the KVFs, as shown in Equation (4).

$$VA_k = \frac{\sum_{f=1}^{m} U_f \times S_{kf}}{2 \times \sum_{f=1}^{m} U_f} \qquad \text{Equation (4)}$$

where k represents one of the seven types of MSOs, m is the total number of KVFs, U_f is the score of KVF f, S_{kf} is 1 if stakeholder k was included in KVF f or 0 if it is not included.

2) Exchange advantage analysis

The indicator of exchange advantages was calculated to quantify the exchange centrality of a specific type of stakeholder (e.g., stakeholder k) within the value chain. This indicator was calculated by the ratio of KVF cycles' number related to stakeholder k and the total number of

KVF cycles, as shown in Equation (5).

$$EA_k = \frac{\sum_{c=1}^{n} S_{kc}}{n} \qquad \text{Equation (5)}$$

where k represents one of the seven MSOs, n is the total number of KVF cycles, S_{kc} indicates 1 if stakeholder k is included in KVF cycle c or 0 if not included. This study set seven types of MSOs as focal organizations, respectively, implying seven scenarios. For example, when stakeholder k is set as a focal organization, all KVF cycles are searched starting and ending with the stakeholder k. In this scenario, the exchange advantages score of stakeholder k is 1, as it appears in all KVF cycles, whereas the exchange advantages scores of the other six types of MSOs (e.g., stakeholder j) are less than 1, as some KVF cycles that start and end with stakeholder k do not flow over stakeholder j. The indicator of exchange advantages for stakeholder k could be determined by calculating the average score of exchange advantages of seven scenarios.

3) Integrated advantage analysis

The integrated advantage was calculated to quantify both value and exchange advantages of a specific type of stakeholder (e.g., stakeholder k) within the value chain, which considers both the utility score and occurrence number of KVF cycles. This indicator was calculated by the ratio of the total score of KVF cycles related to stakeholder k and the total score of KVF cycles, as shown in Equation (6).

$$IA_k = \frac{\sum_{c=1}^{n} U_c \times S_{kc}}{\sum_{c=1}^{n} U_c} \qquad \text{Equation (6)}$$

where k represents one of the seven MSOs, n is the total number of KVF cycles, and U_c is the utility score of the KVF cycle c. Similarly, seven MSOs were set as focal organizations, respectively. The indicator of integrated advantage of stakeholder k could be determined by calculating the average score of integrated advantages of seven scenarios.

3.4.4 Longitudinal case study

The longitudinal case study is a research methodology that analyzes the chronological progression of events and changes in real-world organizational attributes over an extended period. It is a valuable and frequently utilized approach in the field of organization management research (Pettigrew, 1990). The longitudinal approach is often essential for studying organizational processes such as communication breakdowns during the business processes (Saxena and McDonagh, 2022), value creation/destructing (Mills and Razmdoost, 2016), the interplay between servitization and platforms (Fu et al., 2022), and flexibility behaviors in an interorganizational project (Ligthart et al., 2016).

This study applies a longitudinal case study approach to elaborate on the link between IKS and organizational innovation capability enhancement and the role of the owner in the process. This method lets us qualitatively capture the evolution over an extended time horizon (Street and Ward, 2012). It also allows us to focus on the uniqueness of the case to generate theoretical insights and ensures the depth of the case analysis with thick descriptions (Radaelli et al., 2023).

3.4.4.1 Method Selection

The study is structured to attain its goals by employing a longitudinal single case study and utilizing the grounded theory method for data analysis. Several rationales support the selection of this approach:

First, our study was designed to understand “why” and “how” IKS enhances innovation capability in megaprojects. Given the limited theories on this issue, the relevant theories are expected to be generated from the selected case by conducting an in-depth study. The case study approach is suitable for explaining research issues such as explanation mechanisms or processes. Furthermore, case studies are instrumental in concentrating on the existence of specific relationships or the circumstances that instigate change. This focus enables researchers to integrate fresh perspectives for addressing novel issues within their research domain (Martinsuo and Huemann, 2021). Therefore, it is appropriate to choose a case study for this research.

Second, the IKS, innovation capability, and the owner’s role in leading IKS in megaprojects are dynamic and continuous processes involving multiple project stages. Longitudinal case studies, on the one hand, help to discover patterns from complex phenomena, uncover the hidden theoretical logic behind them, and facilitate the induction and presentation of interrelationships among multiple constructs. On the other hand, this method supports presenting detailed evidence to demonstrate the multiple dimensions and stages of the change process to provide a basis for theory construction (Street and Ward, 2012). Therefore, choosing a longitudinal case study for this study is appropriate.

Third, single-case studies are suitable for research objects with uniqueness and scarcity (Siggelkow, 2007), such as best practices in the industry or even world-first, one-of-a-kind projects. Given the need for an in-depth analysis of the relationship between the IKS and innovation capability enhancement, a single case study is conducive to long-term tracking and in-depth research of research topics and can more clearly show the mechanism of action between various constructs, so it is appropriate to adopt a single case longitudinal analysis. This also aligns with the principles of representativeness and typicality in selecting single-case studies (Abushaikha et al., 2021). Therefore, choosing a longitudinal single case study in this study is appropriate.

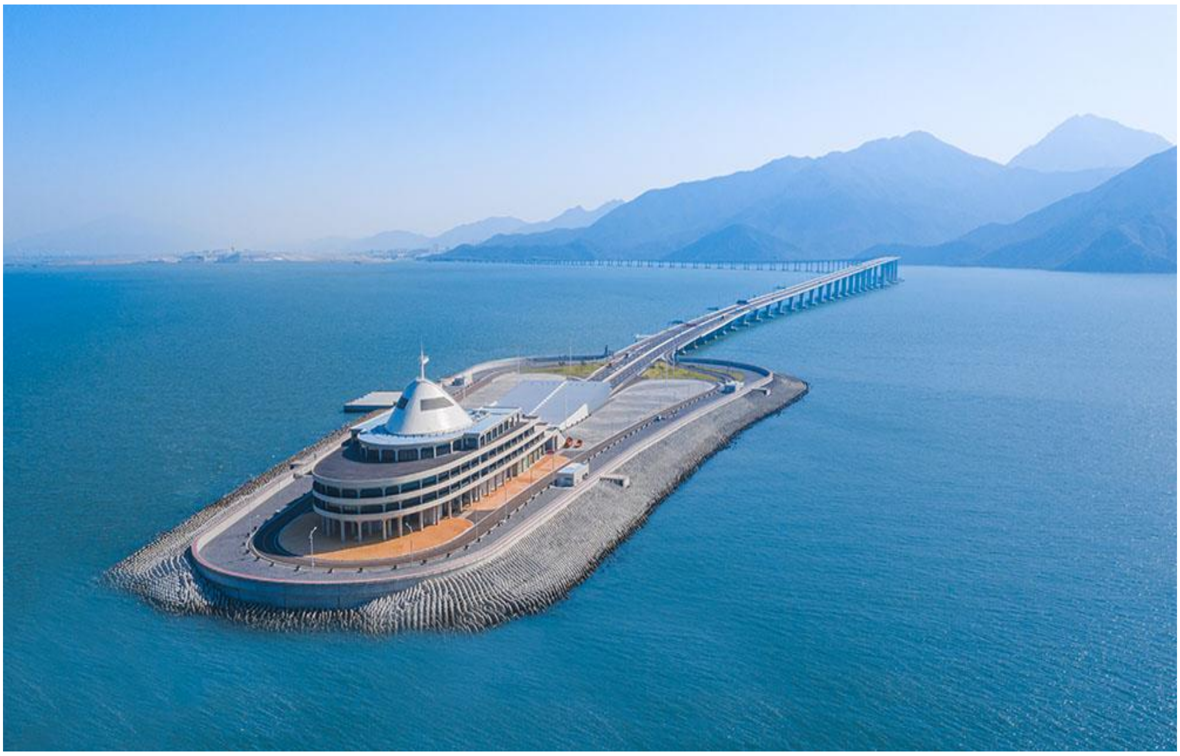
Fourth, the grounded theory approach is suitable for exploring patterns of behavior in dynamic contexts to derive new theoretical elements from qualitative data and for answering the “why” and “how” elements of the research issues (Yin and Liu, 2023).

Hence, the longitudinal single-case study method is suitable for discussing dynamic situational problems, which is helpful in further excavating the connotation behind the real situation, especially for exploring benchmarking cases (Salvato and Rerup, 2011). The longitudinal single-case research perspective is helpful to logically deduce and review the IKS of the Hongkong-Zhuhai-Macao bridge (HZMB) project according to the chronological sequence of the case development and key events to realize the theory construction of IKS under the VUCA scenario. It could reveal the connotation of IKS in megaprojects at different stages and its effects on enhancing organizational innovation capability.

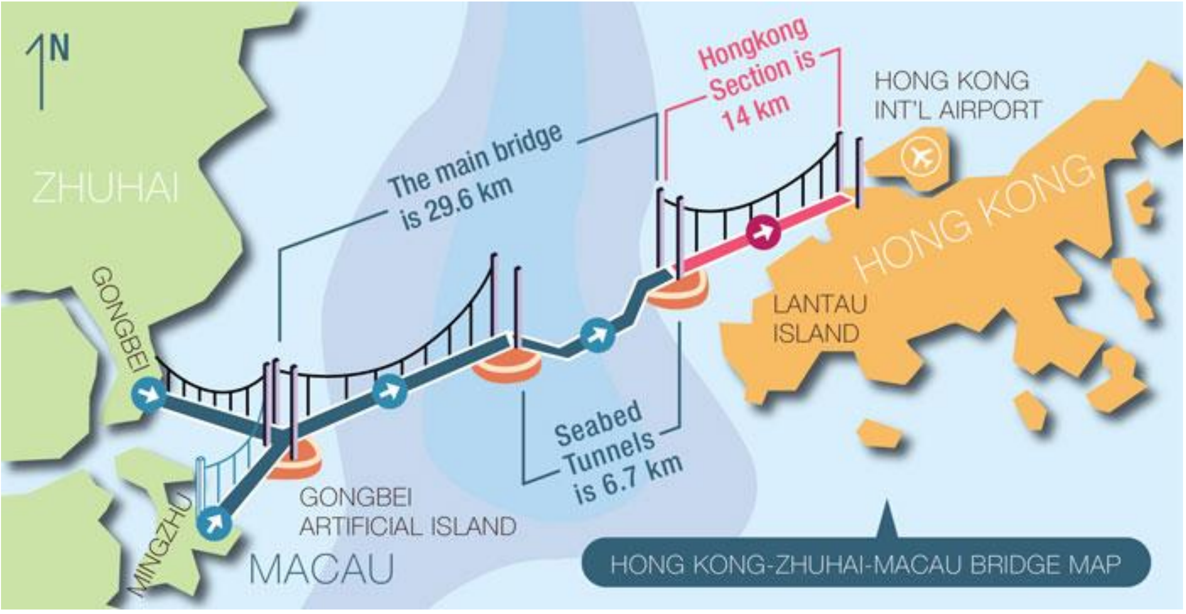
3.4.4.2 Case selection

Based on the principle of theoretical sampling, the HZMB project was selected as the sample case of this research (Yin, 2009). The Hongkong-Zhuhai-Macao Bridge (HZMB) project is a sea-crossing bridge with the longest overall span, the longest steel structure bridge body, and the longest submarine-immersed tunnel worldwide, as shown in Figure 3.6. It has a designed service life of 120 years, breaking the “century-old practice “ of similar bridges. The knowledge and experience accumulated in this project have promoted the high-quality and creative delivery of later megaprojects in China, such as the Beijing Daxing International Airport, Qiongzhou Strait Cross-sea Bridge, Shenzhong Tunnel, and Humen Second Bridge.

(a) **The Hong Kong-Zhuhai-Macao Bridge under construction in April, 2017**



(b) Artificial island of the Hong Kong-Zhuhai-Macao Bridge

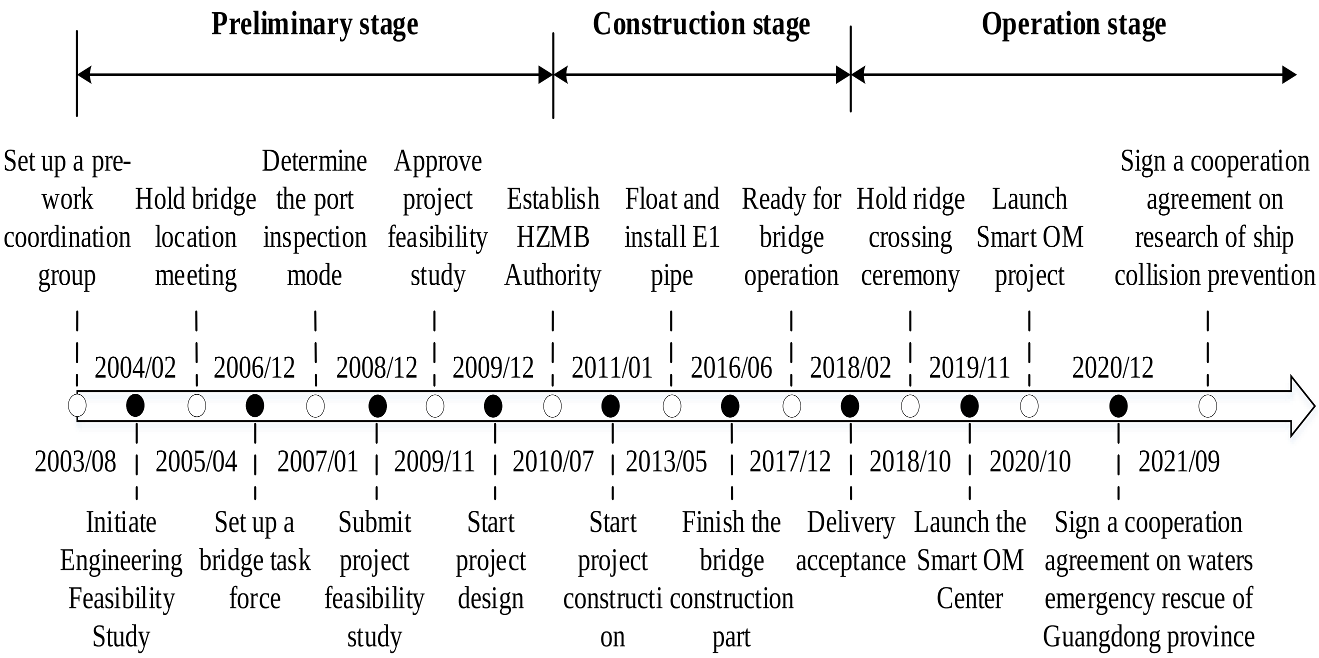


(c) Structural drawing of the Hong Kong-Zhuhai-Macao Bridge

Figure 3.6 The panorama of the Hong Kong-Zhuhai-Macao Bridge[5]

[5] Picture resource: https://www.chinadaily.com.cn/china/2017-06/14/content_29732149.htm, *https://m.thepaper.cn/wifiKey_detail.jsp?contid=9452951&from=wifiKey#* , and *https://www.reduper.com/industry/traffic/bridge/sea-bridge/hong-kong-zhuhai-macau-bridge/*

The cases selected in this chapter have the following uniqueness and scarcity. *First*, the HZMB project is the first cross-sea transportation project jointly constructed by Guangdong, Hong Kong, and Macao under the framework of "One Country, Two Systems". The problems and challenges in the three stages of the HZMB project consist of the different IKS scenarios. The milestone events in the HZMB project are shown in Figure 3.7. *Second*, the HZMB project involves an extensive and comprehensive IKS among MSOs to draw their lessons and best practices from their previously involved megaprojects, such as the Oresund Tunnel, to realize the overall design and independent research and development of key technologies, reflecting the innovative and leap-forward development from "following" to "leading". *Third*, one of the authors of this chapter has long been rooted in the project management front line of the HZMB project and has been deeply involved in its IKS practices during the life-cycle project duration. A massive amount of first-hand material could be obtained, and related practitioners' semi-structured interviews could be conducted to deepen the longitudinal single case study.



Note: The figure was created by the author based on the data from *https://html.hzmb.org/*

Figure 3.7 List of key milestones of the HZMB project

3.4.4.3 Data collection

This chapter follows the suggestion of integrating multi-source data put forward by Glaser and Strauss (2017), including primary data, such as semi-structured interviews (see section 3.3.2 and focus group discussion (see section 3.3.4), and secondary data, such as internal document, public document, and records of industry forums and knowledge Salon minutes (see section 3.3.1) for cross-validation (Yin, 2009), to avoid retrospective sense-making and impression management brought by only primary data analysis (Eisenhardt and Graebner, 2007; Pettigrew, 1990).

3.4.4.4 Data analysis

Based on the grounded theory in qualitative research, this chapter uses three-level coding for text data (Gioia et al., 2013), spirally extracts concepts and abstract relationships between concepts, and sorts out the IKS scenarios, IKS processes, innovation capability enhancement, and the owner's role in guiding MIA conducting IKS in the HZMB project. It is helpful to construct the IKS framework of megaprojects based on existing data analysis and to form a holistic understanding of the effect of IKS on innovation capability enhancement in megaprojects. Specifically, this chapter adopts the paradigm of qualitative research: coding and analyzing textual data based on grounded theory to form a theoretical model (Eisenhardt, 1991). The data analysis process includes four steps.

First, the collected data was imported into NVIVO11 software to openly code the related description of the MSOs' implementation of IKS and their innovation capability in the HZMB project. The descriptions were then reported back to key informants from the owner and other MSOs of the HZMB project to ensure the reliability and comprehensiveness of the research team's understanding of how events unfolded over time (Rodríguez-Labajos et al., 2021).

The second step is forming the first-level concepts (i.e., significant statements/examples). A first-order analysis was conducted to initially identify the different stages of IKS scenarios, MSOs' implementation of IKS, their innovation capability, and the owner's role. The first-order analysis focused on labeling informant-centric terms and codes (Gioia et al., 2013). Then, researcher-centric themes and codes were developed to theoretically interpret the first-order informant-centric concepts (Gioia et al., 2013).

Third, the first-level concepts are merged into medium-level themes through main-axis coding, and there are iterates between data analysis and concept proposition until the data is completely grouped. Several iterations were conducted, which involved comparing and matching concepts generated from the data and those provided in the literature on IKS and innovation capability in megaprojects. After this process, theoretically similar first-order concepts were grouped, and second-order themes emerged. Finally, the research team distilled the second-order themes into aggregate dimensions (Iftikhar et al., 2021).

Finally, high-level themes were formed to establish the theoretical model (Gioia et al., 2013). This study mainly focused on typical fragments of IKS rather than completely describing all IKS contents of the HZMB project.

3.5 Chapter Summary

This chapter illustrates a concise research process and comprehensively describes the data collection methods, including literature review, semi-structured interviews, questionnaire survey, focus group discussion, and data analysis methodologies, including grounded theory, Bayesian network analysis, stakeholder analysis, and longitudinal case study. The research objectives can be achieved through properly combining and using these methods.

CHAPTER 4 MAPPING IKS: CATEGORIZING KNOWLEDGE AND IKS MECHANISM IN MEGAPROJECTS[6]

Organizations tap into outside sources and gain useful knowledge; in particular, they need to access complementary external expertise to help solve novel problems… There are different types of knowledge... Different knowledge sharing tools would guide managers and teams to share different types of knowledge, which can affect the way organizations adopt tools…

(Iftikhar and Ahola, 2022, p 855)

4.1 Introduction

IKS is essential in megaprojects (Iftikhar and Lions, 2022). It greatly contributes to the acquisition of complementary expertise (Woo et al., 2004), fostering technological innovation (Marchegiani et al., 2020), achieving value creation (Möller and Svahn, 2006), and enhancing project performance (Modi and Mabert, 2007). IKS is a complex phenomenon (Hu et al., 2022). Easterby-Smith (2008) summarized four types of factors influencing the outcome and efficiency of IKS, including knowledge characteristics (such as explicitness of knowledge), the capabilities of knowledge donors and recipients (such as knowledge absorption capacity), and interorganizational dynamics (such as project culture encouraging IKS). Among these, knowledge characteristics pose one of the most challenging factors in facilitating IKS in interorganizational project context (Fang et al., 2013). Overcoming obstacles to IKS arising

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[6] This chapter is largely based on the following manuscript:

He, H., He Q., Wang G.*, Chan A.P.C., & Yang Y. (2023). Mapping interorganizational knowledge sharing mechanisms in projects from the socio-technical perspective. Technological Forecasting and Social Change 192: 122537. **(Accepted, First Author)**

from knowledge characteristics through the design of different mechanisms is a research topic that organizational and project management scholars have consistently and actively explored.

IKS mechanisms refer to the use of various managerial or technical means or tools to facilitate IKS across organizations (Hoetker and Mellewigt, 2009). A literature review reveals that previous research broadly categorizes different IKS mechanisms into “social” or “technical” types. Social mechanisms primarily focus on “people”, addressing soft aspects such as social values, norms, and culture, aiming to foster inter-organizational relationships and enhance the willingness to conduct IKS (Oesterreich and Teuteberg, 2019). Specific forms include regular training programs and the establishment of practice communities (Choi et al., 2020). In contrast, technical mechanisms primarily focus on “tasks”, addressing the methods and tools required for the process of IKS. This involves improving IKS through the provision of information technology support, such as document systems (Wang and Ko, 2012). Existing research indicates that the efficiency of implementing IKS mechanisms is closely related to the characteristics of knowledge itself, such as its explicitness: social mechanisms are more suitable for sharing tacit knowledge (Aaltonen and Turkulainen, 2018; Lawson et al., 2009; Vijver et al., 2011), while technical mechanisms are more effective in promoting the sharing of explicit knowledge (Le Dain et al., 2020; Naeem, 2019; Oesterreich and Teuteberg, 2019).

Existing research has yet to address three major issues, particularly in the context of megaprojects. *Firstly*, current studies only explore the optimal IKS mechanisms based on the tacitness of knowledge, overlooking other knowledge characteristics, such as knowledge heterogeneity. For instance, project status information involving project progress or changes in external environmental conditions is explicit knowledge and should be shared through rapid and timely technical mechanisms. Similarly, technical guidelines, also belonging to explicit knowledge, should be shared through structured and systematic technical mechanisms. Therefore, a knowledge classification framework that considers other knowledge features, such as knowledge heterogeneity, would be beneficial for further refining and establishing effective IKS mechanisms. *Secondly,* current research lacks a systematic framework to elucidate and categorize IKS mechanisms from a theoretical perspective encompassing both social and technical dimensions. Such a framework is necessary for devising strategies that complementarily address the sharing of knowledge with different characteristics. *Thirdly,* a matching relationship should be established between the types of knowledge and IKS mechanisms. Moreover, a configuration strategy involving multiple mechanisms should be considered for each type of knowledge rather than relying on a single type of mechanism to promote IKS. For example, interorganizational workshops can be combined with other mechanisms, such as timely or systematic document mechanisms, to facilitate IKS concerning the application of a new technology in megaprojects.

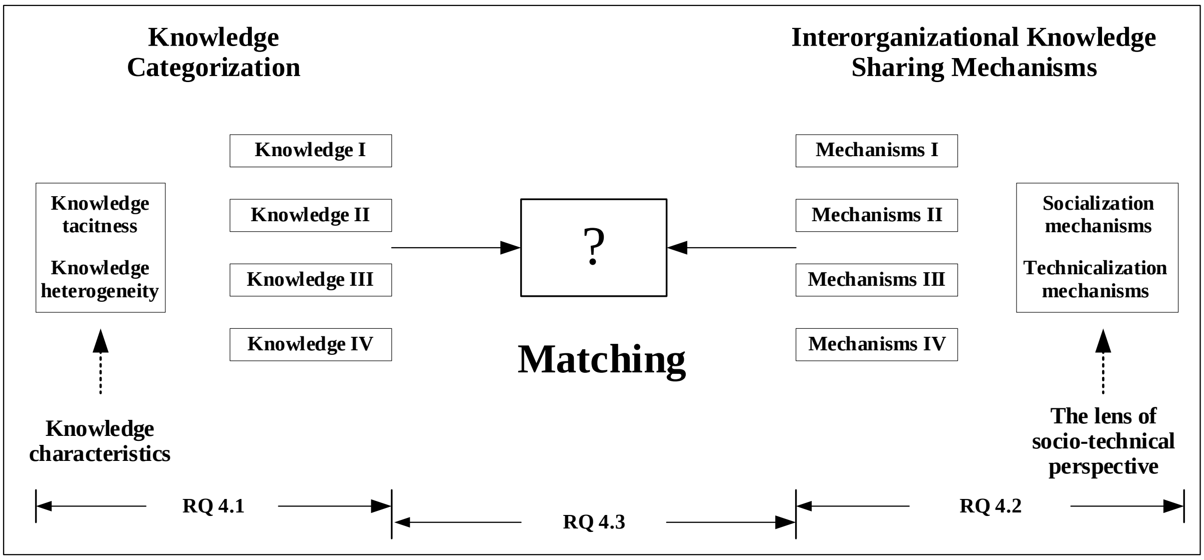

Figure 4.1 Research questions outline

To address these research gaps, this study responds to the call made by Iftikhar and Ahola (2020) to focus on the “process” rather than the “outcome” of IKS and extends the work of Nisula et al. (2022) on exploring the knowledge co-creation in strategic interorganizational projects to categorize knowledge and form proper IKS mechanisms to facilitate the sharing of different types of knowledge in megaprojects. The specific research objectives of this chapter are: (i) to systematically identify the types of knowledge shared across organizations in megaprojects, classifying them based on two-dimensional characteristics — tacitness and heterogeneity of knowledge; (ii) to construct a classification framework for different IKS mechanisms from a social-technical theoretical perspective; (iii) to explore the matching relationships between different types of knowledge and various IKS mechanisms, as illustrated in Figure 4.1. The results provide theoretical framework and practical recommendations for enhancing IKS in megaprojects by addressing the following three research questions:

RQ 4.1: *What categories of knowledge are shared across organizations in megaprojects?*

RQ 4.2: *What IKS mechanisms are adopted in megaprojects from the socio-technical perspective?*

RQ 4.3: *How to match distinct IKS mechanisms with the sharing of different categories of knowledge?*

4.2 Research Design

The qualitative exploration of the three research questions aimed to develop a comprehensive understanding of IKS practices in megaprojects. Qualitative data from both primary sources (such as semi-structured interviews, detailed in section 3.3.2) and secondary sources (including published books and project documents, outlined in section 3.3.2) were employed to form and triangulate the research findings. The grounded theory method was utilized for data analysis, as detailed in section 3.4.1. Additionally, the outcomes of the analysis underwent validation through a focus group discussion, as described in section 3.3.4.

4.3 Findings

This section meticulously presents the results of the grounded theory research, identifying four categories of knowledge (including *real-time project status, innovative management practices, cutting-edge technical skills,* and *integrated technical guidelines*) and a four-dimensional framework of IKS mechanisms (encompassing *large-scale interorganizational* *events, small-scale offline interactions, instant online communication,* and *document synthesis and summarization*). Figure 4.2 showcases the coded theoretical dimensions, secondary, and primary themes, with further elaboration in subsequent sections.

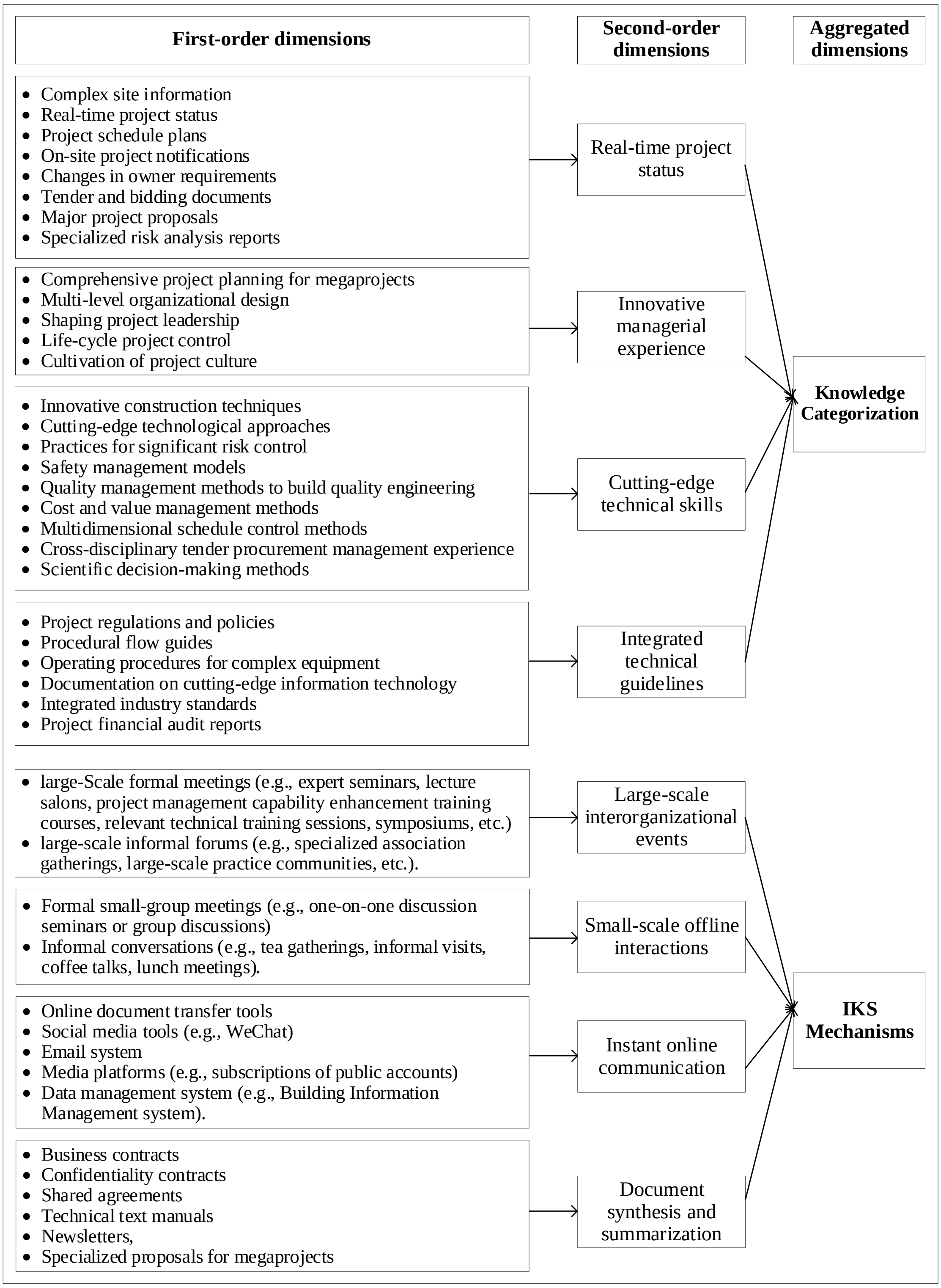

Figure 4.2 Empirical findings of knowledge categories and IKS mechanisms in projects

4.3.1 Identification of knowledge categorization

4.3.1.1 Real-time project status

The research findings reveal that "real-time project status" information is a type of explicit management-related knowledge frequently mentioned by the respondents as shared across organizations in megaprojects, reflecting the real-time and updated status of the project and the dynamic external environment. *Firstly*, due to the complex and ever-changing natural environment in which infrastructure megaprojects are typically situated, having real-time and accurate site information is essential for MSOs to keep them on the right track. For example, in the early stages of project initiation, the designer and consultant should conduct a comprehensive assessment of the project's overall natural geographic environment, forming an investigative report to provide a decision-making basis for other MSOs in design and construction. Additionally, during the construction period of megaprojects, the environmental meteorological team needs to monitor the project's natural geographic environment in real-time and share this information with other MSOs to ensure the smooth implementation of their construction tasks. *Secondly*, understanding the real-time progress of megaprojects through regular project reports, including information on quality, progress, safety, environmental protection, etc., is indispensable for MSOs. For instance, project schedule plans and on-site project notifications are crucial aspects of real-time project status information. *Thirdly*, another important aspect of real-time project status information pertains to the requirements of the project owner. Due to the significant technical and methodological challenges in megaprojects, the owner's understanding and grasp of the project continually improve and change. The specific requirements of the owner may undergo constant changes. For example, during the actual construction process, a new type of material may be used to replace the materials specified in the original design.

Additionally, as megaprojects have long delivery cycles, lasting for decades, the social value they provide and the societal services they need to meet will continually evolve. MSOs in megaprojects need to be keenly aware and responsive to the changing needs of the project owner. For instance, the development of new energy technologies may significantly increase the demand for charging infrastructure, guiding the direction of the project. *Furthermore*, megaprojects face immense technical and managerial challenges, requiring the attraction and adoption of solutions from world-class contractors. Professional tender documents accurately and comprehensively describing engineering challenges, project characteristics, etc., are essential to attract bidders with the best resources. Therefore, bid information needs to be widely shared among MSOs in megaprojects. Moreover, the respondents in this study also proposed materials to optimize project implementation, such as specialized risk analysis reports and project proposals. These materials reflect the real status of the project, providing a scientific analysis basis for decision-making and implementation.

4.3.1.2 Innovative managerial experience

"Innovative managerial experience" is the second type of knowledge shared across MSOs and reflects implicit management-related knowledge shared across organizations in megaprojects, involving insights, understanding, and creativity accumulated by MSOs in project management or organizational management. This type of knowledge can greatly enhance project performance and is crucial for the successful delivery of megaprojects. While this knowledge must be acquired and accumulated in daily project practices or from external resources, it is often not widely shared among MSOs due to its tacitness characteristic. *Firstly*, respondents emphasized managerial experience in project planning. Given the societal attributes of megaprojects, such as creating landmark buildings and driving regional economic development, effective project planning skills contribute to enhancing the social value and sustainability of megaprojects. Good planning skills contribute to a more resilient and comprehensive project planning for megaprojects. *Secondly*, due to the complexity of megaprojects, involving numerous MSOs and often funded by the government, requiring coordination among multiple government departments and compliance with multi-level legal systems, multi-level project management organization design plays a significant role in the smooth and successful delivery of megaprojects.

Moreover, megaprojects face numerous technical and managerial challenges, and charismatic leaders with capabilities can encourage more MSOs to share effective experiences in managing these challenges. For managers from different MSOs in megaprojects, cultivating and enhancing experiences in multidimensional leadership, such as strategic, transformative, and democratic leadership, is another crucial aspect of innovative managerial experience. Encouraging team members to feel “engaged” in the project, fostering a sense of belonging and loyalty, is vital for motivating effects in megaproject management. For instance, several respondents repeatedly mentioned the leadership role of megaproject owners in promoting “partnerships,” resonating with and receiving responses from numerous project contractors and suppliers. *Furthermore*, respondents pointed out that experience in holistic project control, covering processes, costs, quality, progress, etc., is an important aspect of innovative managerial experience. A good plan should be dynamic, adapting to changes in time and the environment and requiring continuous improvement. Mature and effective project control practices, such as the PDCA cycle (Plan-Do-Check-Action), interface management between different processes, just-in-time production strategies, value engineering, and lean construction practices, are often shared among MSOs in megaprojects. *Last but not least*, another significant aspect of innovative managerial experience is how to shape a positive project culture. Organizations participating in the delivery of megaprojects essentially form a social network consisting of multiple MSOs, and project culture shapes their behavior, significantly influencing project performance on the “soft” side. Good project cultural practices, such as collaboration and “partnerships,” need to be jointly cultivated by all MSOs in megaprojects.

4.3.1.3 Cutting-edge technical skills

In addition to management-related knowledge, the types of knowledge shared among MSOs also include technical knowledge. Among them, implicit technical knowledge can be generalized as cutting-edge technical skills, involving implicit technical tricks, best practices, or experiential rules that need to be acquired through learning by doing in engineering practice. The technical challenges MSOs face far exceed imagination and go beyond the control of any single organization. Collaboration and IKS provide the best prescription for addressing complex technical problems. *Firstly*, innovative construction techniques and cutting-edge technical methods are two commonly mentioned types of cutting-edge technical skills. For example, the success of the Hong Kong-Zhuhai-Macao Bridge depended on the key technology of immersed tube tunneling. Traditional immersed tubes involve two structural systems: rigid and flexible. Rigid structures are advantageous for preventing leakage but are not suitable for dealing with ground settlement, while flexible structures are the opposite. The immersed tubes of the Hong Kong-Zhuhai-Macao Bridge are buried more than 20 meters deep, bearing a load five times that of traditional immersed tubes, posing a "technological forbidden zone" where both flexible and rigid structural systems are difficult to adapt. The general contractor for the island tunnel project of the Hong Kong-Zhuhai-Macao Bridge collaborated with multiple research units (consultants), creatively proposing the concept of a "semi-rigid structure" through in-depth comparative studies of flexible and rigid structures. This idea filled the shortcomings of traditional flexible or rigid structural systems and was ultimately theoretically and practically validated through seminars, expert consultations, and simulated experiments conducted back-to-back with different research institutions at home and abroad. The "semi-rigid structure" breakthrough addressed the "bottleneck" challenge of immersed tunnel technology and expanded the application scope of immersed tube tunnels.

Moreover, delivering megaprojects in the implementation process is nonlinear, and difficulties and problems encountered are challenging to foresee in advance. Megaproject management requires achieving a balance between control and change. Project management technical experience is an important component of cutting-edge technical skills shared among MSOs in megaprojects. It can help them adjust actions to achieve balance and involves methods such as major risk control, safety management models, quality engineering, cost and value management methods, multidimensional schedule control methods, cross-disciplinary tender procurement management experience, etc. These technical experiences require the collective wisdom of different MSOs and IKS to achieve higher project performance. *Finally*, complexity and uncertainty are prominent features of the difficulties and problems faced in the delivery process of megaprojects. Experiences in scientific decision-making methods are also frequently shared among MSOs to form consensus and achieve value co-creation.

4.3.1.4 Integrated technical guidelines

Another aspect of technical knowledge is "integrated technical guidelines", classified as explicit technical knowledge. These guidelines guide the production activities of MSOs, including clear technical documents, manuals, and classification documents that support project production activities. *Firstly*, project regulations and procedures are an important part of the integrated technical guidelines among MSOs. They involve public policies and regulatory documents related to megaproject delivery, such as the *Environmental Protection Act, Housing Grants, Construction and Regeneration Act, and BIM Technology Act*. They also involve internal regulations and procedural guidelines for all MSOs, such as safety regulations, quality inspection specifications, change and issue logs, etc. *Secondly*, due to the technical complexity of megaprojects, various large and complex equipment is used in the project delivery process, requiring communication and cooperation among multiple MSOs. Therefore, manuals for the operation procedures of large and complex equipment are another important type of technical guidance document. These manuals guide operators from multiple parties on how to sequentially complete project tasks.

Moreover, due to the technical complexity of megaprojects, a variety of super-large and complex equipment is used in the project delivery process, requiring communication and collaboration among multiple MSOs. Therefore, manuals for the operation procedures of large and complex equipment are another important type of technical guidance document. These manuals guide operators from multiple parties on how to sequentially complete project tasks. *Furthermore*, in the construction process of megaprojects, the application and promotion of cutting-edge technology are often required to create benchmark projects. Therefore, each participating party needs to integrate industry and research documents related to cutting-edge technology, continuously optimize standard procedures, record professional insights and experiences accumulated in practice, share and integrate them with each other, and form new documents for the application of cutting-edge technology. *Additionally*, megaprojects require the integration of the best resources from around the world, and each participating party will engage in cross-industry and cross-domain visits to learn from the most advanced technological experiences during the project execution process. This contributes to the formulation of new industry standards and promotes the successful delivery of the project. For example, the design standards of the Hong Kong-Zhuhai-Macao Bridge project fully absorbed typical design concepts and technical standards from around the world. For example, aspects such as bridge design principles, loads, prestressing, expansion joints, retaining walls and piers, aerodynamic effects, fatigue, use of steel structures, construction safety, lighting, etc., referenced BS (British Standard) standards. *Finally*, cost estimation is crucial for the long-term financing of megaprojects, and regular financial and progress reports are often shared among MSOs.

4.3.2 Identification of IKS mechanisms

Another important goal of this study is to clarify the IKS mechanisms among MSOs. Based on the coding results from grounded theory, these mechanisms can be categorized into four aspects.

4.3.2.1 Large-scale interorganizational events

According to the coding results, the first category of IKS mechanisms involves the event mechanism through organizing large-scale meetings. This mechanism facilitates extensive communication and interaction among a large number of individuals representing various organizations and is characterized by a high degree of socialization and technologization. It includes organizing or attending large formal meetings for IKS, such as expert seminars, lecture salons, training courses for project management capacity enhancement, relevant technical training courses, and roundtable discussions. Additionally, informal forum organizations, such as special associations and large-scale communities of practice, are another essential type of large-scale interorganizational event. The formal organization of large-scale meetings is widely employed in megaprojects to achieve IKS, as it allows knowledge to be transmitted on a large scale and efficiently. Moreover, informal event mechanisms are also prevalent because they create opportunities for direct organizational involvement and obtaining diverse perspectives.

4.3.2.2 Small-scale offline interactions

Secondly, the mechanism of small-scale offline interaction is defined as different MSOs engaging in face-to-face social interactions to exchange information and facilitate IKS. This includes formal small-scale meetings (such as one-on-one or group discussions) and informal conversations (such as tea meetings, informal visits, coffee discussions, and lunch meetings). According to interview results, social mechanisms are conducive to building trust between parties, further promoting the sharing of implicit knowledge among MSOs.

4.3.2.3 Instant online communication

Thirdly, the mechanism of instant online communication refers to the rapid and effective exchange of information for technical communication and IKS through instant messaging. This includes online document sharing tools, social media tools such as WeChat, email, website public accounts, BIM (Building Information Management) systems, and other technological platforms. With the significant development of information and communication technology, technical mechanisms have become increasingly effective and widely used in cross-organizational communication in megaprojects. According to interview results, the use of technical mechanisms for IKS not only offers the advantage of quick and convenient information exchange but also plays a role frequently mentioned by respondents: providing an effective record and storage of shared information and knowledge for further retrieval and application.

4.3.2.4 Document synthesis and summarization

Lastly, the document synthesis and summarization mechanism refers to the IKS by exchanging summarized and condensed documents. This includes collaboratively drafting business contracts, shared document agreements, significant project proposals, technical manuals, and other documents. These documents are crucial for organizations to accumulate and transform implicit project experience into explicit knowledge. According to the interview results of this study, this mechanism is the most widespread in IKS. The knowledge presented in standardized documents is richer and more easily shared and stored by recipients for further reference and use.

4.4 Discussions

Loebbecke et al. (2016) conducted a study on two factors influencing IKS: (1) the type of knowledge, whether explicit or implicit, and (2) the IKS patterns between organizations, either unilateral or bilateral. They proposed four mechanisms for coordinating and promoting IKS: structural, procedural, technical, and social. Additionally, they called for future research to conduct more empirical studies focusing on specific industries or organization-related fields of cross-organizational collaboration and knowledge sharing. Megaprojects are complex mega-projects involving collaboration among multiple temporary organizations (stakeholders) to deliver a common outcome (Flyvbjerg and Turner, 2018). These projects entail numerous situations of IKS. Therefore, this chapter aligns with the work of Loebbecke et al. (2016) and aims to explore megaprojects as a specific type of interorganizational endeavor. The goal is to investigate, identify, and categorize knowledge shared among MSOs and understand the matching relationships between different types of knowledge and various categories of IKS mechanisms. Subsequently, these two research objectives will be discussed in sequence.

4.4.1 Knowledge shared across MSOs

Through systematic literature review, semi-structured interviews, and subsequent text analysis, this study identified four types of knowledge shared among various MSOs: real-time project status, innovative managerial experience, cutting-edge technical skills, and integrated technical guidelines. Based on the characteristics of knowledge tacitness (i.e., explicit or tacit) and heterogeneity (i.e., technical or managerial), these four types of knowledge correspond to four distinct scenarios, as illustrated in Table 4.1.

Firstly, real-time project status is categorized as explicit managerial knowledge. MSOs rely on this type of knowledge sharing to adjust their strategies or approaches to cope with the complexity of the environment and take corresponding corrective measures (H. Liu et al., 2020). Secondly, innovative managerial experience is classified as tacit managerial knowledge. This knowledge is crucial for enhancing organizational efficiency and project performance comprehensively (Zhou et al., 2021), but it is not easy to express explicitly in the practical process, leading to a loss of knowledge value. Moreover, cutting-edge technical skills are another type categorized as tacit technical knowledge. The successful delivery of megaprojects relies on innovation in cutting-edge technology, which results from the combined utilization-based sharing of existing technological experience and exploration of emerging technologies (Liu et al., 2022). Finally, integrated technical guidelines are categorized as explicit technical knowledge. This type of knowledge can be more easily understood and shared to help participants in megaprojects standardize their behavior and promote production performance (Mai et al., 2018).

Table 4.1 Categorization of knowledge shared in megaprojects

Knowledge categorization	**Knowledge characteristics**		**Description**
	Knowledge heterogeneity	**Knowledge tacitness**	
Real-time project status	Managerial	Explicit	Real-time project status refers to updated and useful information reflecting project status and external environment, including site condition, project status, client requirements, project proposals, and special analysis reports.
Innovative managerial experience	Managerial	Tacit	Innovative managerial experience is defined as the essential accumulated organizational insights, understanding, and creativeness in project management or organization management, such as project planning skills, organization design, leadership shaping, process control, and project culture shaping.
Cutting-edge technical skills	Technical	Tacit	Cutting-edge technical skills refer to tacit technological know-how, best practices, or rules of thumb that can be gained through learning by doing, such as construction methods, technique know-how, project management expertise, decision-making experience, and problem-solving methods.
Integrated technical guidelines	Technical	Explicit	Integrated technical guidelines refer to explicit technological documents, handbooks, and sorted files that assist in project production activities, including organizational rules and policies, technique documents, financial and accounting reports, operational procedures, instruction manuals, and human resources data.

Existing research has also made preliminary explorations into the classification of inter-organizational knowledge. For example, Iftikhar and Ahola (2020) identified two different types of knowledge (explicit and tacit) in a case study of a subway train infrastructure project and explored how it is shared at four levels: individuals, teams, organizations, and inter-organizations. However, this fuzzy classification standard for knowledge sharing in megaprojects is insufficient. Other organizational and project management scholars have found that the heterogeneity of knowledge (such as managerial or technical knowledge) greatly influences innovation and project performance (Ye et al., 2016; Zhang and Li, 2016). Xue (2018) indicated that the sharing of managerial knowledge, technological knowledge, and market knowledge can generate different types of sharing networks and innovation clusters. Therefore, based on empirical investigations of practitioner experiences, this study identifies and creates a framework for classifying IKS among MSOs (Loebbecke et al., 2016), providing insights for project managers to recognize what knowledge should be shared in future megaprojects.

4.4.2 IKS mechanisms adopted in megaprojects from the socio-technical perspective

Existing research indicates that different types of IKS mechanisms are suitable for facilitating the sharing of different types of knowledge (Fang et al., 2013). The results of this chapter elaborate on a series of practical IKS mechanisms in megaprojects. The socio-technical perspective provides an ideal theoretical viewpoint for exploring how different characteristics of IKS mechanisms promote the sharing of knowledge with different features (i.e., knowledge tacitness and heterogeneity) (Malhotra et al., 2021; Zhou, 2019). Elia et al. (2021) proposed that the goal of project management was to utilize interdisciplinary knowledge, achieve a combination of “hard” technology based on natural information science and “soft” behavior based on social and humanistic science, and obtain effective socio-technical innovative solutions. From the socio-technical perspective, this chapter categorizes inter-organizational knowledge-sharing mechanisms into four types based on the degree of socialization and technologization, as shown in Table 4.2.

Table 4.2 Categorization of IKS mechanisms

IKS mechanisms	Mechanism Characteristics		Description
	Socialization	Technicalization	
Large-scale interorganizational events	High	High	Large-scale interorganizational events mechanisms refer to the IKS activities involving the meetings and interactions of many people across organizations, including formal types, such as conferences, presentations, incubator training, entity training, talks, and meetings, and informal types, such as communities of practices.
Small-scale offline interactions	High	Low	Small-scale offline interaction mechanisms are defined as all mechanisms with direct human interaction among a few persons, which also could be divided into two types: formal mechanisms, such as one-to-one meetings and group discussions, and informal mechanisms, such as coffee breaks, lunches, and occasional visits.
Instant online communication	Low	High	Instant online communication mechanisms refer to sharing knowledge through powerful technical tools to transfer information quickly and effectively, such as online document transfer, social networks, email, official websites, and information management systems.
Document synthesis and summarization	Low	Low	Document synthesis and summarization mechanisms are defined as tools in explicit, written, well-defined, and systematic forms, such as business contracts, confidentiality contracts, agreements, documents, newsletters, and proposals.

Firstly, the event mechanism of organizing large-scale meetings reflects high levels of socialization and technologization. It provides ample opportunities for interaction and knowledge sharing across organizational boundaries in megaprojects, including organizing or participating in large formal meetings and organizing informal forums for communication, such as specialized associations and practice communities (Hetemi et al., 2022; Wanberg et al., 2017). *Secondly*, the social mechanism of small-scale offline communication has high socialization but low technologization characteristics. It serves as another important black box for successful IKS and collaboration, helping overcome some communication barriers related to people, such as facilitating the establishment of trust relationships (Gal et al., 2014), collaborative emotions, and cognitive representations (White Zuzul, 2018). *Thirdly*, the instant online communication and information technology mechanism has high technologization but low socialization characteristics, which can help overcome spatial, temporal, and geographical barriers in IKS (O'Leary and Cummings, 2007). Malhotra et al. (2021) point out that information media can greatly simplify and accelerate instant information transmission, assisting participants in megaprojects in identifying, sharing, and obtaining various technical documents, such as notices, two-dimensional drawings, and three-dimensional building information models. Finally, the document summarization and summarization mechanisms have low socialization and technologization characteristics. However, due to its flexibility and structure, it can form standardized best practice templates, helping reduce the fragmentation of understanding and being widely used in practical megaprojects (McCarthy et al., 2021).

4.4.3 Matching distinct IKS mechanisms with the sharing of different categories of knowledge

Existing research has explored how different categories of knowledge should be matched with different IKS mechanisms (McCarthy et al., 2021; Nisula et al., 2022). For example, Fang et al. (2013) constructed an IKS mechanism matrix, including market-based, trust-based, reciprocity-based, and norm-based patterns, to elucidate the relationships between knowledge characteristics, such as context ambiguity and content ambiguity, and knowledge transfer barriers, including uncertainty barriers and equivocality barriers, with the performance of IKS. Balle et al. (2019) studied the impact of combinations of four mechanisms—technological mechanisms, social mechanisms, documental mechanisms, and events mechanisms—on the efficiency of IKS for managerial and technical knowledge. Although managerial and technical knowledge should be treated differently (Sammarra and Biggiero, 2008), knowledge heterogeneity was not considered in this model. Based on this, Iftikhar and Ahola (2020) proposed a comprehensive model linking knowledge heterogeneity and organizational hierarchy to IKS mechanisms, exploring mechanisms at different levels, including individual, team, intra-organizational, and inter-organizational levels. Subsequently, Mokhtarzadeh et al. (2021) conducted a systematic review of the literature, combined with a mixed multi-level decision-making approach, and linked inter-organizational knowledge mechanisms, including person-to-person, co-creation, team-oriented, and informational, to networking capability building. Recently, Li et al. (2022) connected knowledge heterogeneity with the demand for project managers' capabilities and skills. By referencing conceptual models and discussions proposed in previous studies (Nonaka et al., 2006; Nonaka and Lewin, 1994) and focus group discussions, this study reveals the matching mechanisms between knowledge categories and IKS mechanisms, as shown in Table 4.3.

This research developed previous mechanisms that mainly focused on transferring and transforming knowledge between "tacitness" and "explicitness" by considering the knowledge heterogeneity.

Table 4.3 Match between knowledge categories and IKS mechanisms

Knowledge categorization	IKS mechanisms			
	Cutting-edge technical skills Cell 1	Innovative managerial experience Cell II	Real-time project status Cell III	Integrated technical guidelines Cell IV
Large-scale interorganizational events	☆	○	○	△
Small-scale offline interactions	○	☆	○	△
Instant online communication	○	○	☆	○
Document synthesis and summarization	△	△	○	☆

Note： ☆= Primary Mechanism; ○=Secondary Mechanism; △ =Unidentified mechanism

Cell I: Mechanisms for sharing cutting-edge technical skills. In megaprojects, cutting-edge technical skills fall under tacit technical knowledge, and their content often spans multiple fields and disciplines, such as construction methods from traditional site-construction methods to prefabricated production and rapid manufacturing approaches. Therefore, a broad and open platform and context for communication are needed when sharing such knowledge across organizations (Hetemi et al., 2022). This chapter found that the event mechanism of organizing large conferences provides such an opportunity. It is an effective platform that stimulates in-depth thinking and exchange of technical skills among professionals from different organizations, such as symposiums, brainstorming sessions, capability enhancement seminars, and skill training sessions (Grabher and Thiel, 2015). This result supports the perspective of Mokhtarzadeh (2021) that the event mechanism of organizing large conferences is more effective in creating new technical knowledge when various understandings are complimented. On the one hand, event mechanisms can facilitate timely interaction and feedback among groups, thereby promoting the sharing of implicit knowledge at the inter-organizational level

(Balle et al., 2019). On the other hand, sharing innovative technical skills requires a climate of interdisciplinary, organizational-intensive discussions, mutual inspiration, and collective wisdom, which was mainly and absolutely facilitated by event mechanisms (Liu et al., 2021). For example, MSOs often encourage the establishment of practice communities, providing a platform for professionals from interdisciplinary organizations to connect, exchange best practices derived from project experience and mature technologies, and seek innovative solutions to certain technical problems, ultimately collectively improving project performance (Choi et al., 2020). In addition to formal and informal conference mechanisms, social mechanisms for organizing small-scale offline communication and technical mechanisms that encourage real-time information exchange also influence the inter-organizational sharing of technical skills. These two mechanisms are more flexible for sharing implicit cutting-edge technical skills than event mechanisms since the latter consumes significant organizational resources and is not used frequently. According to the results of interviews and focus group discussions in this chapter, because implicit knowledge is mostly embedded in organizations, explicit document summarization mechanisms are not advocated by the interviewed experts in the sharing of technical skills.

Cell II: Mechanisms for sharing innovative managerial experience. Due to the nature of implicit knowledge, the innovative managerial experience delivered in megaprojects is challenging to articulate explicitly and is mainly accumulated and mastered by project managers over years of project practice (Grabher and Thiel, 2015). This study found that small-scale offline communication social mechanisms, characterized by formal or informal interactions among a minority of individuals (Lawson et al., 2009), are the optimal mechanisms for promoting the sharing of innovative managerial experience through direct inter-organizational interaction. Unlike the event mechanisms of organizing large conferences that facilitate inter-organizational interaction among groups, small-scale offline communication social mechanisms foster face-to-face interaction among individuals between organizations, which helps deepen their understanding of the managerial experience and its usage context (Mokhtarzadeh et al., 2021). Besides, informal communication through small-scale offline communication social mechanisms enhances trust among individuals and partnerships between organizations more than other mechanisms (Aaltonen and Turkulainen, 2018). MSOs are mostly temporarily formed for collaboration, implying that IKS lacks the foundation of trust and culture. Informal social mechanisms, including formal small-scale meetings (e.g., one-on-one discussion seminars or group discussions) and informal conversations (e.g., tea meetings, informal visits, coffee conversations, lunch conversations), can create opportunities for individual inter-organizational interaction, strengthen connections, and thus promote inter-organizational trust and knowledge sharing (Huang et al., 2021). Innovative managerial experience is an intangible asset for organizations. Close relationships undoubtedly bridge two MSOs and facilitate value exchange through inter-organizational sharing of managerial experience (Neves et al., 2014). This study also found that instant online communication mechanisms can simplify the communication process, reduce physical barriers to information transmission, and, therefore, serve as a secondary mechanism to facilitate the inter-organizational sharing of innovative managerial experience.

Cell III: Mechanisms for sharing real-time project status. Real-time project status is an important type of explicit knowledge that reflects the real-time internal or external conditions of the project site, such as the latest weather conditions and project progress information. This study found that real-time technological mechanisms can meet the needs of inter-organizational sharing of such knowledge among MSOs for the following reasons (Lobo and Abid, 2020; Senaratne et al., 2021). Firstly, the inter-organizational sharing of this knowledge requires ensuring real-time and accuracy. MSOs can use online document transfer tools, social media tools such as WeChat, email, website public accounts, building information management systems, and other technologies to expedite and simplify the process of sharing real-time project status information (Pian et al., 2019). Secondly, such mechanisms can help MSOs update and retain necessary project status information for future reference and traceability (Oliveira and Lumineau, 2017). For example, many conflicts in cost management originate from unclear design change records. In addition, other IKS mechanisms also play a complementary role in sharing knowledge related to real-time project status information. For instance, project information disclosure through large-scale organizational meeting mechanisms can help MSOs simultaneously understand and be informed about project status in a short period (Nahyan et al., 2018). Furthermore, social mechanisms through small-scale offline communication provide an informal channel for inter-organizational sharing of project information. Finally, document summarization mechanisms based on documents facilitate organizations in systematically and comprehensively obtaining project information (Li et al., 2023).

Cell IV: Mechanisms for sharing integrated technical guidelines. Integrated technology guidelines guide the production activities of participants in megaprojects, including explicit technical documents, manuals, and categorized files that support project production activities. This study found that a written, explicit, and well-defined document summarization mechanism efficiently promotes the inter-organizational sharing of integrated technology guidelines (Mahura and Birollo, 2021; Nisula et al., 2022). The main reason is that technology guidelines are usually scattered, documenting a large number of best practices, procedures, and management processes in the technical domain. The best way to store and share such knowledge among organizations is to organize them into a set of systematically complete booklets, namely, a document summarization-based mechanism. For example, in this study, a respondent from a contractor described that when they apply a new technology or equipment from a supplier, having a detailed and comprehensive standard that introduces specifications, procedures, and samples can greatly simplify their time and energy costs. Besides, technical guidelines are explicit, easy to understand, and independent of the donating organizations. Knowledge recipient organizations could search for helpful knowledge at their convenience through document mechanisms (Appel-Meulenbroek et al., 2018). This chapter also reveals that instant information technology can further assist the inter-organizational sharing of such knowledge, providing an informal channel for sharing technical guidance, promoting the dissemination of new technologies, and enhancing understanding and tracking of cutting-edge fields among MSOs (Balle et al., 2019).

In summary, a unique combination of various IKS mechanisms proved effective in facilitating the exchange of diverse knowledge categories across MSOs. A well-aligned model that considers the characteristics of knowledge and IKS mechanisms enhances IKS compared to a misaligned model, as suggested by (Fang et al., 2013). From a socio-technical perspective, IKS mechanisms exhibiting a high degree of socialization (e.g., large-scale interorganizational events and small-scale offline interaction mechanisms) align well with tacit knowledge sharing, encompassing cutting-edge technical skills and innovative managerial experience. Conversely, IKS mechanisms characterized by a high level of technicalization (e.g., instant online communication and document synthesis and summarization mechanisms) are suitable for explicit knowledge sharing, involving real-time project status and integrated technical guidelines. However, it was observed that relying on a single IKS mechanism alone is insufficient. Supplementary mechanisms play a crucial role in compensating for the socialization and technicalization features of IKS mechanisms. For instance, an interorganizational workshop (event mechanism) stands out as the most effective means to promote new technology in megaprojects. Moreover, the combination of coffee breaks and ongoing online discussions post-workshop proves beneficial in fostering a deeper understanding of the newly introduced technology.

4.5 Chapter Summary

In megaprojects, due to the independent engagement of various participants in their respective project tasks and divergent interests, IKS among MSOs is often less than optimal. However, it is necessary for fostering project innovation, value creation, and performance improvement (Marchegiani et al., 2020; Modi and Mabert, 2007). This study responds to the call of Iftikhar and Ahola (2020) by conducting empirical research on IKS processes among MSOs. It provides empirical evidence for knowledge management practices in the context of megaprojects. The study addresses three research questions through theoretical and empirical analyses. *Firstly*, based on semi-structured interviews, a series of knowledge shared among participants in megaprojects was identified (as shown in Figure 4.2). A four-dimensional classification model was also proposed based on the characteristics of knowledge tacitness and heterogeneity to answer RQ 4.1. The model includes integrated technical guidelines, cutting-edge technical skills, real-time project status, and innovative managerial experience (see Table 4.1). *Secondly*, from the perspective of social technology, i.e., based on the degree of socialization and technologization, a four-dimensional IKS mechanism was creatively constructed to answer RQ 4.2, namely large-scale interorganizational events, small-scale offline interatctions, instant online communication, and document synthesis and summarization (see Table 4.2). *Lastly,* configuration strategies between knowledge types and IKS mechanisms were developed to facilitate the inter-organizational sharing of knowledge with different characteristics (see Table 4.3) to answer RQ 4.3.

CHAPTER 5 FACILITATING IKS: EXPLORING THE ANTECEDENTS OF IKS THROUGH BAYESIAN NETWORK ANALYSIS[7]

Multiple factors jointly influence the efficiency of IKS, involving four sets: the resources and capabilities of both the donor and recipient firms, the nature of knowledge that is being shared, and interorganizational dynamics… (Easterby-Smith et al., 2008c, p 678)

The literature review suggests that most papers used quantitative research methods such as questionnaire surveys, limiting the inference of causality between factors. According to the description in the literature, a positive or negative linear relationship exists between factors, but it may be curvilinear. Furthermore, diverse factors form scenarios to influence the efficiency of IKS jointly. (Zhou et al., 2022b, p 234)

5.1 Introduction

In the span of several decades, researchers in the field of organizational studies have progressively recognized the importance of identifying and exploring different barriers and enablers of IKS (Abdelwhab Ali et al., 2019; Becerra et al., 2008; Carnahan et al., 2014; Iftikhar and Lions, 2022; Martin and Emptage, 2019; Ren et al., 2018; Van Wijk et al., 2008; Zhou et al., 2022). In summary, the antecedents of IKS can be categorized into three main groups:

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[7] This chapter is largely based on the following manuscripts:

He, H., He Q.*, & Chan A.P.C. Exploring the driving mechanisms of interorganizational knowledge sharing based on the Bayesian Network Model. (Journal of Construction and Engineering Management, **Under Review**, **First Author**)

He, Q., Chen, Y., **He, H.***, Wang, G., & Chan, A.P.C. How do different types of motivation shape interorganizational knowledge sharing in megaprojects? Findings from PLS-SEM and fsQCA. (International Journal of Project Management, **Under Review**, **Corresponding Author**)

He, Q., Wang, Y., **He, H.**,* Wang, G., & Chan, A.P.C. How does paradoxical leadership facilitate interorganizational knowledge sharing in megaprojects? Through the mediating role of ambidextrous motivations and moderating role of absorptive capacity. (Journal of Knowledge Management, **Under Review**, **Corresponding Author**) factors associated with knowledge characteristics, such as tacitness and complexity (Easterby-Smith et al., 2008; Kim et al., 2013; Milagres and Burcharth, 2019); factors linked to organizational attributes of knowledge donors and collectors, such as the absorptive and sharing capacity (Amoozad Mahdiraji et al., 2022; Iftikhar and Lions, 2022; Martin and Emptage, 2019); and factors related to contextual characteristics, such as project culture and the application of information technology (Bharati et al., 2015; Bosch-Sijtsema and Postma, 2010; Chen et al., 2023; Zhao et al., 2015).

Despite the qualitative and quantitative research identifying and exploring the effects of various ancestral factors, the essential interconnections among these elements have remained relatively unexplored. This hinders the development of more comprehensive and dynamic mechanisms to enhance the efficiency of IKS (Sun et al., 2023). Only a few studies have delved into the interrelationships among a limited set of IKS-related factors using techniques like structural equation modeling (SEM) or traditional regression analysis (Gil-Garcia and Sayogo, 2016; Philsoophian et al., 2022; Zhao et al., 2015). However, these methods often overlook the intricate dependencies between factors and are limited when analyzing causal relationships among multiple factors (Luo et al., 2020). Furthermore, SEM has its limitations regarding prediction since it primarily assesses linear connections between variables and may fail to detect vital associations when nonlinear relationships exist (Sun et al., 2023). Additionally, SEM is unable to simultaneously propagate observations both forward and backward, imposing constraints on optimizing decision-making processes (Gupta and Kim, 2008).

Therefore, delving into these interconnected relationships and potential indirect effects among antecedents within a much broader nomological network makes it possible to uncover more effective approaches for targeting specific factors to form corresponding interventions to enhance. To bridge this research gap, a Bayesian network (BN) approach was utilized to examine the intricacies of interdependencies among influencing factors and their impacts on the IKS efficiency in megaprojects. The research objectives were as follows: (i) construct a comprehensive nomological network quantifying the interrelationships among factors to predict IKS efficiency; (ii) propose corresponding governance strategies, including single strategies by pinpointing the most influential factors, and joint strategies by statistically examining the efficiency of scenarios in forecasting improvements in IKS efficiency. To be more specific, this study has furnished a theoretical framework along with practical recommendations aimed at facilitating IKS in megaprojects by addressing the subsequent two research questions:

RQ 5.1 *How to develop an effective IKS-BN model to quantify the interdependencies of influencing factors and predict IKS efficiency in megaprojects?*

RQ 5.2 *What effective strategies could be formulated to improve the efficiency of IKS?*

5.2 Research Design

The Bayesian network analysis method was employed in this chapter to answer the two research questions. Both qualitative and quantitative data were collected. First, a series of vital factors of IKS was searched through a literature review, as shown in section 3.3.1, based on which questionnaire surveys were conducted to quantify each variable, as shown in section 3.3.3. Besides, Seven industry experts and two professors were invited to join the focus group discussion to form an in-depth understanding of the interrelationship between antecedents of IKS in megaprojects to develop and optimize the IKS-BN model, as shown in section 3.3.4. Last, the procedure of Bayesian network analysis was elaborated in section 3.4.2.

5.3 Results

5.3.1 Model establishment

The finalized IKS-BN model is obtained by following the process of structure learning and parameter learning, as illustrated in Figure 5.1.

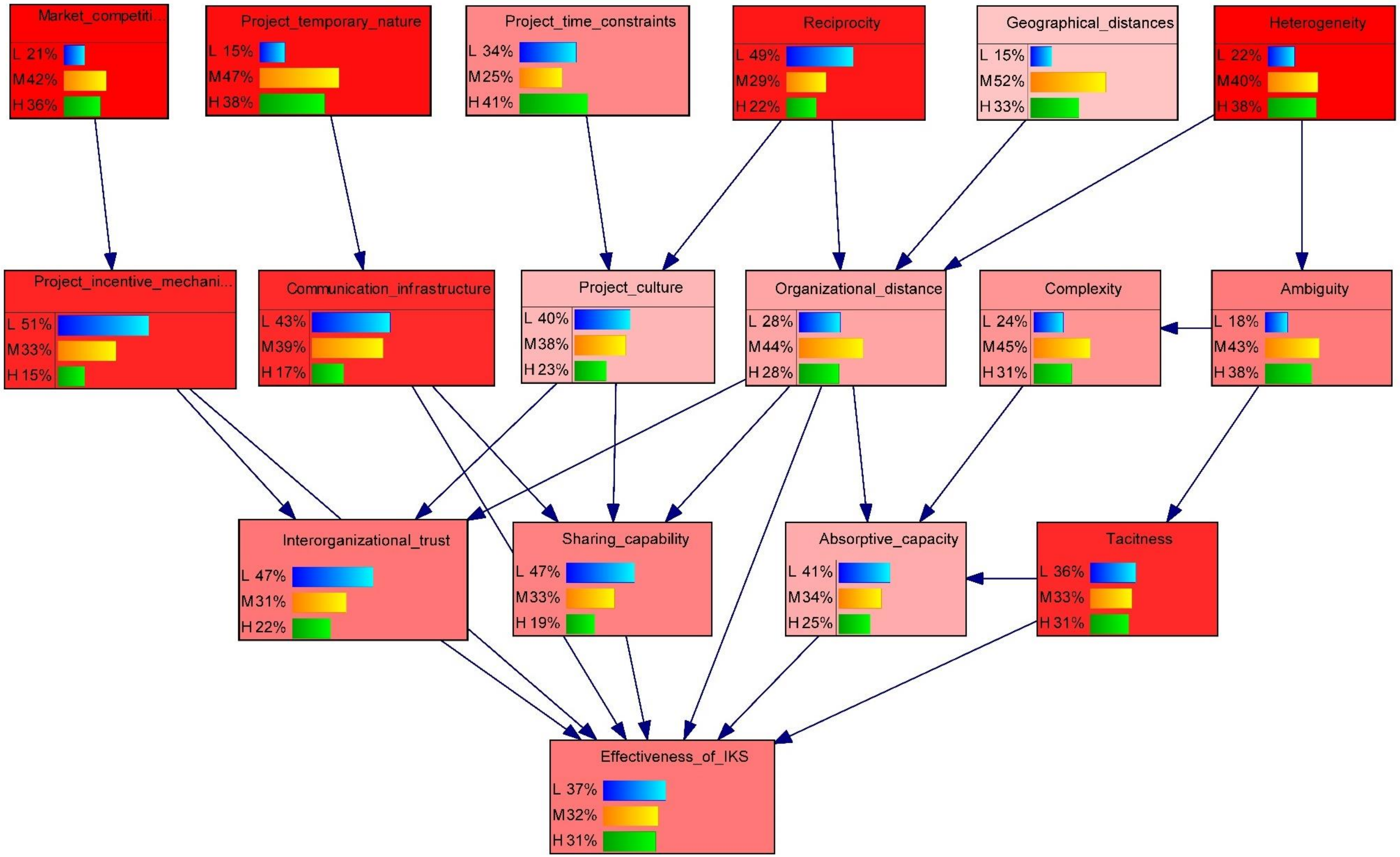


Figure 5.1 The proposed IKS-BN model

The model predicted that around 69% of MSOs suffered from low efficiency of IKS, whereas around 31% of this target population had a high efficiency of IKS. High market competition, the project's temporary nature, project time constraints, lack of reciprocity, long geographical distances, and high heterogeneity of knowledge were root nodes.

Based on the IKS-BN model, multiple factors commonly lead to the MSOs' low efficiency of IKS, including poor interorganizational trust (L= 47% and M= 31%), dissatisfactory sharing capability (L= 47% and M= 33%) and absorptive capacity (L= 41% and M= 34%), inferior project incentive mechanisms (L= 51% and M= 33%), poor communication infrastructure (L= 43% and M= 39%), long organizational distance (M= 44% and L= 28%) and high tacitness of knowledge (M= 33% and H= 31%). Besides, results denote that poor project culture (L= 40% and M= 38%), complexity (M= 45% and H= 31%), and ambiguity of knowledge (M= 43% and H= 38%) indirectly influence the efficiency of IKS by influencing other factors.

5.3.2 Model validation

5.3.2.1 Predictive accuracy validation

The confusion table for predicting the efficiency of IKS is shown in Table 5.1.

Table 5.1 Confusion table of the IKS-BN model

The actual efficiency of IKS	Predicted IKS			User's accuracy	Overall accuracy
	L	M	H		
L	**123**	0	0	1.000	
M	7	**57**	1	0.877	0.941
H	3	3	**46**	0.885	
Producer's accuracy	0.925	0.950	0.979	-	-

Note: The actual efficiency of IKS represents respondents' evaluation in the questionnaire survey. Bold represents the number of times the predicted results are consistent with the actual situation.

The overall accuracy reached 0.942 (226/240), more than 0.8, falling within the acceptable range in extant research (Sun et al., 2023). The producer's accuracy for different levels of IKS efficiency, namely low, moderate, and high, was found to be 0.925, 0.950, and 0.979, respectively, while the user's accuracy was measured to be 1.000, 0.877, and 0.885, respectively.

The ROC (Receiver Operating Characteristic) curves were employed to visually represent the performance of the BN analysis, and these curves are presented in Figure 5.2. The Area Under the Curve (AUC) values for each level of IKS efficiency were all greater than 0.9, which indicates an outstanding level of predictive accuracy for the proposed BN. This high AUC value signifies that the model can effectively distinguish between different levels of IKS efficiency, further supporting the reliability and validity of the IKS-BN prediction model (Sun et al., 2023).

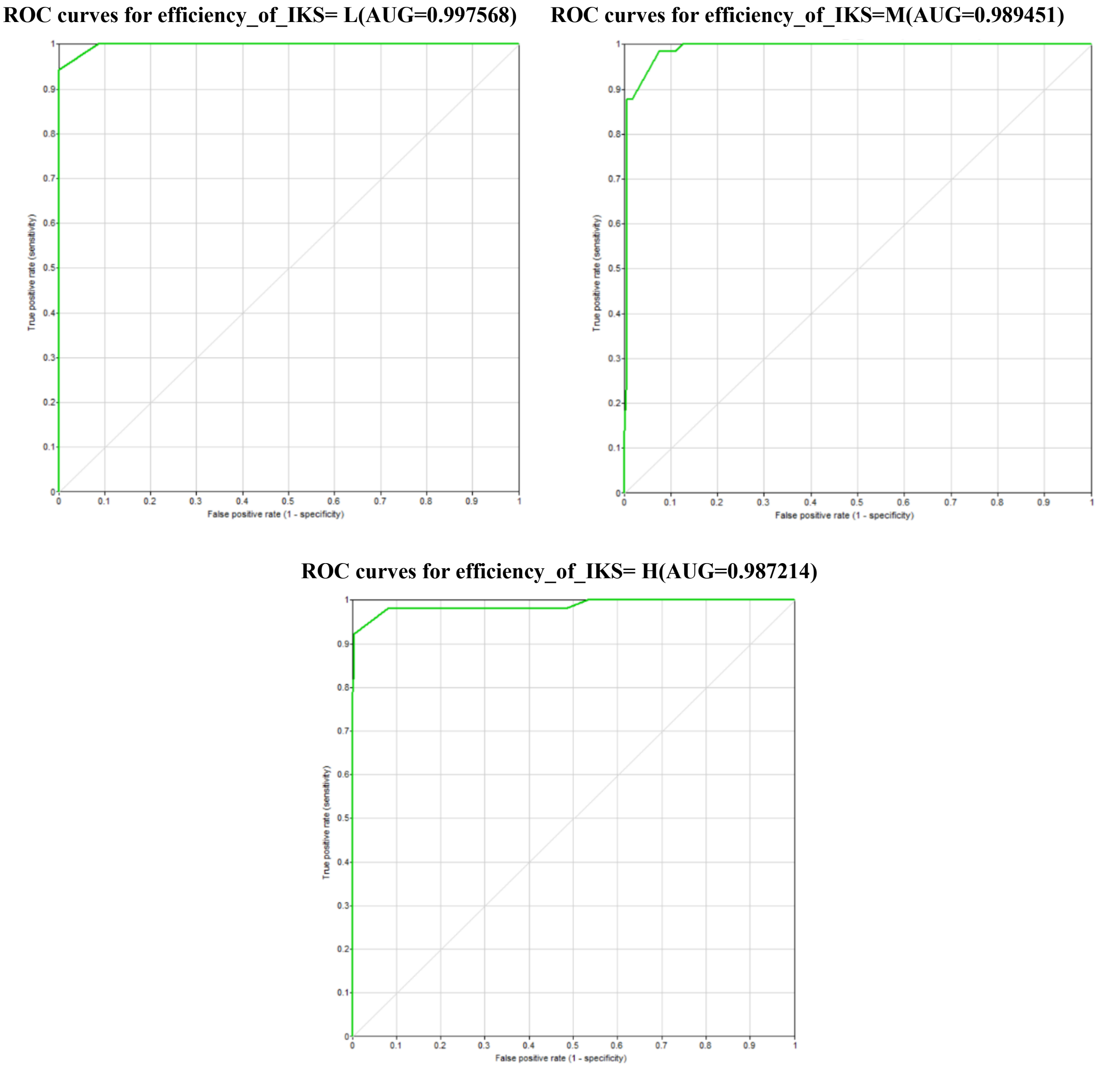


Figure 5.2 ROC curves for Low, moderate, and high levels of IKS efficiency

5.3.2.2 Sensitivity analysis

Two kinds of **sensitivity analysis** were conducted in this study. First, the results of the Mutual Information (MI) statistic measuring the **sensitivity to findings** are denoted in Table 5.2, which ranks the influence of different factors on the efficiency of IKS. A higher MI value for a specific factor indicates a stronger association between that factor and the state of the IKS efficiency. In other words, when information about a factor with a higher MI is known, the efficiency of the IKS outcome becomes more certain. According to the results, absorptive capacity emerged as the most influential factor for the efficiency of IKS. Following closely behind were sharing capability, interorganizational trust, and project incentive mechanism, in descending order of influence. It is also revealed that geographical distances, project time constraints, market competition, the project's temporary nature, and the complexity of knowledge are not sensitive factors for predicting the efficiency of IKS.

Table 5.2 Mutual information between IKS efficiency and its influencing factors

Variables	Mutual information
Absorptive capacity	0.00663
Sharing capability	0.00656
Interorganizational trust	0.00626
Project incentive mechanism	0.00564
Project culture	0.00390
Communication infrastructure	0.00328
Organizational distance	0.00311
Tacitness	0.00305
Ambiguity	0.00147
Heterogeneity	0.00137
Reciprocity	0.00113
Complexity	0.00084
Project temporary nature	0.00084
Market competition	0.00076
Project time constraints	0.00031
Geographical distances	0.00007

Second, sensitivity to parameters involves assessing how different states of IKS efficiency are affected by variations in the conditional probabilities within the IKS-BN model. Figure 5.3 presents an example of a tornado diagram, displaying the top 10 most sensitive parameters for decreasing the efficiency of IKS, sorted from the most to the least sensitive.

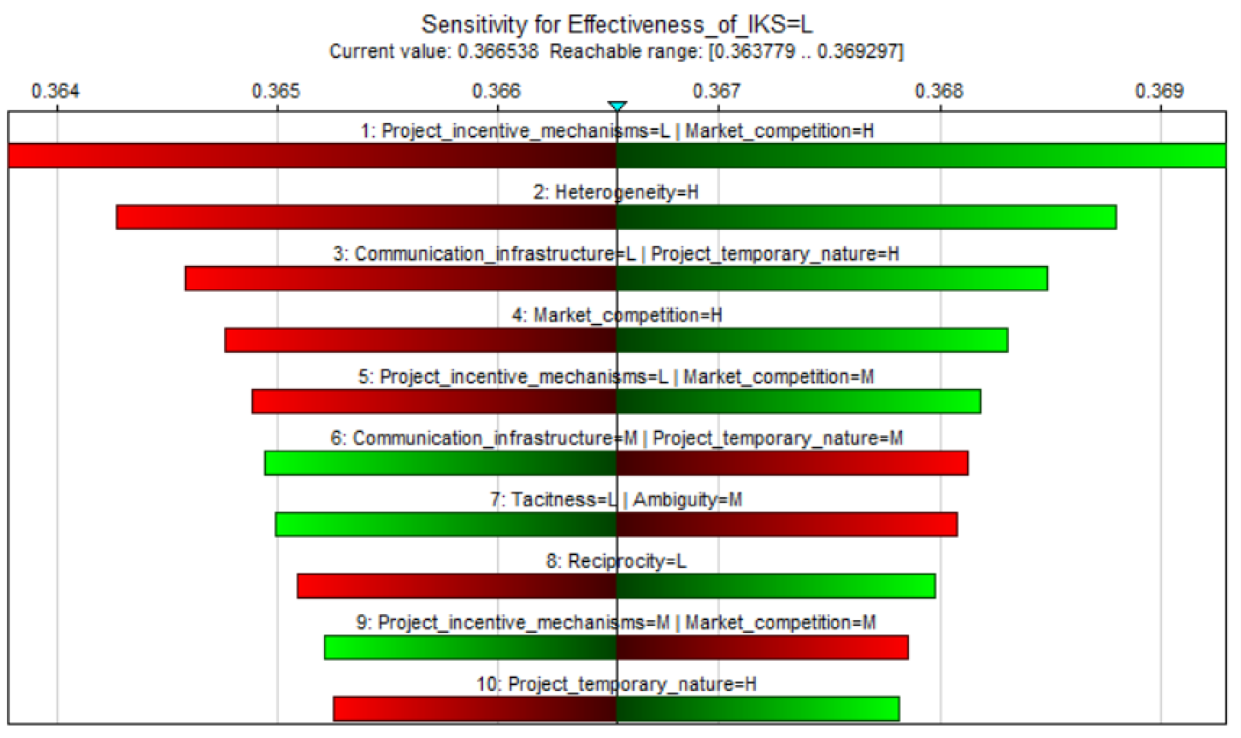


Figure 5.3 Tornado diagram for Efficiency_of_IKS = Low

The length of each bar in the diagram represents the range of changes, either decrease or increase, in the probability of achieving a low level of IKS efficiency. Tornado diagrams are useful for verifying the proposed IKS-BN model, especially in examining if the direction of change in probabilities aligns with expectations. The sensitivity analysis results indicated that, in general, the different states of IKS efficiency were not highly sensitive to small changes in the CPTs within the range of default ±10% of their current values. This finding suggests that the IKS-BN model's outcomes remain relatively stable even with minor probability variations, enhancing the model's robustness and reliability. Besides, the GeNIe software was used to compare the maximum sensitivity of parameters in each node and color them to varying degrees, as shown in Figure 5.1. Nodes that appeared darker in color, such as "project incentive mechanism", "market competition", "heterogeneity," and "communication infrastructure", had larger sensitivity values to influence the efficiency of IKS.

5.3.3 Model analysis

5.3.3.1 Forward reasoning (predictive analysis)

Based on the given evidence, forward reasoning was conducted to forecast future outcomes (Luo et al., 2020). Different scenarios were devised to assess the effects of altering the levels of different influencing factors on the efficiency of IKS.

First, simple scenarios by controlling a single factor were depicted in Table 5.3, where the changes in the probabilities of high and low levels of IKS efficiency were presented when only one individual factor to an optimistic state was set, specifically at a 100% low or high level.

Table 5.3 Scenarios for enhancing IKS efficiency through controlling a single factor

	Efficiency_of_IKS = High			**Efficiency_of_IKS = Low**		
Influencing factors	**Original value (%)**	**New value (%)**	**Variation (%)**	**Original value (%)**	**New value (%)**	**Variation (%)**
Interorganizational trust (100% high level)	31	35	4	37	32	-5
Project incentive mechanisms (100% high level)	31	35	4	37	33	-4
Communication infrastructure (100% high level)	31	35	4	37	33	-4
Organizational distance (100% low level)	31	34	3	37	31	-6
Sharing capability (100% high level)	31	34	3	37	33	-4
Absorptive capacity (100% high level)	31	34	3	37	33	-4
Project culture (100% high level)	31	34	3	37	33	-4
Project temporary nature (100% low level)	31	34	3	37	33	-4
Market competition (100% low level)	31	33	2	37	32	-5
Tacitness (100% low level)	31	33	2	37	32	-5
Reciprocity (100% high level)	31	33	2	37	33	-4
Complexity (100% low level)	31	33	2	37	34	-3
Ambiguity (100% low level)	31	32	1	37	34	-3
Heterogeneity (100% low level)	31	32	1	37	34	-3
Project time constraints (100% low level)	31	32	1	37	36	-1
Geographical distances (100% low level)	31	31	0	37	36	-1

The analysis revealed that increasing interorganizational trust, improving project incentive mechanisms, and strengthening communication infrastructure to a high level had the most significant effects on enhancing the efficiency of IKS, leading to a 4% increase in the probability of high IKS efficiency. Similarly, controlling a single factor also leads to a decrease in the probability of a low level of IKS efficiency, such as organizational distance (-6%), interorganizational trust (-5%), market competition (-5%), and project incentive mechanisms (-4%). Interestingly, properly controlling each factor had a slightly greater effect on decreasing the probability of low IKS efficiency than increasing the probability of a high IKS efficiency. However, it's important to note that while controlling a single specific factor can have some positive influence on IKS efficiency outcomes, a more comprehensive approach that considers implementing a combination of interventions and strategies that target various factors in conjunction simultaneously can potentially yield more significant and sustainable results for promoting IKS efficiency.

Second, the results of joint scenarios by combining multiple factors are shown in Table 5.4. 1) For parsimony, only joint scenarios leading to a high probability (over 70%) of a high level of IKS efficiency were presented (Chan et al., 2020; Sun et al., 2023). These joint scenarios demonstrated a simultaneous decrease in the likelihood of a low level of IKS efficiency to a similar range between 6% and 15%. 2) Notably, the combination of interorganizational trust (100% high level), sharing capability (100% high level), and absorptive capacity (100% high level) played a pivotal role in all of these joint scenarios, contributing to a prediction of 42% probability of high level of IKS efficiency. 3) The study found that at least five factors could jointly predict a high level of IKS efficiency with over 70% probability. The highest probability (74%) was jointly predicted by interorganizational trust (100% high level), sharing capability (100% high level), absorptive capacity (100% high level), project incentive mechanisms (100% high level), and communication infrastructure (100% high level).

Table 5.4 Joint scenarios for improving the efficiency of IKS

Number of factors	Joint influencing factors of IKS	Efficiency_of_IKS = High (%)	Efficiency_of_IKS = Low (%)
Five factors	IT+SC+AC+PIM+CI	74	13
	IT+SC+AC+PTN+PIM	73	14
	IT+SC+AC+MC+CI	71	14
	IT+SC+AC+MC+PTN	70	15
Six factors	IT+SC+AC+PIM+CI+A	88	6
	IT+SC+AC+PTN+PIM+A	87	7
	IT+SC+AC+PIM+CI+H	86	7
	IT+SC+AC+PTN+PIM+H	85	8
	IT+SC+AC+PTN+MC+A	84	8
	IT+SC+AC+CI+MC+A	84	8
	IT+SC+AC+PIM+CI+OD	84	8
	IT+SC+AC+PTN+PIM+OD	83	8
	IT+SC+AC+PTN+PIM+C	83	9
	IT+SC+AC+CI+MC+H	83	9
	IT+SC+AC+PIM+CI+C	83	8
	IT+SC+AC+PTN+MC+H	82	9
	IT+SC+AC+CI+OD+MC	82	9
	IT+SC+AC+CI+C+MC	81	10
	IT+SC+AC+PTN+OD+MC	81	9
	IT+SC+AC+PIM+CI+PC	81	10
	IT+SC+AC+PIM+CI+R	81	9
	IT+SC+AC+PTN+PIM+R	80	10
	IT+SC+AC+PTN+MC+C	80	10
	IT+SC+AC+PTN+PIM+PC	80	10
	IT+SC+AC+CI+MC+R	79	11
	IT+SC+AC+PTN+MC+R	78	11
	IT+SC+AC+CI+PC+MC	78	11
	IT+SC+AC+PTN+PC+MC	77	12
	IT+SC+AC+PIM+CI+PTC	76	12
	IT+SC+AC+PTN+PIM+GD	75	13
	IT+SC+AC+PTN+PIM+PTS	75	12
	IT+SC+AC+PIM+CI+GD	75	12
	IT+SC+AC+PIM+CI+MC	74	13
	IT+SC+AC+PTN+PIM+CI	74	13
	IT+SC+AC+PTN+PIM+MC	73	14
	IT+SC+AC+CI+MC+PTC	73	13
	IT+SC+AC+CI+MC+GD	73	13
	IT+SC+AC+PTN+MC+PTC	72	14
	IT+SC+AC+PTN+MC+GD	72	14
	IT+SC+AC+PTN+CI+MC	71	14
	IT+SC+AC+CI+PC+A	71	15
	IT+SC+AC+PTN+PC+A	70	15

Note: IT denotes "Interorganizational trust"; SC denotes "Sharing capability"; AC denotes "Absorptive capacity"; PIM denotes "Project incentive mechanisms"; CI denotes "Communication infrastructure"; PTN denotes "Project temporary nature"; MC denotes "Market competition"; PTC denotes "Project time constraints"; R denotes "Reciprocity"; GD denotes "Geographical distances"; H denotes "Heterogeneity"; PC denotes "Project culture"; OD denotes "Organizational distance"; C denotes "Complexity"; A denotes "Ambiguity"; T denotes "Tacitness"

Another essential finding from Table 5.4 is that scenarios controlled over four factors could predict a higher probability of a high level of IKS efficiency. For instance, a joint scenario consisted of six factors, including interorganizational trust (100% high level), sharing capability (100% high level), absorptive capacity (100% high level), project incentive mechanisms (100% high level), and communication infrastructure (100% high level), and ambiguity of knowledge (100% low level), predicted the highest probability (88%) among the joint scenarios involving six factors.

5.3.3.2 Backward reasoning (diagnostic analysis)

In the study, the **diagnostic inference** was also carried out to investigate how the probabilities of influencing factors (i.e., factors of IKS) change when evidence for target nodes (i.e., IKS efficiency) is considered (Luo et al., 2020). Due to the scale difference of influencing factors, when IKS efficiency was set at a higher level, some factors got greater (e.g., project incentive mechanisms) while others got smaller (e.g., the ambiguity of knowledge). Table 5.5 presents the influencing factors with the first six most significant fluctuations in their probability distribution under different levels of IKS efficiency. Once the IKS efficiency of MSOs was measured at a low level, these identified influencing factors exhibiting substantial changes in probability are crucial in prioritization for intervention and management. By focusing on these specific factors, targeted strategies can be implemented to address and mitigate their effects on IKS efficiency.

Specifically, MSOs with low IKS efficiency had a higher likelihood of owning low sharing capability and absorptive capacity than those MSOs with average IKS efficiency. On the contrary, MSOs with moderate or high levels of IKS efficiency were more susceptible to interorganizational trust, project incentive mechanisms, organizational distance, or communication infrastructure than their peers with a moderate level of IKS efficiency. The significance of absorptive capacity and interorganizational trust was evident across all levels of

IKS efficiency, highlighting its effects on organizational capability in IKS. Besides, the overall probability of the situation where influencing factors of IKS were at highly terrible levels (generally less than 30%) was not as prevalent as that of low and moderate levels (generally more than 30%), and the probability distributions for influencing factors of IKS showed a relatively stable pattern.

Table 5.5 Relative variation in the probability of factors for different IKS efficiency

IKS State	Factors of IKS	Low (%)	Moderate (%)	High (%)
L 100%	Sharing_capability	54 (+7)	29 (-4)	17 (-2)
	Absorptive_capacity	48 (+7)	30 (-4)	22 (-3)
	Interorganizational_trust	53 (+6)	27 (-4)	20 (-2)
	Project_incentive_mechanisms	57 (+6)	29 (-4)	14 (-1)
	Organizational_distance	24 (-4)	49 (+5)	27 (-1)
	Tacitness	31 (-5)	35 (+2)	34 (+3)
M 100%	Interorganizational_trust	42 (-5)	36 (+5)	22 (+0)
	Absorptive_capacity	36 (-5)	38 (+4)	26 (+1)
	Project_incentive_mechanisms	47 (-4)	37 (+4)	16 (+1)
	Sharing_capability	43 (-4)	37 (+4)	20 (+1)
	Tacitness	40 (+4)	22 (-1)	28 (-3)
	Organizational_distance	31 (+3)	41 (-3)	28 (-0)
H 100%	Absorptive_capacity	37 (-4)	36 (+2)	27 (+2)
	Interorganizational_trust	44 (-3)	31 (+0)	25 (+3)
	Project_incentive_mechanisms	48 (-3)	34 (+1)	18 (+3)
	Communication_infrastructure	41 (-2)	40 (+1)	19 (+2)
	Organizational_distance	31 (+3)	40 (-4)	29 (+1)
	Tacitness	38 (+2)	32 (-1)	30 (-1)

5.3.3.3 Explanation reasoning (influence chain analysis)

Influence chain analysis was conducted to illustrate the extent of mutual influence between nodes to describe the level of dependency between conditional probabilities and identify the most likely path leading to a particular outcome. Specifically, the strength of influence between the connected nodes was represented by the width of the directional arcs. The maximum influence causal chain consists of multiple nodes with the strongest influence relations toward the target node. The efficiency of IKS was set as the target node in this research. Figure 5.1 also shows the results of the influence chain analysis of the IKS-BN model. Combined with the strength of influence between all nodes, as depicted in Table 5.6, five essential influencing causative chains could be found, as shown in Table 5.7.

Table 5.6 Weighted strength of influence between all nodes

Parent Node	Child Node	Weighted strength of influence
Heterogeneity	Ambiguity	0.753556
Project temporary nature	Communication infrastructure	0.627594
Reciprocity	Project culture	0.548968
Market competition	Project incentive mechanisms	0.522766
Ambiguity	Complexity	0.434031
Ambiguity	Tacitness	0.396475
Project time constraints	Project culture	0.367108
Communication infrastructure	Sharing capability	0.364261
Reciprocity	Organizational distance	0.35729
Heterogeneity	Organizational distance	0.328606
Project incentive mechanisms	Interorganizational trust	0.304574
Geographical distances	Organizational distance	0.304483
Organizational distance	Sharing capability	0.276266
Tacitness	Absorptive capacity	0.270553
Complexity	Absorptive capacity	0.260759
Organizational distance	Absorptive capacity	0.252236
Project culture	Interorganizational trust	0.249822
Organizational distance	Interorganizational trust	0.24619
Project culture	Sharing capability	0.223927
Sharing capability	Efficiency of IKS	0.0111986
Communication infrastructure	Efficiency of IKS	0.0109674
Absorptive capacity	Efficiency of IKS	0.0108904
Interorganizational trust	Efficiency of IKS	0.0105486
Project incentive mechanisms	Efficiency of IKS	0.0103785
Organizational distance	Efficiency of IKS	0.00997468
Tacitness	Efficiency of IKS	0.00899999

Table 5.7 Results of influence chain analysis of the IKS-BN model

No	Description of causal chains
1	Heterogeneity→Ambiguity→Complexity→Absorptive capacity→Efficiency of IKS
2	Project temporary nature→Communication infrastructure→Sharing capability→Efficiency of IKS
3	Market competition→Project incentive mechanisms→Interorganizational trust→Efficiency of IKS
4	Project time constraints→Project culture→Sharing capability→Efficiency of IKS
5	Reciprocity→Organizational distance→Efficiency of IKS

Based on the results, the first influencing causative chain, “Heterogeneity →Ambiguity→ →Complexity →Absorptive capacity →Efficiency of IKS,” denotes that knowledge characteristics greatly influence the efficiency of IKS by the mediating effect of organizational factors. Specifically, the sharing of different knowledge (i.e., heterogeneity of knowledge, such as managerial or technological knowledge) brings ambiguity of knowledge perception and complexity of understanding knowledge, which influences the organizational absorptive capacity, decreasing the efficiency of IKS.

The second, third, and fourth influencing causative chains connect project context characteristics and organizational characteristics with the efficiency of IKS. The second one is “Project temporary nature→ Communication infrastructure →Sharing capability →Efficiency of IKS”. The project’s temporary nature describes the extent of liquidity and instability of MSOs. When MSOs are in an unstable state, their cross-organizational communication channels would be affected, further decreasing organizational sharing capacity and impeding the efficiency of IKS. The third one is “Market competition →Project incentive mechanisms →Interorganizational trust → Efficiency of IKS”. The finding denotes that a competitive market would influence project incentive mechanisms and interorganizational trust, discouraging the IKS of MSOs. It concludes that Interorganizational trust and project incentive mechanisms play an important role in facilitating MSOs’ IKS, which proves the consistency with the above conclusion. The fourth is “Project time constraints→ Project culture → Sharing capability → Efficiency of IKS”. Similarly, when MSOs are all under strict time pressure, conducting IKS would be an extra burden for them. An isolated project culture unwilling to share information and knowledge with others would be formed and not be beneficial for enhancing IKS efficiency. Thus, a vital strategy for facilitating IKS is shaping good project culture, promoting inter-organizational trust, and building communication infrastructure.

The last is “Reciprocity → Organizational distance → Efficiency of IKS”. The result means that organization characteristics could largely influence its IKS performance. A common social norm among MSOs to undertake the obligation to repay others in return when getting their assistance would shorten the organizational distance and facilitate inter-organizational cooperation, leading to improved IKS efficiency (Ren et al., 2020).

5.4 Discussion

5.4.1 Developing the IKS-BN model to quantify the interdependencies among factors and effects on IKS efficiency

IKS has been recognized as crucial for elevating project performance, particularly in interorganizational projects. While researchers have recognized the significance of delving into IKS, there is a shortage of effective methods to tackle the associated challenges. This study aims to make strides in bridging this gap by innovatively introducing a BN model to unveil how different factors influenced the IKS efficiency of MSOs. The results of questionnaire surveys to establish the BN model depicted that around 51% of MSOs' efficiency of IKS was at a low level, 27% at a moderate level, and only 22% at a high level, indicating the terrible reality that knowledge was not sufficiently shared in megaprojects. A total of 16 influencing factors were identified in the IKS-BN network, as shown in Figure 5.1. The model identified the root nodes of high market competition, the temporary nature of projects, time constraints, lack of reciprocity, long geographical distances, and high heterogeneity of knowledge. These root nodes played a crucial role in predicting the likelihood of other factors falling into low, moderate, and high levels. The overall predictive accuracy of the established IKS-BN model was all within the acceptable range in extant research (Chan et al., 2020; Luo et al., 2020; Sun et al., 2023).

Two kinds of sensitivity analysis were conducted to investigate the properties of the IKS-BN model. First, the results of sensitivity to findings revealed the relatively most influential individual factors, including absorptive capacity, sharing capability, interorganizational trust, and project incentive mechanism (see Table 5.2). Second, the results of sensitivity to findings indicated that, in general, the different states of IKS efficiency were not highly sensitive to small changes in the CPTs within the range of default ±10% of their current values, verifying the model's robustness and reliability.

5.4.2 Formulating effective strategies to improve the efficiency of IKS

The Bayesian network's inherent reasoning capability enables us to quantify the impact of various factors on IKS efficiency. Based on the developed IKS-BN model, different scenarios were devised to formulate diverse targeted interventions and strategies to enhance the efficiency of IKS in different contexts and settings in megaprojects.

5.4.2.1 Single strategy

In this study, two types of model analysis, including forward (i.e., Table 5.3) and backward reasoning (Table 5.5), were conducted to calculate the changes of the targeted node (i.e., the efficiency of IKS) when the other factors were kept constant (Chan et al., 2020; Sun et al., 2023). The top six influencing factors were discussed, including four factors related to organizational characteristics, two to context characteristics, and one to knowledge characteristics.

First, Table 5.2 shows that amongst all the factors, "interorganizational trust" was the most sensitive to the efficiency of IKS. Thus, this research supports Westergren and Holmström (2012) and Rungsithong and Meyer (2020) that IKS requires a high level of mutual trust. Interorganizational trust is built upon a subjective belief and anticipation that collaborative partners are inclined to fulfill their obligations, which forms the foundation for MSOs to establish strategic alliances, foster robust partnerships, and facilitate inter-organizational communication and interactions, which ascertain the scope and extent of conducting IKS with their partners (Panteli and Sockalingam, 2005). Chen et al. (2014) further added that interorganizational trust is reinforced as organizations establish common goals, cultivate embedded social relations, and conduct collaborative influence strategies. Recently, Wang et al.

(2023) proposed an interesting opinion that a low level of trust can also facilitate cross-border knowledge sharing if trust congruence exists. Thus, it is vital to maintain comparable levels of trust between two parties, irrespective of their specific trust levels.

Second, project incentive mechanisms were also revealed to be essential for improving the efficiency of IKS, including financial rewards (Carnahan et al., 2014; Dawande et al., 2019) and non-financial rewards (Huang et al., 2021; Ren et al., 2020). The reward system has the potential to incentivize MSOs to engage in reciprocal activities and establish mutual relationships with one another. Furthermore, Sarafan et al. (2022) also note that bonuses and penalties take effort. Penalties function as negative rewards, often involving monetary deductions from a base pay-out, imposed when contract specifications are not fulfilled (e.g., late delivery). Conversely, bonuses are positive rewards, offering gains when performance objectives are highly achieved.

Next, the research findings echoed with extant studies that highly efficient communication infrastructure was essential for IKS, such as expertise locator systems, email systems, online meeting systems, information repositories, best practice databases, team collaboration tools, lessons learned systems, and knowledge maps (Al-Busaidi and Olfman, 2017; Gil-Garcia and Sayogo, 2016). Social media and blockchain technologies recently attracted many scholars' attention. Social media, such as the community of practice (Nisar et al., 2019), contributes to frequent and smooth electronic connections across MSOs (Bharati et al., 2015), which helps cultivate trust, shared values, deep understanding, and thereby foster IKS among organizations (Lobo and Abid, 2020; Zhao et al., 2020). Besides, the blockchain-based system with a decentralized and distributed nature largely enhances interorganizational trust and the efficiency of IKS in a strategic alliance, which ensures that no individual organization could add information to the chain without obtaining approval from others in the alliance (Chen et al., 2023; Philsoophian et al., 2022). this research showed that geographical distance rarely impacts the IKS behavior in megaprojects, which was quite different from extant studies (Jenke and Pretzsch, 2021; Zhou et al., 2022). Maybe it is the efficient communication infrastructure that overcomes obstacles such as different time zones and long transmission channels (Milagres and Burcharth, 2019).

In this research, organizational distance emerged as the fourth significant factor. It gauges the extent to which the knowledge donator and collector are similar in demographic attributes, such as organizational structure, operational mechanisms, business practices, management style, rules and regulations, and organizational culture (Zhou et al., 2022). Extended organizational distance hinders IKS due to the potential for discord between the knowledge donator and collector. This dissimilarity can lead to factionalism, distortion of messages, and other communication challenges (H. Liu et al., 2020). Moreover, coordination costs increase with increased organizational distance (Ambos and Ambos, 2009; Hsiao et al., 2017).

Sixth, a high level of sharing and absorptive capacity revealed significant conditions for facilitating IKS in megaprojects, which also supported prior studies (Easterby-Smith et al., 2008; H. Liu et al., 2020; Milagres and Burcharth, 2019; Nodari et al., 2016). MSOs with a robust absorptive and sharing capacity can swiftly assimilate external information to create new knowledge collaboratively and effectively (Zhao et al., 2015). Sharing and absorptive capacity are interconnected, as an organization proficient in absorbing external knowledge will likely be adept at disseminating that knowledge within its boundary (Easterby-Smith et al., 2008).

Last but not least, knowledge itself characteristics also determine the efficiency of sharing it across MSOs. This research shows that the tacitness of knowledge is the most influential one. Knowledge tacitness was frequently explored in extant studies to form knowledge governance mechanisms as explicit knowledge should be subsequently dealt with compared with tacit knowledge (Fang et al., 2013; He et al., 2023; Iftikhar and Ahola, 2022).

5.4.2.2 Joint strategies

Our study revealed that controlling multiple factors jointly could enhance the efficiency of IKS more substantially than individual factors. Based on the result of forward reasoning (i.e., Table 5.4), joint strategies controlling multiple factors to obtain the expected state of the targeted node (i.e., the efficiency of IKS) could be formulated, demonstrating the following features.

First, to reach a high level of IKS efficiency, three basic factors should be carefully controlled, including interorganizational trust (100% high level), sharing capability (100% high level), and absorptive capacity (100% high level), predicting a probability (42 %) of good IKS efficiency. To compare the net effects of different antecedents, Amoozad Mahdiraji et al. (2022) utilized a multi-layer decision-making approach to rank the effects of ten factors on interorganizational knowledge management based on the three types of experts' overall opinion (i.e., business, academic and the mixed groups). The results showed that sharing capability and absorptive capacity generally ranked between 3-7, which supports the results in section 5.3.3, while interorganizational trust ranking 5-8 is quite different from ours. The current studies hardly explored the combinational effects of different antecedents. The research tries to fill the gap by considering the cause-effect relationships among diverse factors and using a novel simulation approach for measuring the efficiency of IKS under different scenarios (Li et al., 2022; Vithanage et al., 2022).

Second, to confirm the probability of good IKS efficiency over 70%, at least five factors should be controlled at the best state to form five-factor scenarios. Besides the above three factors, interorganizational trust, sharing capability, and absorptive capacity, managing the combination of project incentive mechanisms (100% high level) and communication infrastructure (100% high level) achieved the highest probability (74%) of good IKS efficiency among the five-factor scenarios. Moreover, based on this particular scenario, further managing ambiguity of knowledge (100% low level) led to the highest probability (88%) of good IKS efficiency among six-factor scenarios. The number of six-factor scenarios is larger than five-factor scenarios. A greater percentage of IKS efficiency could be obtained when more factors are controlled. Nevertheless, it's noticeable that there is a declining trend in the percentage of improvement in IKS efficiency. This diminishing trend aligns with findings reported in existing BN literature (Bhuiyan et al., 2023; Chan et al., 2020). This outcome suggests that increasing resource investment to control more factors at better states might not necessarily lead to a better state of IKS. As a result, allocating organizational resources beyond this point could prove ineffective. This model provides a practical approach for diagnosing effective measures to enhance IKS efficiency.

Third, scenarios combined with multiple dimensional factors (i.e., knowledge, organizational, and context characteristics) could contribute to a high level of IKS efficiency. By referring to the forward reasoning results in Table 5.4, all six-factor scenarios consisted of factors in two dimensions and more than half in all three dimensions, which were also verified by the results of the explanation reasoning (i.e., the five casual chains in Table 5.7). This finding denotes that the efficiency of IKS is simultaneously affected by multiple dimensional influencing factors. Furthermore, even though there may be subtle variations in the combination of factors, their interconnections within the network can ultimately lead to similar states of IKS efficiency. This underscores the significance of acknowledging the interconnected influence of knowledge, organizational conditions, and the contextual setting. The results of a recent study by Liu et al. (2021) partly verified the finding through a systematic dynamic approach, which denoted that the combination of organizational absorptive and sharing capability and IKS contexts, such as interorganizational relations and organization distance, have key influences on the IKS performance in megaprojects.

5.5 Chapter Summary

Our research established an innovative IKS-BN model encompassing 16 influencing factors of IKS to explore their cause-effect interconnections and their joint effects on the IKS efficiency in megaprojects. *First*, the qualitative model was established through a literature review and focus group discussion. *Then*, the IKS-BN model was quantified by structure learning and parameter learning, based on which the predictive accuracy and sensitivity of the model were tested to answer RQ 5.1. *Next*, three kinds of model analysis, including predictive, diagnostic, and influence chain analysis, were carried out to formulate effective strategies for enhancing the efficiency of IKS by identifying the most influential scenarios and factors to answer RQ 5.2. This approach enables the prediction of IKS efficiency levels and aids MSOs in implementing appropriate management strategies to mitigate potential obstacles that hinder IKS efficiency. Additionally, the findings offer scholars a catalyst to incorporate BNs into organizational behavior research within the context of megaprojects.

CHAPTER 6 FACILITATING IKS: PROMOTING STAKEHOLDER SYNERGY IN MEGAPROJECT IKS NETWORK[8]

The stakeholder synergy concept offers researchers a new perspective for examining real-world management decisions regarding strategic stakeholder relations and value co-creation... For example, how might focal organizations use the particular multi-attribute utility functions to identify stakeholder subgroups to pursue more effective strategies for value co-creation?

(Tantalo and Priem, 2016, p 326)

6.1 Introduction

Megaprojects are temporary endeavors with a high level of complexities and obstacles (Caldwell et al., 2009; Davies et al., 2017; Salvador et al., 2021) involving interactions within a complex stakeholder network (Roehrich et al., 2020; Winch, 2017). IKS across MSOs forming *knowledge flows* is revealed as a crucial resource for coping with complexities, facilitating decision-making and problem-solving, improving project performance, and realizing innovation (Ramasesh and Browning, 2014). Nevertheless, many MSOs are still reluctant to adopt it. There are three potential reasons leading to this phenomenon.

First, MSOs keep vague about how to measure their benefits from IKS through a direct and quantified method. Two research perspectives are essential for measuring the MSOs' IKS benefits. First, from the *value-focused thinking* perspective (Bai et al., 2021), the benefits of

[8]This chapter is largely based on the following manuscripts:

He, H., Wang, G.,* He, Q., &. Chan, A.P.C. Governing the knowledge value chain in large interorganizational projects: A stakeholder value network perspective. (Journal of Management Studies, **Under Review**, **First Author**)

He, H., He, Q., Chan, A.P.C., Wang, G.,* & Xie, J. Interorganizational knowledge sharing in projects: A qualitative-quantitative network approach. (IEEE Transactions on Engineering Management, **Under Review**, **First Author**) *knowledge flows* could be qualified as *knowledge value flows (KVFs),* and show a multidimensional feature. A KVF is formed when a specific "need" of one stakeholder is met by another' IKS (Zheng et al., 2021). Extant research mainly focused on the economic benefits (i.e., business value) of KVFs by referring to resource dependence theory (Pfeffer and Salancik, 2003) and transaction cost economics (Williamson, 1993), which indicate that behaviors are shaped by the economic rewards from interactions. However, there are some intangible benefits (i.e., social value) of KVFs, such as perceived satisfaction (Clark and Aragón, 2013; Shaheen and Azadegan, 2020) according to social exchange theory, which highlights that intangible social factors also facilitate some organization behaviors other than economic factors in operations and supply chain management (Narasimhan et al., 2009). Hence, business and social value could be a two-dimensional rule to quantify the value of KVFs. Besides, according to the social exchange theory, business and social value could be assessed and integrated by a *utility* function (Merle et al., 2010; Sampson, 2015).

Second, IKS in megaprojects involves multiple MSOs. Value co-creation from the IKS network should be assessed by searching for and combining various KVFs across different MSOs from a *network-based* perspective (Bendoly et al., 2021). Primary operations and supply chain management studies usually adopted a *linear* (Autry and Golicic, 2010) or *hub-and-spoke* (Hu, 2010) model to explore inter-organizational governance (i.e., Figure 6.1 (a) and (b)). Multiple KVFs consist of a KVF path (KVC), such as A→B→C, or the KVF cycle, which is a closed KVF path that begins from and ends with the same stakeholder, such as A→B→A. There are two limitations: 1) a focal organization should be selected (e.g., A); 2) only *restricted exchanges* between the *focal organization* and its MSOs (i.e., direct and dyadic, such as A→B→A) could be explored, which depicts a centralized and hierarchical feature. In such a case, A may struggle to understand exchanges between B and C, which impedes their collective actions in value co-creation (Bridoux and Stoelhorst, 2022). Recently, Roehrich et al. (2020)

called for a systematic perspective rooted in the *network-based* model (i.e., Figure 6.1 (c)) in future inter-organizational governance research to depict complex network-level interactions across MSOs. In the *network* model, 1) each stakeholder could be set as the focal organization, which depicts a horizontal and project-based structure (Das and Teng, 2002); 2) the *generalized exchanges* among three or more MSOs (i.e., indirect and multiple, such as A→B→C→A) should be considered, which exhibit ambiguity when taking into account the relative intangibility of knowledge resources. Hence, the *network-based* perspective demonstrates the potential to extend the understanding of IKS and facilitate value co-creation.

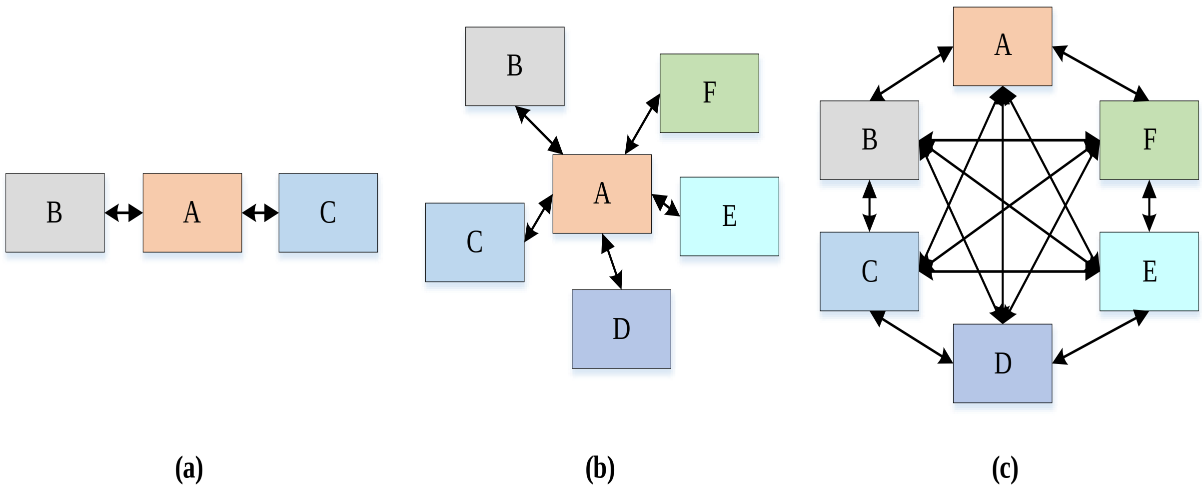


Figure 6.1 Inter-organizational models: (a) linear; (b) hub-and-spoke; (c) network

Second, each stakeholder owns a different initial knowledge repository and occupies a different structure position in the IKS network. This leads to a unique stakeholder power in the IKS network and influences successful project delivery. However, MSOs are unclear about their advantages (power) in obtaining benefits from the IKS. The gap between their self-cognitions and the actual situation impedes the maximal value co-creation. Megaprojects are complex endeavors (Brookes and Locatelli, 2015; Caldwell et al., 2009; Davies et al., 2017; Salvador et al., 2021), and a single organizational stakeholder rarely has sufficient resources (e.g., knowledge) to autonomously achieve the grand idea (Gil et al., 2021). Thus, MSOs (e.g., owners, contractors, designers, project supervisors, consultants, and suppliers) have to form a temporary alliance for the duration of the project to pool knowledge resources in the pursuit of value co-creation (Iftikhar and Ahola, 2022). Organization science scholars often utilize *stakeholder power* to describe the stakeholder's capability to influence the objectives and strategy-making of other MSOs in the temporary stakeholder alliance network (Ackermann and Eden, 2011; Boaventura et al., 2020; McGahan, 2021; Wu, 2013). From the above value-focused thinking and network-based perspective, stakeholder power in the IKS network could be formed in two aspects. On the one hand, MSOs occupying essential knowledge resources that other MSOs depend on would occupy a high level of stakeholder power (i.e., *value advantages*) (Boaventura et al., 2020; Savage et al., 1991). For example, the consultants provide valuable technical knowledge to help the contractor solve key technical challenges in megaprojects. On the other hand, MSOs centrally located in the IKS network also occupy a high level of stakeholder power (i.e., *exchange advantages*) (Boaventura et al., 2020; Rowley, 1997). For instance, the contractors play a knowledge-exchange-hub role in bridging all of the knowledge and information together from others, such as owner, designers and government, during the construction stage of megaprojects.

Third, the benefits of IKS can be achieved or maximized only when it is reciprocally implemented. Hence, joint benefit improvement should be a common goal for MSOs. However, MSOs are generally confused about how to collaborate with partners to reach the reciprocal goal. The risk of unilateral IKS discourages MSOs' commitment as their partners may not or opportunistically adopt similar activities. Traditional theories of value creation based on power depict that the gains of one stakeholder must be original from the losses of the others. However, new theories considering justice and reciprocity depict that a win-win relationship could be reached where the gains of one stakeholder may also increase the value creation of the others (Garcia-Castro and Aguilera, 2015). This phenomenon is labeled as *stakeholder synergy*, highlighting the upside value creation of the whole stakeholder network instead of the downside value appropriation by the partially powerful MSOs (Tantalo and Priem, 2016). Powerful MSOs could also keep their willingness to stay and contribute to the whole value creation system in this synergy situation because they could benefit more from a bigger value "pie" (Tantalo and Priem, 2016). These arguments change the focus from emphasizing bargaining stakeholder power to prioritizing stakeholder cooperation and power complementarity to contribute to total value creation (Bosse and Coughlan, 2016). In sum, a key governance challenge met by MSOs is attending to the strategic and operational needs of islands of shared knowledge in a sea of mutual ignorance (Postrel, 2002). Knowledge flows span organizational boundaries. Hence, the collaborative advantage of a single organization is linked to the embedded interactive network (Lipparini et al., 2014). IKS should be systematically assessed in tangible and intangible aspects across MSOs by knowledge flows from a *network-based* view (Gaimon and Ramachandran, 2021). Furthermore, as each stakeholder is unique in the IKS network, they need to identify their stakeholder power (e.g., *value or exchange advantages*) and adjust their cooperation strategies correspondently to invest more effort to strengthen their cooperation with other MSOs who have complemental knowledge resources and stakeholder power. However, extant studies hardly provide theoretical and practical expertise for MSOs to help them identify their power in the IKS network (Szulanski et al., 2016) and propose appreciative cooperation strategies to form *stakeholder synergy* to realize value co-creation (Reus et al., 2016).

Hence, this chapter aims to develop a quantified method to measure the IKS value and further answer the following three research questions:

RQ 6.1 *How to measure the stakeholder power in the IKS network of megaproject?*

RQ 6.2 *What internal strategies could be adopted to improve stakeholder power in the IKS network of megaprojects?*

RQ 6.3 *What external strategies should MSOs adopt to collaborate with others to facilitate stakeholder synergy for value co-creation in the IKS network of megaprojects?*

6.2 Research Design

Through the lens of *value-focused thinking* and *network-based* view, a four-step *stakeholder value network* (SVN) analysis method is developed (Ferreira et al., 2019; Zheng et al., 2021), as shown in section 3.4.3. Both qualitative and quantitative data were also collected in this Chapter. Specifically, typic MSOs and KVFs are identified first to map the SVN model through a literature review (Section 3.3.1) and 18 semi-structured interviews (Section 3.3.2). *Then,* the utility function is used to quantify each KVF through the 198 questionnaire surveys (Section 3.3.3). *Third,* the design structure matrix was utilized to enumerate all KVF cycles, which unveil complex interactive IKS (i.e., *restricted* and *generalized exchanges*) between and among MSOs, and quantify them with a multiplicative propagation rule. *Finally,* three types of stakeholder advantages in the IKS network (i.e., *value*, *exchange,* and *integrated* advantage) were calculated to categorize MSOs into four types and propose different internal strategies to promote stakeholder power in promoting value co-creation through IKS. Eighteen industry experts were invited to join the focus group discussion to triangulate the results of identified stakeholder power, as shown in section 3.3.4. Besides, by analyzing the top *restricted* and *generalized* KVF cycles, two essential external strategies were formed to improve IKS collaboration and facilitate stakeholder synergy and value co-creation in megaprojects.

6.3 Results

6.3.1 Mapping the SVN model

After conducting literature reviews and semi-structured interviews, seven types of primary MSOs within the IKS network were identified (Table 6.1). A total of 98 KVFs were identified among the seven types of MSOs. Each KVF was numerically coded by order of *sender, serial number* (indicating knowledge category: *1- managerial document, 2-managerial experience, 3-technical skills, and 4-technical guidelines*), and *recipient*. For example, CS1O indicates that this KVF (belonging to *managerial documents*) was delivered from the consultant to the owner. According to the distribution of the primary MSOs and corresponding KVFs, the SVN model could be depicted as shown in Figure 6.2.

The qualitative SVN model exhibits two features. First, MSOs play different roles in the KVFs network. Of the total 98 KVFs, most were related to the contractors (44 KVFs, 44.9 %) or the owner (40 KVFs, 40.8%). The project supervisors and suppliers were less connected in the KVF network, occupying only 19.4% and 15.3% (19 and 15 KVFs, respectively). Second, KVFs between the two MSOs were not distributed evenly. For example, more knowledge flows were shared from project supervisors to owner (4 KVFs referring to all knowledge categories) than from owner to project supervisors (only 2 KVFs referring to *managerial documents* and *technical guidelines*).

Table 6.1 Primary MSOs within the IKS network

No.	Stakeholder	Description
1	Designers	The designers refer to architects responsible for the conceptual design and its development into drawings, specifications, and instructions required for construction.
2	Government	The government refers to administrative agencies regulating the project's development and authorizing related certifications to project stakeholders.
3	Project supervisors	Project supervisors are appointed by the owner and responsible for supervising the construction progress, particularly the project quality and safety.
4	Contractors	Contractors are appointed by the owner to carry out construction works for a given duration.
5	Owner	The owner refers to the entity that commissions and invests in the project.
6	Consultants	The consultants offer advice and expertise to the owner, such as feasibility studies, cost estimates, and tender management.
7	Suppliers	The suppliers refer to materials and equipment providers for projects.

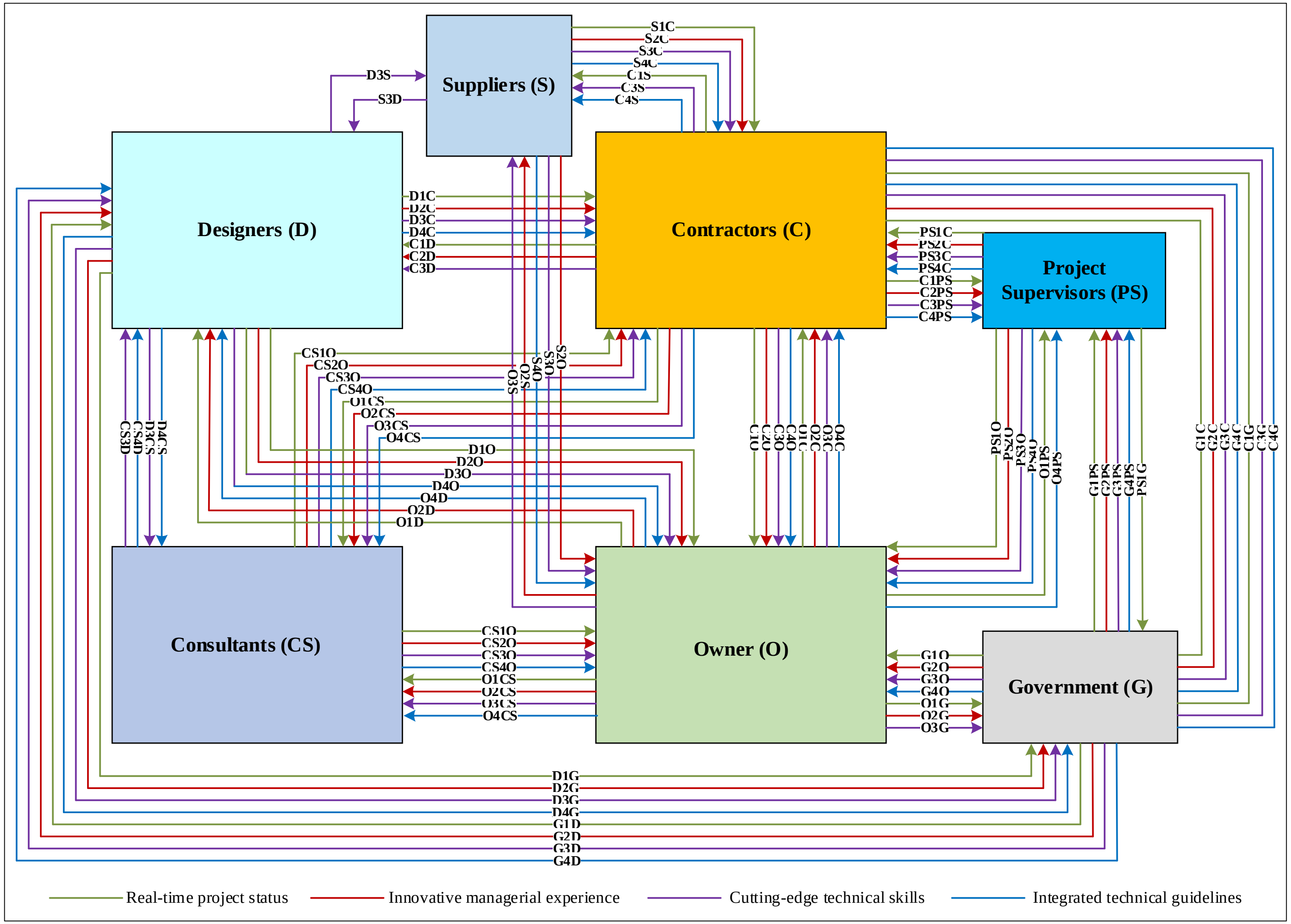


Figure 6.2 Qualitative SVN model

6.3.2 Quantifying the SVN model

After questionnaire surveys with 198 experts and two rounds of re-evaluation, an agreed utility score U_f for each KVF was reached, ranging from 0.19 to 0.87, with a mean value of 0.51 (as shown in **Appendix D**).

6.3.3 Searching for KVF cycles

There are 633438 KVF cycles among MSOs (Figure 6.3). The number of KVF cycles beginning and ending with the contractors was the largest (106,108), followed by those for the owner (105,772) and designers (102,016). The next are all less than 100,000, government, 98024, project supervisors, 81124, consultants, 79220, and suppliers with only 61174 KVF cycles. Furthermore, Figure 6.3 shows the length distributions of the KVF cycles. The term cycles_length-2 (i.e., KVF cycles consisting of two KVFs) denotes restricted exchange between two MSOs, while cycles length more than 2 denotes generalized exchanges among over two MSOs. In sum, the lengths of the cycles for the seven types of MSOs follow a normal distribution, and contractors and owners demonstrate advantages in the total number of KVF cycles.

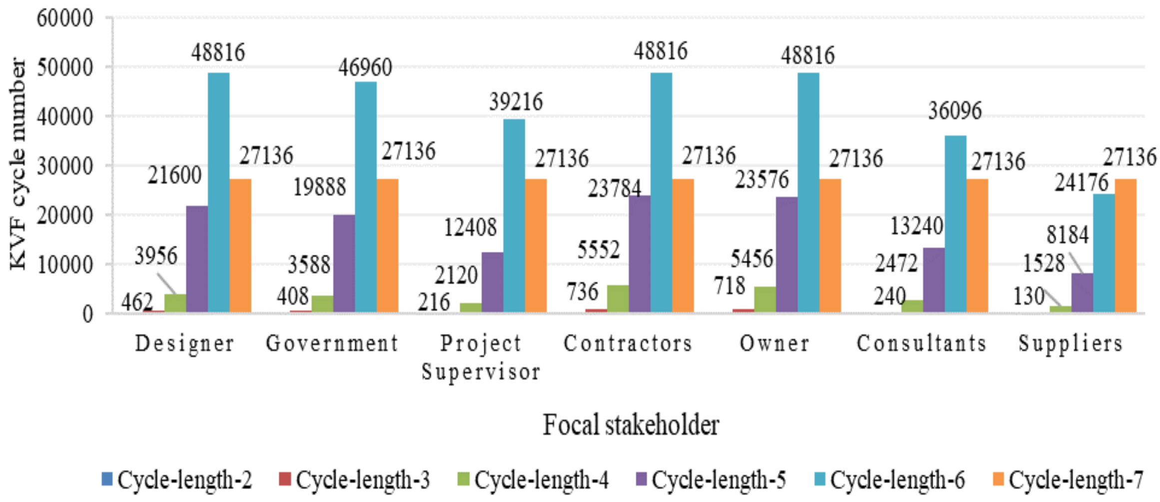


Figure 6.3 KVF cycle number in different lengths

6.3.4 Analyzing the SVN model

In SVN studies (Ferreira et al., 2019; Zheng et al., 2021, 2019b), a certain stakeholder is generally selected as the focal organization to analyze the network exchange process, which presupposes the core of the network ex-ante. However, exploring the interactive value co-creations among different MSOs suffers from being limited to a singular perspective of a focal organization. An overall analysis from different MSOs' perspectives could help provide a form of governance to cope with collective action problems in value co-creation (Bridoux and Stoelhorst, 2022). Equations 5 and 6 in section 3.4.3.5 show that each stakeholder was chosen as the focal organization respectively when analyzing exchange and integrated advantage, thus forming seven scenarios. Therefore, the results of value, exchange, and integrated advantage are derived considering the seven scenarios' average score.

6.3.4.1 Value advantage analysis

The results of the value advantage of seven types of MSOs are shown in Table 6.2. The value advantages of contractors, owners, and consultants are evaluated at a high level, while the designers, government, project supervisors, and suppliers are rated low. Value advantage level (i.e., high or low) is determined based on the median of the average score of value advantage among the seven types of MSOs. Overall, the contractors feature a prominent value advantage (i.e., 0.254) within the IKS network.

Table 6.2 Value advantage scores of seven MSOs

MSOs	D	G	PS	C	O	CS	S
Average score of value advantage	0.112	0.101	0.085	0.254	0.237	0.144	0.068
Value advantage level	**Low**	**Low**	**Low**	**High**	**High**	**High**	**Low**

Note: "O" represents owner, "G" represents government, "CS" represents consultants, "PS" represents project supervisors, "C" represents contractors, "S" represents suppliers, and "D" represents designers.

6.3.4.2 Exchange advantage analysis

The results of the exchange advantage of seven types of MSOs are shown in Table 6.3. The two highest exchange advantage scores are obtained by contractors (i.e., 0.989) and owners (i.e., 0.986). Different from the results of the VA score, the exchange advantage of designers (0.960) and government (0.925) are evaluated as high, while the project supervisors (0.783) are evaluated as low level. Similarly, the EA scores of consultants (0.765) and suppliers (0.617) are considered at low level.

Table 6.3 Exchange advantage scores of seven MSOs

MSOs (focal organizations)	D	G	PS	C	O	CS	S
D→ D	**1.000**	0.916	0.751	0.985	0.981	0.746	0.582
G→G	0.950	**1.000**	0.758	0.983	0.980	0.730	0.520
PS→PS	0.944	0.939	**1.000**	0.987	0.984	0.721	0.545
C→C	0.947	0.910	0.755	**1.000**	0.981	0.738	0.573
O→O	0.947	0.910	0.755	0.984	**1.000**	0.739	0.573
CS→CS	0.961	0.903	0.738	0.988	0.987	**1.000**	0.525
S→S	0.971	0.896	0.722	0.994	0.990	0.680	**1.000**
Average exchange advantage	**0.960**	**0.925**	**0.783**	**0.989**	**0.986**	**0.765**	**0.617**
Exchange advantage level	**High**	**High**	**Low**	**High**	**High**	**Low**	**Low**

Note: "O" represents owner, "G" represents government, "CS" represents consultants, "PS" represents project supervisors, "C" represents contractors, "S" represents suppliers, and "D" represents designers.

6.3.4.3 Integrated advantage analysis

Table 6.4 illustrates the asymmetric interactive value co-creation among MSOs using the indicator of integrated advantage. All KVF cycles starting and ending with the focal organization are searched. The integrated advantages reflect MSOs' relative comprehensive advantages in value and exchange. Overall, the contractor is the most powerful stakeholder, receiving the highest score (0.975). The owner (0.969) and designers (0.824) also play a prominent role across the IKS network due to the owner's high demands for their value-added expertise and skills. The consultants (0.763), government (0.734), project supervisors (0.557), and suppliers (0.432) are rated as having low levels of integrated advantages.

Table 6.4 Integrated advantage scores of seven MSOs

MSOs (focal organizations)	D	G	PS	C	O	CS	S
D→ D	**1.000**	0.738	0.478	0.963	0.958	0.766	0.395
G→G	0.837	**1.000**	0.562	0.967	0.963	0.718	0.319
PS→PS	0.746	0.773	**1.000**	0.979	0.971	0.693	0.288
C→C	0.765	0.677	0.498	**1.000**	0.956	0.747	0.356
O→O	0.765	0.678	0.497	0.962	**1.000**	0.750	0.353
CS→CS	0.788	0.652	0.457	0.968	0.967	**1.000**	0.311
S→S	0.866	0.617	0.405	0.984	0.970	0.664	**1.000**
Average integrated advantage	**0.824**	**0.734**	**0.557**	**0.975**	**0.969**	**0.763**	**0.432**
Integrated advantage level	**High**	**Low**	**Low**	**High**	**High**	**Low**	**Low**

Note: "O" represents owner, "G" represents government, "CS" represents consultants, "PS" represents project supervisors, "C" represents contractors, "S" represents suppliers, and "D" represents designers.

6.3.5 Robustness Tests

Two types of robustness tests were conducted to examine the sensitivity of the results. First, a non-linear scale was used to calibrate the two attributes of each KVF's utility score (i.e., U_f (satisfaction) and U_f (importance). By referring to Pereira et al. (2018) and Zheng et al. (2021), the levels of "satisfaction" and "importance" scores do not necessarily follow a linear scale (e.g., 0.2, 0.4, 0.6, 0.8, and 1.0) and may conform to a non-linear scale (e.g., 0.11, 0.19, 0.33, 0.57, and 0.98). Second, by referring to Hein et al. (2017), a "quadratic" aggregation rule (instead of the multiplicative propagation rule) was further employed for calculating the score of a KVF cycle. The difference between the two rules is that the quadratic aggregation rule uses the square of the utility scores of the last KVF returning to the focal organization. The quadratic aggregation rule captures the discrimination of the focal organization against other KVFs than the last one, which satisfies the focal organization's own needs (Cameron et al., 2008). The results are shown in **Appendix E**. Different calibration approaches and aggregation rules have not influenced the results (i.e., the classification of MSOs based on value, flow, and integrated advantages).

6.3.6 Qualitative Triangulation

Besides, further semi-structured interviews with the previous 18 experts were conducted to triangulate the findings. The details are shown in **Appendix F**. The interview findings support the survey findings and clarify how three types of advantages are formed. First, the value advantage of consultants is at a high level. Consultants are the "think tank" for the owner and contractors and play an essential role in facilitating project delivery by bringing in new and creative ideas and tackling technical and managerial challenges. Second, the flow advantage of designers is at a high level. Challenges of complex inter-organizational construction projects necessitate, on the one hand, early involvement of the designer to better align with the owner's needs and, on the other hand, a close connection with the contractor for the subsequent construction stage. Thus, designers need to establish extensive interactions with others. Third, the integrated advantages of owner and contract are both high. They play the role of "system integrator" and "knowledge hub" in projects to lead the inputs and outputs of knowledge resources. Fourth, the value and flow advantages of project supervisors and suppliers are low. Project supervisors are more involved in monitoring project quality and safety and less involved in predictive problem-solving to improve their knowledge contribution. Suppliers mainly interact with designers and contractors for materials and equipment and less with other MSOs.

6.4 Discussion

This chapter conceptualized, quantified, and visualized the KVF cycles to reveal how MSOs conduct IKS to realize value co-creation in megaprojects. The results reinforce the need to consider IKS as complex interactive activities and emphasize the need to shape governance strategies targeted toward different types of MSOs to promote value co-creation. This section first provides a comprehensive analysis of the features of the IKS-SVN model constructed in this study, based on the results of Section 6.3.3. Secondly, based on the calculating results of value, exchange, and integrated advantages in Section 6.3.4, a comparative analysis is conducted to identify seven main collaborating organizations' knowledge influence. Corresponding (internal) strategies are then proposed to assist different collaborating organizations in enhancing their levels of knowledge influence. Finally, based on the identified top KVF cycle in Section 6.3.3, (external) cooperation strategies are proposed to facilitate collaboration among different collaborating organizations, aiming to achieve collaborative knowledge value creation.

6.4.1 Characteristics of IKS networks

Prior research mainly focused on restricted exchanges between MSOs (Roehrich et al., 2020), which exist in the *hub-and-spoke* model with direct and dyadic exchanges (Figure 6.1). In contrast to the *hub-and-spoke* model, recent inter-organizational governance research has revealed the potential for generalized exchanges in facilitating value co-creation (Bridoux and Stoelhorst, 2022). Following the call to explore indirect reciprocity in the network (Roehrich et al., 2020), this chapter reveals two general characteristics of IKS networks, further forming Proposition 1. *First*, the generalized exchange is the dominant pattern after searching for all

KVF cycles (633, 110 KVF cycles are identified as generalized exchanges while 328 KVF cycles as restricted exchanges in Figure 6.3). More specifically, this result indicates that most KVF cycles rely on generalized exchanges (multiple and indirect exchanges) mediated by two or more MSOs. *Second*, KVF cycles demonstrate a dominant pattern of *negative skewed distribution*. The generalized exchange (cycle length = 6) occurs most frequently. The restricted exchange (cycle length =2) and generalized exchange (cycle length = 3) occur least frequently.

Proposition 1: *KVF cycles demonstrate a dominant pattern of negative skewed distribution and generalized exchanges.*

It is interesting to explore the reasons for explaining the proposed characteristics of IKS networks. Viewed through social exchange theory, a stakeholder repays the favor gained from one stakeholder in the network to another stakeholder. In other words, the rewards that a stakeholder receives are not directly contingent on the resources provided by that stakeholder. The generalized exchange, therefore, faces a long-running dilemma concerning the potential free-riding problem (Yamagishi and Cook, 1993). Regarding the generalized exchange, the more MSOs involved, the more resources are pooled, and the greater the potential opportunism risks are (e.g., the stakeholder is better positioned to access more opportunities to reap benefits at a lower cost through indirect reciprocity in a larger network). Despite all this, the generalized exchange does provide the basis for a value co-creation process among MSOs (Das and Teng, 2002). The results of this chapter promote the view that it is promising to design generalized exchange processes based on the moderate length of KVF cycles, and the appropriate length is relevant to the size of the whole network.

6.4.2 Distinct power of distinct MSOs

Stakeholder governance research usually treats *power* as a characteristic of stakeholders (Bacq and Aguilera, 2021; Scherer and Voegtlin, 2020). Extant studies usually explore the interactive IKS among stakeholders from a single value perspective (e.g., economic aspect) rather than from multiple value perspectives (e.g., a combination of the economic and social aspects) as the basis for understanding the characteristics of stakeholder power. Moreover, discussing stakeholder power requires a network perspective (indirect and multiple exchanges) rather than the *hub-and-spoke* or *linear* perspective (direct and dyadic exchanges). Dyadic exchanges lack social alternatives (Das and Teng, 2002). Power emerges and evolves in a network model of exchanges of valuable resources (Carnovale et al., 2017). Based on the social exchange theory, this chapter responds to the call of Roehrich et al. (2020) to interpret the value co-creation original from IKS from the network-based perspective.

Table 6.5 Classification of MSOs according to value, exchange, integrated advantages

Stakeholder type	**Stakeholder advantages**			**Stakeholder example**
	Value advantage	**Exchange advantage**	**Integrated advantage**	
Powerful stakeholder	High	High	High	Owner, contractors
Wealthy stakeholder	High	Low	Low	Consultants
Central stakeholder	Low	High	Low	Designers, government
Powerless stakeholder	Low	Low	Low	Project supervisor, suppliers

Our study reveals three kinds of stakeholder powers (i.e., value, exchange, and integrated advantages) combined in four distinct types of MSOs (i.e., *powerful*, *wealthy*, *central*, and *powerless*), as shown in Table 6.5 and Proposition 2. The value advantage reflects the interactive quality between MSOs, whereas the exchange advantage reflects the interactive quantity between MSOs. Integrated advantage manifests the comprehensive interactive intensity between MSOs. MSOs with both high value and exchange advantages are considered *powerful*; those with only high value advantages are *wealthy*; those with only high exchange advantages are *central*; those with both low value and exchange advantages are *powerless*.

Proposition 2: *Based on the value, exchange, and integrated advantages of stakeholder power in the interorganizational knowledge value network, primary megaproject organizations can be classified into different types, namely powerful, wealthy, central, and powerless.*

Besides, this study also reveals that the relative importance (power) between two MSOs is asymmetric. For instance, when the owner acts as the focal organization within the IKS network (i.e., O→O), the most prominent interactive MSOs in facilitating the KVFs are the contractors (integrated advantage = 0.962) and designers (integrated advantage = 0.765). When the designer acts as the focal organization within the IKS network (i.e., D→D), the most important prominent interactive MSOs are the contractor (integrated advantage = 0.963) and the owner (integrated advantage = 0.958). It could be concluded that the extent to which the government controls the owner is lower than the extent to which the owner influences the government. Each stakeholder involved in the project delivering process could be taken as a focal organization, thereby revealing how value could be maximized through targeted interactive exchanges. As Roehrich et al. (2020) suggested, understanding the differences (possible asymmetries) between stakeholders in an interactive value co-creation is the key to understanding inter-organizational governance mechanisms. Thus, the focal organization should align strategies regarding its relative power status to other MSOs to overcome IKS difficulties (Szulanski et al., 2016), and realize value co-creation (Bridoux and Stoelhorst, 2022).

6.4.3 Internal strategies to promote stakeholder power

Foss et al. (2010) highlighted the challenge for managers to promote stakeholder power through appropriate governance mechanisms. To maximize the benefits of KVFs, managers need to understand the different situations faced by distinct types of MSOs. A systematic framework was developed for governing the IKS network in megaprojects (Figure 6.4). This framework provides four types of governance strategies (exchange, adaptive, integrated, and value strategies) to foster and align KVFs targeted toward different stakeholders.

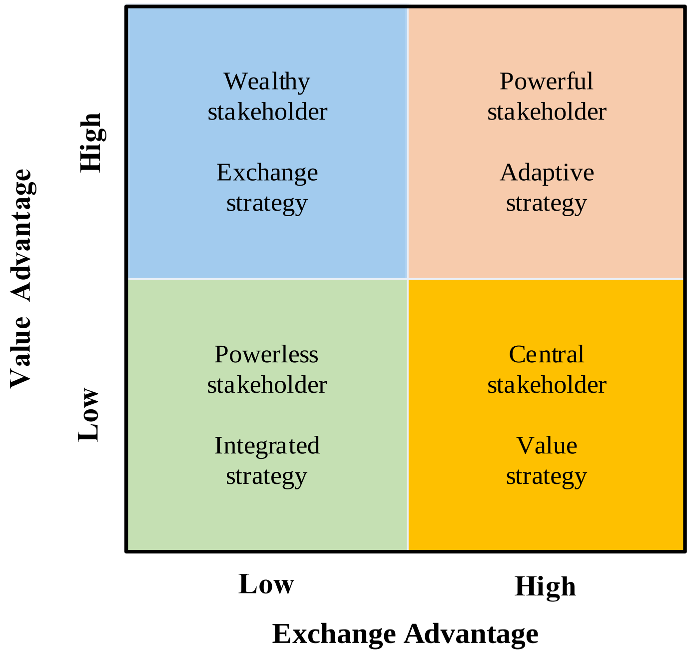


Figure 6.4 Stakeholder governance strategies for IKS

6.4.3.1 Exchange strategy for wealthy stakeholders

According to Table 6.5, wealthy stakeholders (e.g., consultants) face a high value but low flow advantage. Wealthy stakeholders exhibit a relatively strong interactive quality but a weak interactive quantity in the knowledge sharing process. In addition to providing better consulting advice, consultants should invest more time and effort into brokering new ties. Therefore, wealthy stakeholders have great potential to adopt strategies to expand the role of communication platforms. In contrast to the traditional perspective that prioritizes strengthening established value advantages (Bacq and Aguilera, 2021), wealthy stakeholders should take a more networked view by exploiting the role of brokers to mitigate flow disadvantages (i.e., from low flow advantage to moderate or high flow advantage). Forums and conferences could provide important opportunities to broker ties across stakeholders (Gualandris et al., 2021). Discussion of the role of wealthy stakeholders within the IKS network provides the following proposition:

Proposition 3a: *The exchange strategy is effective in promoting the value creation of wealthy stakeholders by brokering new ties.*

6.4.3.2 Value strategy for central stakeholders

According to Table 6.5, central stakeholders (e.g., designers and government) face a high exchange advantage but a low value advantage. More specifically, central stakeholders exhibit a relatively strong interactive quantity but weak interactive quality for the IKS process. In addition to maintaining communication channels, central stakeholders should invest more time and effort into customizing and tailoring values for projects, particularly at the front end of project development programs (Liu et al., 2019). Megaprojects are usually commissioned by governments and delivered by private organizations (van Marrewijk et al., 2008). The front end is often the most important stage for opportunities to create value in projects (Edkins et al., 2013). Technical complexities and construction solutions are more common at the design stage than at the project execution stage (Worsnop et al., 2016). It would be, therefore, more effective for central stakeholders to adopt strategies to obtain more value advantages. For example, designers should share knowledge at the front end to make or break project boundaries and bring a strong interest in promoting practical and inventive ideas (Kumaraswamy et al., 2017). Leveraging exchange advantages, central stakeholders should monitor other stakeholders' needs in both business and social interactive value co-creation (Shaheen and Azadegan, 2020). Recognition of the role of central stakeholders within the IKS network provides the following proposition:

Proposition 3b: *The value strategy is effective in promoting the value creation of central stakeholders by monitoring other stakeholders' needs, in particular at the front end of project development programs.*

6.4.3.3 Integrated strategy for powerless stakeholders

According to Table 6.5, powerless stakeholders (e.g., suppliers and project supervisors) suffer from a low level of value advantage as well as exchange advantage. More specifically, powerless stakeholders demonstrate both a relatively weak interactive quantity and quality during the IKS process. In megaprojects, communication interruption or information delay between suppliers and other stakeholders often causes resource shortages, relationship estrangement, or loss of further cooperation (Cao and Zhang, 2011). Reaping greater benefits from knowledge exchanges, powerless stakeholders could simultaneously take an integrated strategy to cope with the exchange and value disadvantages. It isn't easy to form a collaborative advantage by improving the exchange or value aspect separately. Zhou et al. (2014) indicated that relational ties act as conduits for KVFs. A voluntary association between suppliers, project supervisors, and other stakeholders is encouraged to increase the frequency of interactions in the IKS process (Mishra et al., 2015; Wang and Hu, 2020). The number of ties that new suppliers or project supervisors could potentially develop with existing MSOs, based on their technical and relational capabilities, could be a central selection criterion (Gualandris et al., 2021). However, highly connected relational ties are likely to create a lock-in trap (Zhou et al., 2014) that constrains KVFs and increases the risk of opportunistic exploitations (Villena et al., 2011). Suppliers and project supervisors could become involved in collaborative learning to provide solutions for challenging problems (Huo et al., 2014). The solutions would then be reviewed, and the best solution would be chosen to enhance the interactive quality (Ofreneo, 2008). This evidence about the role of powerless stakeholders within the IKS network provides the following proposition:

Proposition 3c: *The integrated strategy is effective in promoting the value creation of powerless stakeholders by strengthening relational ties and enhancing collaborative learning.*

6.4.3.4 Adaptive strategy for powerful stakeholders

According to Table 6.5, powerful stakeholders (e.g., owners and contractors) demonstrate a high level of exchange and value advantage. More specifically, powerful stakeholders exhibit both a relatively strong interactive quantity and interactive quality during knowledge exchanges. According to Vuorinen and Martinsuo (2019), the way owners or contractors manage the project supply chain is focused on shaping value-oriented stakeholder influence strategies in delivering megaprojects. To maximize the value co-creation within the IKS network, powerful stakeholders could adopt adaptive strategies to promote a collectivistic and supportive culture (Gualandris et al., 2021) and balance the exchange and value advantages to accommodate other stakeholders' situations. This evidence on the role of powerful stakeholders within the IKS network leads to the following proposition:

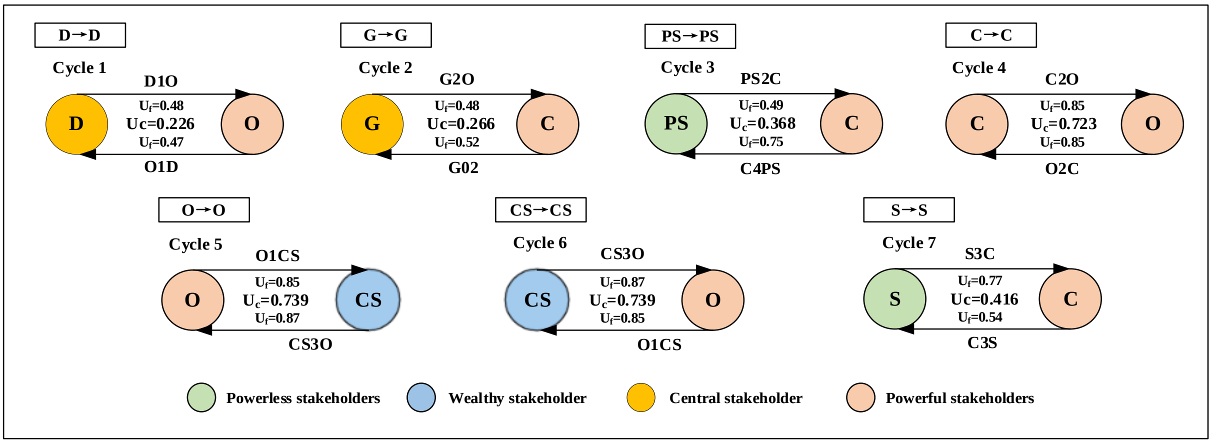
Proposition 3d: *The adaptive strategy is effective in promoting the value creation of powerful stakeholders by collectivistic cultural development and early-stage involvement.*

6.4.4 External strategies to facilitate stakeholder synergy

Although internal strategies could help stakeholders identify and improve their stakeholder power in the IKS network, the value creation of IKS can be achieved or maximized only when it is reciprocally implemented. Hence, stakeholder synergy for joint benefit improvement should be a common goal for stakeholders in inter-organizational projects. By analyzing the top restricted and generalized KVF cycles in the IKS network, two external strategies were formed to facilitate stakeholder collaboration in IKS.

6.4.4.1 Power incongruence

Figure 6.5 presents the top restricted KVF cycles with the highest utility scores when each stakeholder is set as the focal organization, respectively. This study showcases typical scenarios for different stakeholders to match partners through targeted restricted exchanges to facilitate value creation (Arora et al., 2021; Artto and Turkulainen, 2018). The extant IKS research has focused on the sharing willingness of knowledge senders and the absorptive capability of knowledge recipients. However, insufficient attention has been accorded to the match between knowledge senders and recipients. Power and dependence (e.g., congruence or incongruence between buyer-supplier) are the underlying functional themes of social exchange theory-based studies (Narasimhan et al., 2009).



Note: “O” represents owner, “G” represents government, “CS” represents consultants, “PS” represents project supervisors, “C” represents contractors, “S” represents suppliers, and “D” represents designers. There is no restricted KVF cycle when the project supervisor is set as the focal organization.

Figure 6.5 Top restricted KVF cycles for each stakeholder as the focal organization

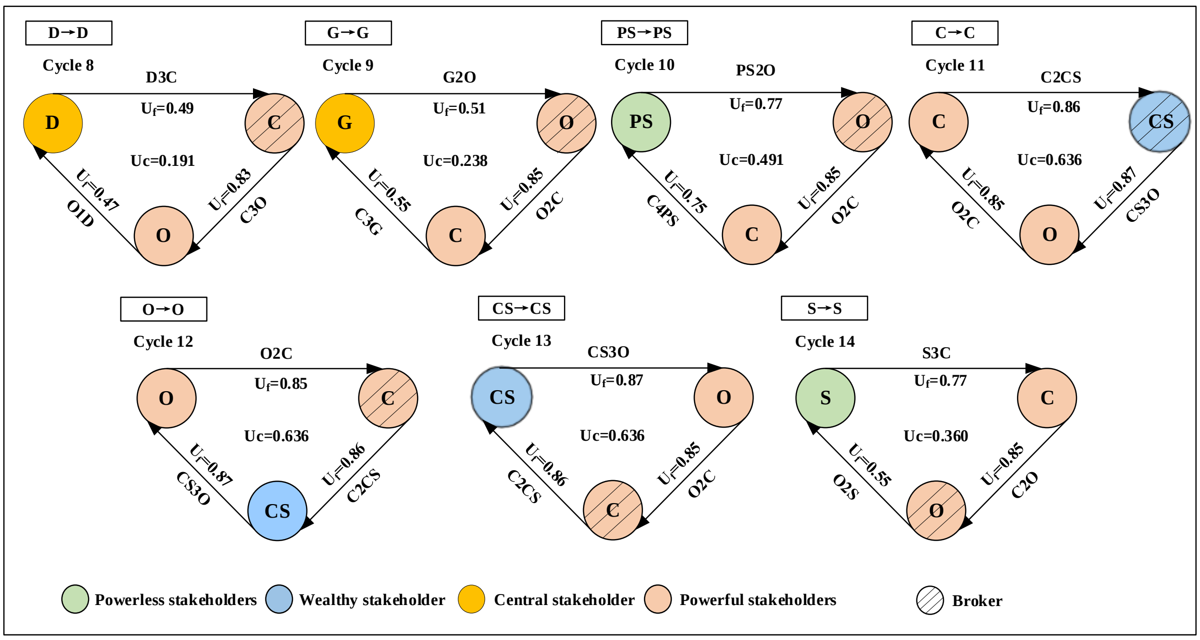
Traditional management literature indicated that buyer-supplier congruence is useful (Deng et al., 2021). However, Figure 6.5 shows that non-powerful stakeholders (i.e., powerless, wealthy, and central stakeholders) make restricted exchanges with powerful stakeholders to top the utility score (e.g., cycles 1, 2, 3, 6, and 7). Therefore, the power status between the knowledge sender and the recipient is incongruent. This incongruence is beneficial for non-powerful stakeholders to balance their value advantages and exchange advantages by virtue of the integrated advantages of powerful stakeholders. Moreover, Figure 6.5 also shows that powerful stakeholders can select either powerful or non-powerful stakeholders to make restricted exchanges to top the utility score (e.g., cycle 4 and cycle 5). In sum, non-powerful stakeholders with relatively low integrated advantages should cooperate with powerful stakeholders to implement IKS for value co-creation (Aaltonen and Turkulainen, 2018). Powerful stakeholders are encouraged to nurture a collectivistic culture to establish wide interactions with others (Gualandris et al., 2021; Karlsen, 2010; Kohtamäki, 2010). In this case, powerful stakeholders should be aware that multiple interactions could contribute to a commitment from their partners that goes beyond a simple summation of each KVF's costs and benefits within the IKS network. The above discussion on top restricted exchanges between stakeholders within the IKS network leads to the following proposition:

Proposition 4a: *The incongruence between knowledge sender and recipient in terms of power status (non-powerful stakeholder vs. powerful stakeholder) contributes to value co-creation.*

6.4.4.2 Knowledge broker

Figure 6.6 depicts the top generalized KVF cycles with the highest utility scores when each stakeholder is set as the focal organization, respectively. This study sheds light upon the *triadic collaboration* (i.e., non-powerful-powerful-powerful stakeholder collaboration) in knowledge exchanges to facilitate value co-creation. Generalized knowledge exchanges could be reached when the discrete knowledge sharing across MSOs was bridged through *brokers* (Kickul et al., 2011; Reagans et al., 2015; Roehrich et al., 2020; Zhao et al., 2021). In particular, inter-organizational triads attract growing interest in project management (Wynstra et al., 2015). Dyads are insufficient in characterizing the interactive value co-creation inherent in a network (Choi and Wu, 2009). Triads are considered building blocks for understanding the complex interactions in a network, especially the balanced role of the broker (Reagans et al., 2015).

There are also two types of triadic scenarios in Figure 6.6. *First,* as for non-powerful stakeholders (e.g., cycles 8, 9, 10, 13, and 14), powerful stakeholders work as brokers. To cope with their imbalanced value advantages and exchange advantages, non-powerful stakeholders could cooperate with a powerful brokering stakeholder to increase their influence through coalition strategies and facilitate the value co-creation with the final powerful stakeholder (Hsieh, 2009; Rastegar and Ruhanen, 2021; Williams et al., 2015). If the focal organization is non-powerful, a powerful broker is an antecedent to establish a balanced status for effective value co-creation. *Second*, as for powerful stakeholders, due to their integrated advantages within the IKS network, they have more room to select the *broker*, either powerful stakeholders (e.g., cycle 12) or non-powerful stakeholders (e.g., cycle 11). Interestingly, the consultant works as a *broker* to facilitate the generalized exchange between the owner and contractor (cycle 11), which aligns with Wu (2018) that the consultants are central stakeholders in megaprojects. KVFs can be successfully driven when the consultants are encouraged to engender interdependencies and cooperation between potentially mutually competitive contractors and the owner, not just providing consulting services at the front end of project development programs. If the focal organization is powerful, a non-powerful stakeholder provides an alternative to establishing a balanced status for effective value co-creation.



Note: "O" represents owner, "G" represents government, "CS" represents consultants, "PS" represents project supervisors, "C" represents contractors, "S" represents suppliers, and "D" represents designers.

Figure 6.6 Top generalized KVF cycles for each stakeholder as the focal organization

Integrated project delivery, an emerging project delivery approach, integrates people, project, business, and social interactions into a process that collaboratively harnesses the knowledge of different stakeholders to facilitate triple or multiple value co-creation (Walker and Rowlinson, 2020). In the context of integrated project delivery of megaprojects, the early involvement of powerful stakeholders can provide a more advantageous solution for complex challenges (Piroozfar et al., 2019). In contrast to a traditional strategy focusing on dyadic and direct exchanges (Wilhelm, 2011), powerful stakeholders can provide the conditions for leveraging triadic or more complex generalized exchanges. For example, a contractor contributes to the owner through early involvement in design work. The owner provides valued suggestions to the designers. A designer forms a sense of obligation and reciprocates with suitable responses to project problems. A typical case is the Shanghai Expo, which includes 136 pavilions and more than 160 supporting facility buildings. This project launched a *golden idea* activity to seek constructive suggestions at an early stage, which fostered a collective culture and facilitated successful project delivery (Wang et al. 2017). The discussion of the importance of *triadic collaboration* within the IKS network provides the following proposition:

***Proposition 4b**: The selection of the broker in triadic knowledge exchanges is contingent on the power status of the focal organization (non-powerful stakeholder vs. powerful stakeholder) to establish a balanced status for value co-creation.*

6.5 Chapter Summary

The increasing proliferation of projects in organizational activities entails new governance challenges (Maylor et al., 2018), particularly regarding value co-creation in project settings (Caldwell et al., 2017; Davies et al., 2014; Mishra et al., 2015; Zerjav, 2021). Knowledge is among the most valuable resources for survival, growth, and productivity (Szulanski et al., 2016). IKS is an important strategy for promoting collaborative advantage and value co-creation. Still, it is extremely difficult to manage because MSOs cannot quantify these benefits, find their power in the IKS network, and form internal enhancement strategies and external collaboration strategies. This chapter applies a novel SVN approach to quantify the benefits of IKS through *value-focused thinking* and extend the systematic and dynamic understanding of how internal MSOs interact from a *network-based* perspective. Specifically, 98 typical KVFs among 7 primary MSOs in megaproject were identified and quantified through semi-structured interviews and questionnaire surveys. Then, the design structure matrix was utilized to search out all KVF cycles that unveil complex interactive IKS (i.e., *restricted* and *generalized exchanges*). KVF cycles demonstrate a dominant pattern of *negative skewed distribution* and *generalized exchanges*. Next, three types of stakeholder advantages were calculated in the IKS network to categorize MSOs into four types (i.e., *powerful, wealthy, central,* and *powerless* stakeholders) to answer RQ 6.1, and propose different internal (i.e., *exchange, value, integrated* and *adaptive* strategies) to promote stakeholder power in promoting value co-creation through IKS to answer RQ 6.2. Finally, the top seven restricted (direct and dyadic) and general (indirect and multiple) exchanges were analyzed to form external strategies (i.e., *power incongruence* and *knowledge broker*) to facilitate IKS collaboration and reach value co-creation for answering RQ 6.3.

CHAPTER 7 APPLYING IKS: LINKING IKS WITH INNOVATION CAPABILITY ENHANCEMENT IN MEGAPROJECTS[9]

There is a close relationship between interorganizational knowledge sharing and the likelihood of innovation capability enhancement for stakeholders in megaprojects...Owners should adopt measures to create an atmosphere of trust and promote inter-organization openness, such as perfecting related contracts and establishing knowledge sharing mechanisms to form megaproject innovation alliances (MIAs).

(Jin, Z., Zeng, S., Chen, H., & Shi, J. J, 2022, p 654).

7.1 Introduction

To address these original challenges, overall innovation in multiple aspects, such as managerial and technical, is indispensable (Söderlund et al., 2017). Effective IKS is an important guarantee and prerequisite for megaproject innovations. For example, by defining construction objectives, conducting preliminary research, creating bid documents, and establishing technical standards, the owner paves the way and provides a foundational framework for innovation for both the designers and contractors. The designer, in return, aids the owner in refining innovative solutions by undertaking focused research, devising inventive design proposals, compiling technical documentation, and offering consultancy services, using these as the cornerstone for the contractor's innovations. Ultimately, it falls upon the contractor to implement these innovative solutions. IKS, among the owners, consultants, and contractors,

[9]This chapter is largely based on the following manuscript:

He, H., Wang, G. *, He, Q., Chan, A.P.C & Gao, X., Interorganizational knowledge sharing and innovation capability enhancement in megaprojects: a longitudinal case study of the Hong Kong-Zhuhai-Macau Bridge Project. (International Journal of Project Management, **Under Review**, **First Author**) jointly contribute to the final innovation and enhance their innovation capability (Nesheim and Hunskaar, 2015; Taminiau et al., 2009). Moreover, successful innovations are achieved not only by creating new knowledge within the innovation alliance of the ongoing project but also by obtaining, sharing, and diffusing knowledge across MSOs (Hartmann and Dorée, 2015; Prencipe and Tell, 2001). History shows that most problems and challenges for new innovation alliances in projects are the same as those encountered in previous projects. IKS helps innovation alliances avoid time and money wastes to re-acquire "lost" knowledge, decrease the frequency of "Reinventing the wheel", and benefit from the experiences of previous and other projects (Ren et al., 2018).

Innovation capability is defined as the organizational capability to adopt and conduct new practices to obtain competitive advantage (Lin et al., 2010), and solve problems in aspects of product technology, management process, business model, and institutional system (Figueiredo et al., 2020; Sáenz et al., 2009; Teece et al., 1997). Knowledge has strategic value due to its uniqueness and complexity (Ragab and Arisha, 2015). As a typical complex giant system, the HZMB project is embedded in the VUCA scenarios (Gao et al., 2021). MSOs cannot rely solely on internal knowledge of the *megaproject innovation alliance* (MIA), which is formed by all primary MSOs involved in project delivery, including the owner, contractors, suppliers, designers, project supervisors, and consultants. The MIA needs to conduct efficient IKS with external organizations who are involved in similar megaprojects but have not participated in the delivery of the ongoing megaprojects to acquire, absorb, and integrate external knowledge resources to improve their innovation capabilities when facing special problems (Argote and Miron-Spektor, 2011; Huber, 1991), and eliminate fragmentation due to professional division of labor, avoid the "island effect" caused by the transformation (Chen et al., 2018), and achieve effective stakeholder synergy.

However, existing IKS research faces the following challenges. *First,* coping with multiple challenges in managerial and technological is the prominent motivation and scenario for MSOs to conduct IKS. However, there is still a lack of systematic exploration of the scenario features embedded in megaprojects (Argote & Miron-Spektor, 2011). *Second,* extant research mostly explored the effects of IKS on innovation capability enhancement in the context of enterprise management. Different from permanent enterprise organizations, megaprojects are delivered by multiple temporary MSOs where distinct MSOs are involved in distinct project stages or sub-projects. MSO conducting IKS in megaprojects faces more constraints ignored by the existing studies. The IKS strategies for MSOs and their effect on MIA's innovation capability enhancement need further exploration. *Finally,* as the captain leading the direction of megaproject delivery, the owner is essential in guiding MIA in conducting IKS in different project stages (i.e., preliminary, construction, and operation). Further research needs to clarify the owner's role. In sum, enhancing organizational innovation capabilities through IKS has become a common concern of scholars and practitioners (Troise et al., 2022), specifically involving the following two research questions.

RQ 7.1 *What are the characteristics of practical challenges, IKS strategies, and innovation capability enhancement in megaprojects?*

RQ 7.2 *What role does the megaproject owner play in guiding MIA conducting IKS in different project stages?*

7.2 Research Design

This chapter uses a longitudinal case study method to explore these two research questions. The HZMB project, as a representative megaproject case, is chosen as the research object to conduct the research. Multi-source data was collected, including a literature review of academic papers and project documents, as shown in sections 3.3.1 and 3.3.2. A case study based on the grounded theory method was conducted to analyze the data (Section 3.4.4). A focus group discussion was also conducted to verify the coding results of this study (Section 3.3.4).

Besides, the "*scenario-process-capacity*" framework is the mainstream of this study to conduct an in-depth analysis of IKS in megaprojects. *Scenarios* reflect the problems and needs faced by MSOs are also the starting point for triggering IKS; the *process* depicts the IKS strategies in megaprojects; *capability* is an important output of the IKS, reflecting the creative solutions for problems and challenges in the megaproject delivery. In the realm of megaproject management, two distinct modes of thinking are typically employed: practical thinking and theoretical thinking. Practical thinking is concerned with the "what to do" and "how to do it" aspects, while theoretical thinking seeks to elucidate the "what it is" and "why it is" questions. The framework "Scenario-Process-Outcome" addresses the "what" and "how" dimensions of IKS in megaprojects, while the "role of the owner" addresses the "what" and "why" inquiries.

7.3 Findings

This chapter analyzed the IKS and innovation in the preliminary, construction, and operation stages of the HZMB project based on the grounded theory to map a conceptual model for IKS in megaprojects, as shown in Figure 7.1 and Figure 7.2. Among them, the IKS scenario is rooted in the characteristics of VUCA, including *environmental variability, uncertainty of needs, complexity of objects, and cognitive ambiguity*. The IKS strategies involve two aspects, including *IKS in tactic and IKS in operation*. Innovation capability enhancement through IKS is shown in the *institution, business, technology,* and *management* aspects. In the above stages, the project owners have experienced role changes from *"leader"* to *"coordinator"* to *"supporter"* in guiding the MIA in conducting IKS. The specific coding process is shown in **Appendix G**.

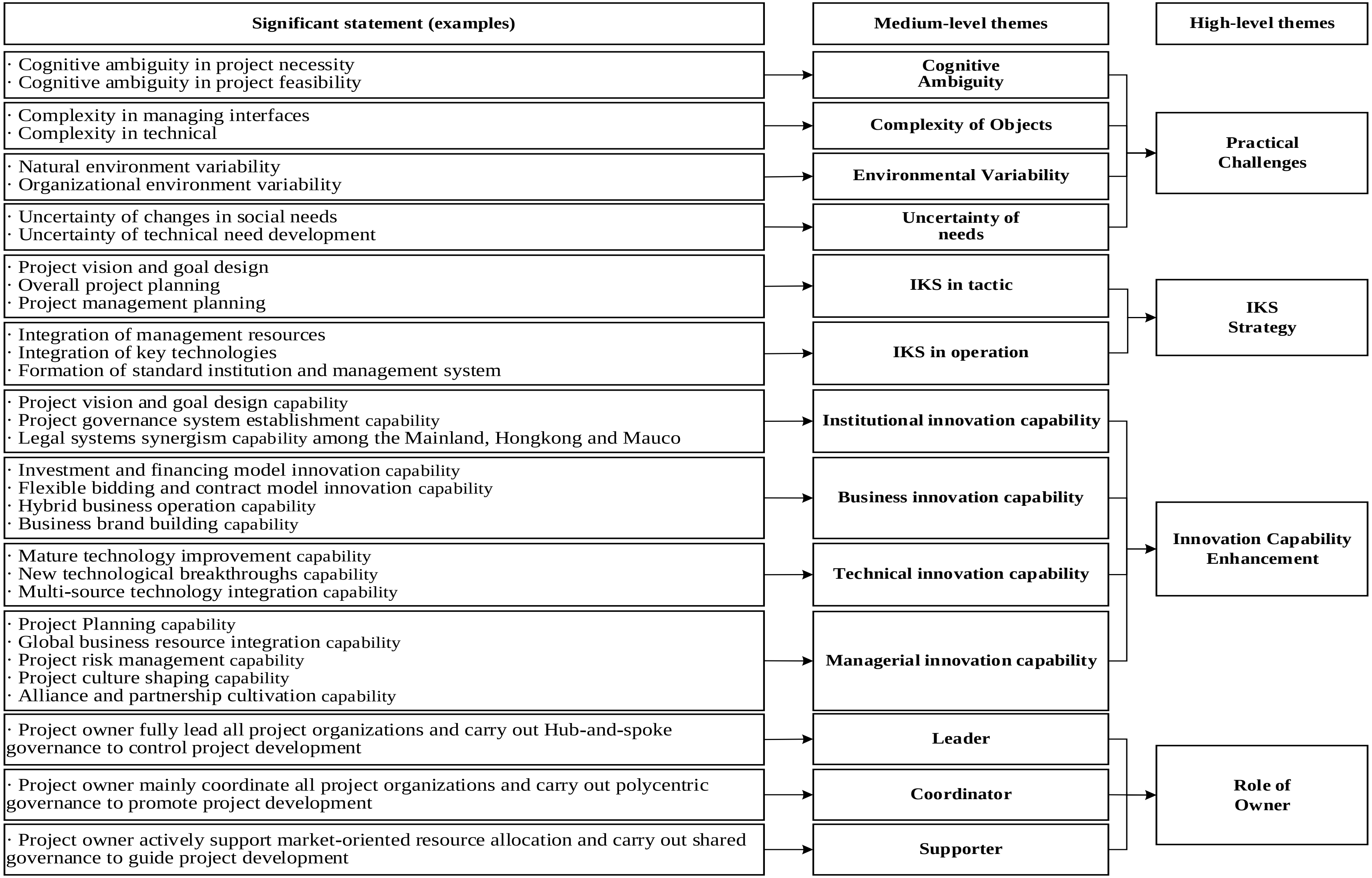


Figure 7.1 Text data structure

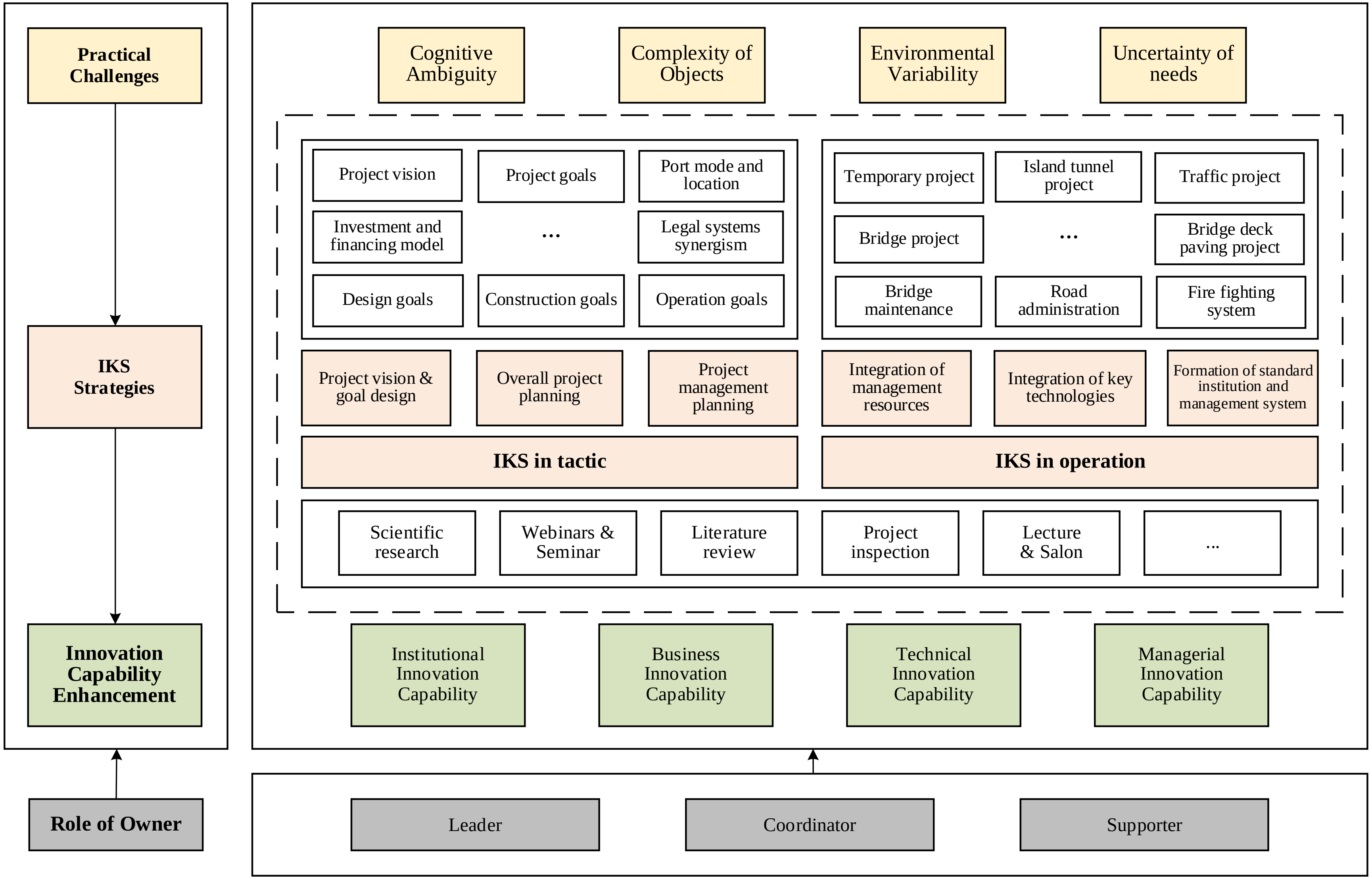


Figure 7.2 Conceptual model of IKS for the HZMB project

7.3.1 Practical challenges

The HZMB project is an infrastructure megaproject in transportation, closely and profoundly related to the society, economy, and the environment. The VUCA scenario, including *environmental variability, the uncertainty of needs, the complexity of objects, and cognitive ambiguity,* are the main practical challenges motivating MSOs' IKS to enhance their innovation capability for successful project delivery of the HZMB project.

7.3.1.1 Cognitive ambiguity

The construction of a bridge can have intricate and wide-ranging effects that extend beyond current knowledge and existing cognitive boundaries. Given the extended design life of the project, spanning 120 years, accurately and comprehensively predicting these impacts is a challenging task. IKS in megaprojects initially confronts a central aspect known as "*cognitive ambiguity*", which pertains to a series of questions regarding the project's necessity and feasibility. For instance, what are the value and the benefits of undertaking the HZMB project? Can it adequately address the social and economic development needs of the Guangdong-Hong Kong-Macao Greater Bay Area? Will the HZMBs project yield the anticipated benefits compared to the substantial financial and resource investments? What institutional and legal difficulties and challenges might the HZMB project encounter? Is it feasible and controllable regarding project financing, technology, and risk management?

7.3.1.2 Complexity of objects

MSOs in the HZMB project faced the situational characteristics of object complexity, involving both *technical* and *managing project interfaces*. For instance, the construction of the HZMB project posed significant challenges to several engineering frontiers: it entailed building the world's longest island tunnel (6.7 kilometers), the deepest underwater tunnel, the largest single immersed tube by volume, the longest projected service life, and the most extensive tunnel lane network. Besides, project interface management also became highly intricate to complete such an unprecedented project. Different specialized areas formed intricate engineering subsystems, with intricate interdependencies and interfaces among these subsystems.

7.3.1.3 Environmental variability

"*Environmental variability*" involves the *natural environment* and *organizational environment*. For instance, during the construction of the immersed tunnel project, it had to contend with unpredictable natural conditions, such as the protection of white dolphins, the threat of tsunamis, and the impact of typhoons. Between 2011 and 2017, the project encountered 38 averted typhoons, evacuating over 33,000 people and 1,800 ships. Furthermore, the collaborative efforts involving MSOs from different cultures, regions, and disciplines presented significant management challenges.

7.3.1.4 Uncertainty of social and technical needs changes

The MSOs in the HZMB project encountered a scenario characterized by "Uncertainty of needs", including *uncertainty of changes in social needs* and *uncertainty of technical need development*. The social, economic, and natural environment in which megaprojects are embedded is a complex self-organizing system. Hence, new needs will emerge during the long-period megaproject operation stage. For example, in the preliminary stage of the HZMB project, the technology of new energy vehicles was not yet mature. However, in the operation stage, with the popularization and development of new energy vehicles, there is an urgent need to build substations, line grids, and charging piles on the artificial island to improve the reliability of the power supply. Furthermore, these needs are often challenging to identify and predict based solely on past experiences. For instance, the traffic flow was lower than expected due to cross-boundary traffic policies influenced by the COVID-19 pandemic. To maximize social benefits, an ongoing effort is to establish a world-class cultural and creative brand by bridging tourism, cultural, and creative businesses with the HZMB project operation.

7.3.2 IKS strategies

To address these practical challenges, the MSOs in the HZMB project have refined the problems layer by layer from the perspective of a long-term span and carried out a series of IKS activities, including scientific research, webinars, seminars, sharing of relevant literature, project inspection, expert consultation, and training (e.g., bridge lecture hall, cultural salon). IKS strategies can be divided into two aspects: *IKS in tactic* and *IKS in operation*, as shown in Figure 7.2 and **Appendix H**. First, *IKS in tactic* is primarily concerned with refining the project's vision and goals to establish a shared understanding among MSOs and to align their actions, thus reducing cognitive ambiguity. Second, *IKS in operation* is focused on practical knowledge sharing and facilitating resource integration to address specific technical and managerial challenges and enhance the efficiency and efficiency of particular project tasks by solidifying standard systems.

7.3.2.1 IKS in tactic

The case study of the HZMB project reveals that *IKS in tactic* mainly refers to three aspects: *project vision and goal design*, *overall project planning*, and *project management planning*. Initially, IKS in the design of the project's vision and goals proves valuable in addressing cognitive ambiguity and in the holistic planning of project decision-making. In the case of the HZMB project, the MSOs systematically examine the vision and construction goals of model projects, such as the Brooklyn Bridge and the Dujiangyan Dam, through comprehensive literature reviews and project inspections. This approach is adopted to avoid making "short-sighted" and biased decisions. The Brooklyn Bridge, for instance, is globally renowned in the Bay Area. It has significantly enhanced the efficiency of resource allocation, including the movement of people, goods, capital, and technology in the region. Moreover, it has become a crucial driver of the Bay Area's economy and a cultural symbol not just of New York but the

United States (McCullough, 2012). Similarly, the Dujiangyan Dam is a vital water conservancy structure in China, which has been operational for over two millennia, delivering immeasurable cultural, economic, and social benefits. Following effective IKS, *the project vision and goal design* for the HZMB project was creatively framed as "connecting Hong Kong, Guangdong, and Macao to create a world-class regional hub, fostering economic and cultural ties among them." Simultaneously, the project vision emphasizes "constructing a world-class cross-sea passage and landmark, offering users high-quality services." These objectives reflect the project's collective spirit and determination and establish a common direction for creating a high-quality, world-class project.

Furthermore, the MSOs gained valuable insights and experience in *overall project planning* through a range of specialized research activities. These activities encompassed the harmonization of laws and regulations across the three regions, the selection of investment and financing models, the design of bridge locations and landing points, the choice of port models, and the preservation of the Chinese white dolphins. For instance, regarding the harmonization of laws and regulations across the three regions and to elucidate potential legal issues and countermeasures for the HZMB project, the project owners and legal consultants engaged in various IKS activities, including an extensive review of legal documents and case studies, on-site legal research, hosting seminars to discuss similar projects, and consulting legal experts to avoid investment errors. More specifically, the MSOs of the HZMB project meticulously reviewed laws across different levels and domains, as well as bilateral treaties, agreements, and contracts, covering a wide array of international and cross-regional public transport infrastructure projects. Simultaneously, they conducted a series of on-site legal investigations, participated in legal seminars focused on similar projects, and integrated legal consultants throughout the project management lifecycle to clarify crucial legal matters and establish effective countermeasures.

Third, *project management planning* is another aspect of the *IKS in tactic* conducted in the HZMB project, which aims to provide MSOs with unified guidelines and cognitive map and form a planning system covering quality, bidding, information, HSE (Health Safety Environment) management through project investigation, cultural salon, bridge lecture hall.. There are some typic examples. 1) Deming's quality management principles and PDCA (Plan Do Check Act) cycle are sufficiently integrated into the high-quality bridge planning system to drive operation-oriented planning, design, construction, and continuous improvement through bridge lectures, HZMB magazines, cultural salons, and other channels. 2) Rather than dividing bidding management by functional subsystems, the HZMB project adopts a lesson from the high-speed rail industry by dividing bidding management by project sections. This approach proves beneficial for attracting high-quality market resources, optimizing resource allocation, and reducing interfaces and risks. 3) Drawing from best practices in the nuclear power industry, the HZMB project develops and enhances a comprehensive information management system to advance the intelligent development of project management. 4) The project's quality management plan incorporates lean production practices inspired by Toyota. It creatively proposes and implements four principles for project design: large-scale, factory-based, standardized, and assembled. These principles aim to achieve the highest management efficiency, lowest cost, and quickest response. 5) The HSE management plan system leverages the experience of the petrochemical industry, which involves high-risk operations like oil drainage, fire, and explosion. Given the HZMB project's complex environmental conditions, such as typhoons, rainstorms, high temperatures, and torrents, a stringent HSE management plan is deemed necessary to ensure safety and environmental protection.

7.3.2.2 IKS in operation

The *IKS in operation* refers to *integrating key technologies* and *management resources* and *forming a standard institution and management system*. This integration process involves combining discrete elements to create a valuable and efficient whole, ultimately simplifying the complexity of megaprojects by cutting and assembling subsystems.

First, *key technical* challenges were effectively solved through *IKS in operation*, such as deep burring and accurate installation of immersed pipes, and optimizing the pavement of steel bridge decks. 1) Deep burring of immersed pipes is the key technology determining whether the HZMB project can be successfully finished. Traditional immersed tubes involve either rigid or flexible structural systems. Rigid structures are good for preventing leakage but not good for dealing with foundation settlement, while flexible structures are the opposite. The immersed tubes of the HZMB are buried more than 20 meters deep and carry five times the load of traditional immersed tubes. Thus, both rigid and flexible structural systems are not adapted in technical. The general contractor of the island and tunnel project of the HZMB project creatively proposed the idea of a “semi-rigid structure” with an integrated idea through in-depth comparative research on flexible and rigid structures, which made up for the deficiencies of traditional flexible or rigid structural systems. Preliminary theoretical support was also obtained through seminars and expert consultation. Then, it was further verified by the calculation results of back-to-back simulation experiments by different research institutions. Therefore, the idea of integration is not simply to choose but to creatively resolve the conflicts by integrating existing solutions into a new and superior solution. The “semi-rigid structure” breaks through the “neck stuck” problem and broadens the application scope of the immersed tunnel. 2) Ensuring the precise installation of the prefabricated immersed tunnel was another significant challenge for the HZMB project. Similar to satellite launches, a short “window period” occurred each month suitable for immersed pipe installation due to weather conditions, ocean currents, and construction considerations. Accurate ocean forecasting was crucial, requiring a 10 to 15-day advance forecast to prepare for installation during these windows. Leveraging intelligent control technology from China’s aviation industry, the project successfully addressed measurement and control issues related to docking under complex ocean current conditions. 3) Another technical challenge involved the choice between GA (Guss Asphalt) and MA (Mastic Asphalt) for steel deck paving. These two asphalt pouring methods were widely used in bridge deck pavement, with MA involving a two-stage mixing process, resulting in good performance stability but lower construction efficiency. In contrast, GA offered high construction efficiency but lacked performance stability. To capitalize on the advantages of both methods, the HZMB project owner conducted extensive research, including project investigations (e.g., such as the Severn No. 1 and No. 2 Bridges in the UK, the Guyuri Bridge in Japan, and the Tsing Ma Bridge in Hong Kong), market research, and collaboration with consultants, and finally proposed the new technology of GMA (Guss-Mastic Asphalt) pouring for the first time. This innovative approach met the requirements for rapid and high-quality construction, combining the strengths of both GA and MA technologies.

Second, allocating and optimizing management resources to address practical challenges and better adapt to VUCA scenarios is another aspect of *IKS in operation*. 1) By referring to the project experience of the Oresund Tunnel and the Jujia Sea-Crossing Bridge, the DB (Design-Build) project delivery method is employed to coordinate the design and construction resources better and cope with the complex and volatile project environment. However, this mode brings new problems in practice. For example, the contractors have weak control over the design scheme because of their insufficient experience in design. However, some excellent design and consulting companies cannot directly participate in the design and consulting tasks because they do not have the qualifications required in China. To fill in the gap, the HZMB project owner encourages construction-driven design and builds joint ventures between designers and contractors to cope with the "island effect" caused by the separation of the construction stage (i.e., MSOs form distinct sub-systems in each project stage so that there is a lack of synergy within sub-systems). An international consortium with strong alliances and complementary advantages helps to integrate high-quality resources to solve difficult problems and decrease risks in the project delivery. 2) In terms of business model design, there are two typic models: market-based commissioning mode (e.g., Canadian highways and tunnels) and owner-owned mode (e.g., the Chesapeake Bay Bridge). These two modes have both advantages and disadvantages. The former is beneficial for decreasing costs but may lead to serious information asymmetry between the owners and contractors, and even the phenomenon of "the owners are ultimately controlled by the contractors". On the contrary, the letter brings high operation independence, but operation costs will increase significantly. To cope with the uncertainty of demand development in the operation stage, MSOs in the HZMB project have fully compared these two modes through project inspection and market research. Finally, a hybrid model was creatively proposed to retain control over the core technology and prevent potential risks due to excessive marketization. This hybrid model integrated the strengths of both approaches to strike a balance between operational independence and efficiency.

Third, *forming a standard institution and management system* was designed to embed the repeated business into the system process and make overall project sub-systems to clarify the implementation path of the project vision and goals. 1) A technical standard and management process system covering all project stages was established in the HZMB project through literature study, project inspection, and market research. Then, a special design guidebook was developed based on the special design standard guide. 2) Institutionalization helps consolidate the best practices of the HZMB project and promotes the dissemination and optimization of business experience. For example, the HZMB project design standards guide fully absorbed typical design concepts and technical standards from all excellent stakeholders. This included a thorough reference to British Standard (BS) standards in areas such as bridge design principles, loads, prestressing, expansion joints, retaining walls and piers, aerodynamic effects, fatigue, use of steel structures, construction safety, and lighting design. 3) Similarly, specific systems at different project stages were implemented in the HZMB project, including the preliminary coordination group office system, the main project management system, and the main project operation management system. The technical standards and management system at the operational level align with the strategic-level goals, vision, overall planning, and management planning, supporting the HZMB project's high-quality development.

7.3.3 Innovation capability enhancement

Innovation ability is a systematic reflection of an organization's creative problem-solving ability, and the IKS is an important source of innovation ability improvement. To address practical challenges, MSOs in the HZMB project have comprehensively improved *institutional, business, technical, and managerial innovation capabilities* through *IKS in tactic and operation.*

7.3.3.1 Institutional innovation capability enhancement

The institution is the strategic arrangement that regulates organizational activities by rules or operating modes. Institutional innovation capability is the ability of an organization to change and replace existing institutions to adapt to new situations involving objectives and rules, organizational governance structures, and supporting institutional systems. The institutional innovation capability enhancement in the HZMB project mainly includes *project vision and goal design capability, project governance capability,* and *legal systems synergism capability among the Mainland, Hong Kong, and Marco.* First, to maximize the HZMB project value, MSOs confirmed different project objectives in different periods by project inspection and market research on the experience of similar projects, which greatly facilitates the *project vision and goal design capability*. Second, to solve the problems of long coordination time and poor handling of problems between the three governments, a three-level governance system "task force (led by central government)—joint working committee of the three regions (led by local governments)—project legal (i.e., the HZMB Authority)" and the implementation plan of "territorial division, joint investment, and unified construction" is established by the central government. Simultaneously, a technical expert group is established to provide consultation for the decision-making of the three-level governance system, which contributes to *project governance capability* enhancement. Third, one single project involving three different administrative and legal systems is unprecedented in the history of world transportation projects. The extensive and in-depth legal research on the HZMB project ensured the project schedule and avoided corruption and waste, which showed a high-level innovation in *legal systems synergism of the three places*.

7.3.3.2 Business innovation capability enhancement

Business innovation capability is the ability of an organization to change the process of creating and delivering economic value according to the characteristics of the situation, involving multiple aspects, including investment and financing, operation, and business brand building. The main business innovation capabilities in the HZMB project refer to *investment and financing model innovation capability, flexible bidding and contract model innovation capability, hybrid business operation capability,* and *business brand building capability.*

First, investment and financing model selection is essential to successful project delivery. The HZMB project needs a huge investment, but its benefits (mainly referring to vehicle tolls) are not so optimistic. Specifically, the HZMB project owner has jointly conducted detailed investment and financing model research with consultants, such as government investment mode and the Build-Operate-Transfer model. After rounds of discussions, a proper model in which the three local governments jointly undertake the full funding was adopted, which will help control the project financing cost and ensure the public welfare of the bridge. On this basis, through the comparison and selection of equal share, territorial share, an equal share of benefits, and equal share of cost-benefit ratio, the principle of benefit-to-benefit ratio sharing that is beneficial to Guangdong, Hong Kong, and Macao is determined, which effectively solves the capital investment issue and enhance *investment and financing model innovation capability*.

Second, the HZMB project comprehensively considers factors such as risk, specialization, and market conditions to set up different bidding and contract models based on project inspection and market research, such as the Engineering Procurement Construction mode in bridge projects and Design and Build mode in island tunnel projects, which reflects the *flexible bidding and contract model innovation capability*. Third, in terms of business operation, the market-based entrustment model may lead to serious information asymmetry between managers (owners) and contractors, while the self-operated model will increase operational costs. The HZMB project explores a hybrid operation model, seeking the best balance between market-based commissioning to decrease operation costs and owner-owned mode to ensure operation dependence and meet future demand, which reflects the *hybrid business operation capability*. Fourth, the *business brand building* was a great innovation in the HZMB project to make up for the shortage of tolls and reduce the financial expenditure and burden of the governments by drawing on the operational experience of South Korea's Gwangan Bridge. Large-scale social events in Busan City (e.g., bicycle races, fireworks shows, the Busan Film Festival) are often held at Gwangan Bridge. The comprehensive *business brand* was developed in tourism, exhibition, advertising, cross-border logistics, etc. The socialized operation of the business brand was realized in the HZMB project by shaping the project image and increasing project adaptability to meet future needs.

7.3.3.3 Technical innovation capability enhancement

Technical innovation capability is an organization's ability to improve, develop, and innovate different types of technical methods. The technical innovation capabilities in the HZMB project mainly include *mature technology improvement capability, new technological breakthrough capability,* and *multi-source technology integration capability*.

First and foremost, when operating within limited time and resources, introducing and enhancing established technologies offer distinct advantages, including minimal investment requirements, shortened construction periods, and improved overall performance. These characteristics are pivotal in nurturing innovation capabilities that can swiftly create a competitive advantage. For example, compacting sand piles is a *mature technology* in Japanese companies. MSOs in the HZMB project invited experts to share their experience and conduct training on parameter design to adapt to environmental changes through pile tests. Finally, this technology was successfully used and set a record of 64 piles in a single day, which reflects a high level of *mature technology improvement capability*. Besides, mature bridge maintenance and cost optimization technology in the Akashi Strait Bridge was also introduced and improved in the HZMB project. A total of 5 coatings are installed in the steel structure anti-corrosion project. Before the third coating is damaged, overcoating protection is arranged to extend the life of the coating to 40 to 50 years. MSOs in the HZMB project improved this technology by clarifying the classification of structural defects and their corresponding maintenance methods, especially for steel box girder painting and underwater structures, to control project costs and extend the operation duration.

Second, key core technologies rely on independent and original research to achieve breakthroughs, which refers to *new technological breakthrough capability*. These core technologies are often difficult to obtain through market transactions, described as “stuck neck”. For example, the offshore immersed tunnel is the core technology in the island tunnel project, which involves the *design of the immersed pipe structure system*, the *prefabrication of the immersed pipe,* and *the floating installation*. The “semi-rigid structure” of the *immersed pipe structure system* was first proposed and applied in the HZMB project, breaking through the international mainstream rigid or flexible structural system. The traditional tube prefabrication is called the “dry docking” method, carried out in a fixed and limited space with low quality, low work efficiency, and a large storage area. The HZMB project invited project consultants for the Oresund Tunnel, the first project in the world to use the factory method to *prefabricate* *tunnel tubes*. The production efficiency and quality of pipe joints have been significantly improved due to *new technological breakthroughs*. Moreover, the HZMB project owns the world's largest immersed tunnel tubes, which must be floated and sunk in the harsh marine environment. The research and development of intelligent control and operation systems have effectively overcome the huge challenges brought by the harsh marine environment to floating and installation. The HZMB project has formed a complete technical system for constructing offshore immersed tunnels with independent intellectual property rights, reflecting a high level of *new technological breakthrough capability*.

Third, new technologies are not completely "inventions" out of nothing but are based on integrating existing technologies, which refers to *multi-source technology integration capability*. An intelligent operation and maintenance platform for cross-border collaborative traffic in the HZMB project is a typical example. Ensuring the smooth flow of cross-border passages under different institutional backgrounds to realize orderly and efficient operation management is an urgent task in the operation stage. Cross-border channel project between Singapore and Malaysia has successful operation experience in integrating innovative technology applications, such as passenger information and action recording systems, self-check customs clearance systems, bubble detection systems, and motorcycle biometric authentication customs clearance systems. By referring to the experience of the Singapore-Malaysia Corridor, many other technologies such as the Internet of Things, big data, and Artificial intelligence were integrated to realize intelligent operation and maintenance, data and knowledge sharing for the local governments of Guangdong, Hong Kong, and Macau, enhancing their *multi-source technology integration capability*.

7.3.3.1 Managerial innovation capability enhancement

Managerial innovation capability is an organization's ability to improve and innovate management plans, methods, and processes to operate effectively, reduce potential risks, and form a good organizational atmosphere and cooperative relationship (Gulino et al., 2020). Different from the institutional innovation capability that focuses on strategic arrangements, the managerial innovation capability focuses more on project and process management. The managerial innovation capabilities enhancement through IKS in the HZMB project mainly includes *project planning capability, global business resource integration capability, project risk management capability, project culture shaping capability,* and *alliance and partnership cultivation capability*. First, the *project planning* reflects the overall business implementation guideline, referring to multiple aspects, such as quality, informatization, bidding, and HSE management, through integrating best practices across industries and fields (e.g., nuclear power, petrochemical, and automobile manufacturing industry).

Second, the HZMB project appeared to top suppliers in the international market, formed cross-time and cross-regional IKS, and integrated their advantages in management or technology to avoid decision-making biases caused by cognitive limitations, which reflected high-level innovation in *global business resource integration*. Besides, compared with general projects, project risks in the HZMB project were increased significantly, and the degree of harm is far greater than that of general projects once it occurs (Flyvbjerg et al., 2003). Therefore, it is necessary to increase assessment and consultation in project risk. Since some foreign companies with rich experience in megaproject management do not have the required qualifications, they cannot directly and dependently undertake consulting tasks. The consortium mode was creatively applied in the HZMB project, where multiple organizations could jointly participate in bidding and develop their strengths to cope with project complexity. For example, Shanghai Municipal Engineering Design and Research Institute established a consulting consortium with Dutch TEC Tunnel Engineering Consulting Company, TYLI International Group, and Guangzhou Metro Design and Research Institute in the island and tunnel project. Among them, Holland TEC Tunnel Engineering Consulting Company has rich experience in bridge and tunnel project risk management. From the end of 2008 to September 2011, TEC submitted six consultation reports to emphasize the risk of tunnel flooding and highlight the influence of sea level rise caused by climate change. Finally, a special design change consultation meeting was held in June 2014, based on which the height of the artificial island wave retaining wall was increased. The north side of the east island was adjusted from 6.2 to 8 m, and the south side from 7 to 8.5 m. The north side of the west island was adjusted from 6.5 to 8.5 m. and the south side from 8 to 9.5 m. The artificial island has withstood the test of super typhoons such as “Hato” in 2017 and “Mangosteen” in 2018, reflecting *global business resource integration capability* and *project risk management capability.*

Third, project culture is gradually formed in the practice of project management. For example, sustained excellent operational performance is inseparable from the construction of project culture. MSOs in the HZMB project are committed to building a stable, long-term partnership and dedicated working atmosphere by viewing the Chesapeake Bay Bridge. The organizational structure of the Chesapeake Bay Bridge operation management has remained stable since its opening to traffic in 1964, with little change from 167 people at the time of the project opening to 159 people at the time of the survey (mainly due to the retirement of some employees). The staff in the Chesapeake Bay Bridge check the intercom, lighting, ventilation, and other systems 6 times a day, check the backup power once a month, and keep the machine room clean, and the power ventilation system and the air quality detection system in normal, and the air quality good for over 50 years.

Furthermore, MSOs are structured as a temporary strategic alliance. In line with this, the HZMB project emphasized fairness, *alliance building, and partnership development* when designing the selection scheme and defining contract terms. The goal was to allocate risks to the party best equipped to manage them effectively. Maintaining effective coordination between the owners and contractors, designers, consultants, and other participants in the construction is essential for megaproject management. The HZMB project owner draws on the idea of building a partnership in the Oresund Tunnel, jumps out of the traditional concept of “Party A’s advantage”, and tries their best to achieve a fair and reasonable distribution of risks in the setting of contract terms to ensure an appropriate degree of freedom and leave risks to the party that is most conducive to risk management and control.

7.3.4 The owner’s role

From the preliminary stage, construction stage, to the operation stage in the HZMB project, the project owners have experienced role changes from *“leader”* to *“coordinator”* to *“supporter”* in guiding the MIA in conducting IKS.

7.3.4.1 Leader (Hub-and-spoke governance)

Facing the VUCA scenarios, especially *cognitive ambiguity* in the preliminary stage, the HZMB project owner, as the core of the MSOs in the HZMB project, mainly played the role of *“leader”* to guide and coordinate all MSOs to conduct IKS and enhance their multiple types of innovation capacities. Specifically, the owner coordinated the feasibility analysis and preliminary design, integrating and referring to cross-disciplinary literature and deeply mined typical cases and industry markets. Consequently, these cross-disciplinary and international inspections helped MSOs improve their understanding of project boundaries. All MSOs in the HZMB project jointly reflected project values and strategic goals and improved understanding of project boundaries to avoid early decision-making and planning deviations caused by the limited cognitive scope of the owner. The series of special studies helped MSOs clarify their thinking on key issues, such as legal synergy among the three places, investment and financing model selection, bridge location design, and port layout design.

The owner made *Hub-and-spoke governance* on MSOs’ interorganizational cooperation on IKS and has a prominent central position and structural advantages in the cooperation network (Bridoux and Stoelhorst, 2022). This type of governance model is beneficial for dealing with the *cognitive ambiguity* in the preliminary stage as different MSOs should be united by a core organization to conduct IKS activities so that these vague issues with uncertain solutions can be focused and internalized into a relatively clear system in managerial or technical. For example, the formulation of the HZMB project vision and goals is an iterative process led by the project owner. 1) From August 2003 to November 2006, it belonged to the coordination and decision-making stage on project necessity and feasibility by the Guangdong, Hong Kong, and Macao governments. The preliminary work coordination group was formed to hold joint meetings regularly. 2) In December 2006, the HZMB project task force was established to resolve major issues and disputes between the three places under the coordination of the central government, such as the project investment and financing model, port layout, and protection of Chinese white dolphins. 3) At the beginning of 2007, the HZMB task force reached a consensus on these issues to accelerate project decision-making. 4) In December 2008, the project feasibility study report marked the end of the preliminary stage and confirmed the final project vision and goals of the HZMB project.

7.3.4.2 Coordinator (Polycentric governance)

During the construction stage, MSOs in the HZMB project faced different practical challenges and VUCA scenarios highlighting the "*complexity of objects*" and "*environmental variability*". As the core MSOs, the owner mainly plays the role of "coordinator" to facilitate the positivity and business advantages of contractors and other MSOs in conducting IKS activities to cope with the new "stuck neck" challenges and control the trial-and-error cost of excessive innovation (i.e., innovation beyond project needs) and divergent innovation (i.e., innovation away from core problems). Specifically, MSOs conducted a series of IKS activities, such as cross-disciplinary literature reviews, typical project inspections, market surveys for industry benchmarks, and special research at different levels (commissioned by nation, province, or cities). Consequently, knowledge resources across fields were integrated to tailor new technologies and managerial experience fitting with project requirements in different sub-projects, such as island tunnels, bridges, and traffic projects. Besides, the IKS culture of encouraging business partnerships and research exploration contributed to avoiding path dependence and promoting breakthroughs in technology and management.

Different from its central position and advantages in the preliminary stage, the owner conducts "polycentric governance" through partnerships with other MSOs and allocates more autonomy to others in the construction stage (Bridoux and Stoelhorst, 2022). New problems and challenges not involved in the preliminary stage emerged along with the project development. The owner guided the MSOs with special and professional knowledge to jointly establish a strong network-style synergistic relationship between subjects to cope with the technical and management challenges. For example, the "semi-rigid" immersed tube structure of the HZMB project is an original solution proposed by the contractor of the island-tunnel project. However, this original plan was doubted largely by the Dutch consultant TEC. These two MSOs jointly conducted a detailed exploration and demonstration of this plan to minimize project risk. This plan was finally successfully implemented. In solving business frictions and accumulating experience in cross-cultural cooperation, the contractor and consultants established a stable partnership to jointly promote high-quality project delivery.

7.3.4.3 Supporter (Shared governance)

Complex outcomes with high *uncertainty of needs* may emerge during the operation stage. There may be a "gap" between the functional design in the preliminary stage, the functional realization in the construction stage, and the functional requirements in the operation stage. MSOs in the HZMB project followed the principle "adaptability is optimality" and built a need-oriented operating system through IKS. The owners of the HZMB project mainly play the role of "supporters" in this stage. On the one hand, the owner supported that the project service function was designed based on real on-site social and market needs by investigating typical cases. On the other hand, under the owners' advocacy, the HZMB project is becoming a social platform that creates social spillover effects far exceeding the service function of the project itself.

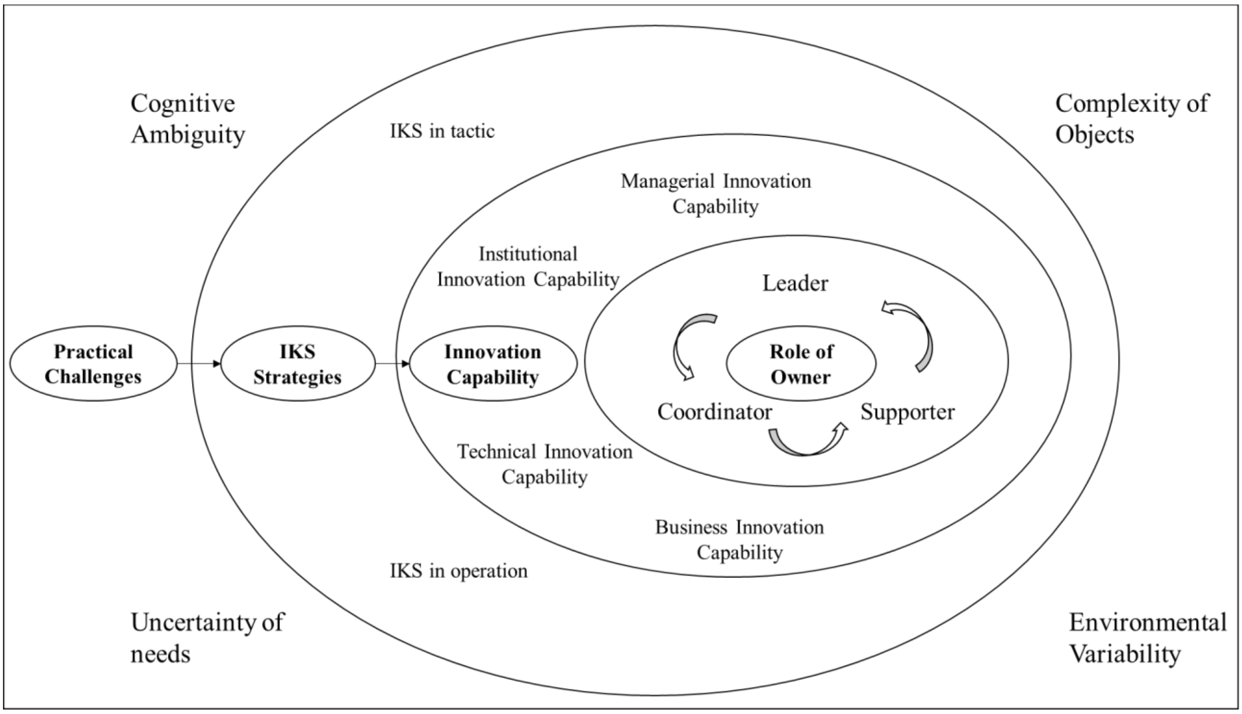
Unlike its role in the preliminary and construction stages, the owner's central position and dominant advantage in the operation stage are constantly weakening, and the "shared governance" of the project is carried out to give more autonomy to the market. The HZMB project has internalized the MSOs' experience through IKS to form a hybrid business operation model to ensure the stable realization of the project functions and comprehensively enhance the organizational innovation capability in the institution, business, technology, and management. For example, in view of the operation experience in "cultural and creative" of Guang' an Bridge in South Korea, the HZMB project also follows the "project + cultural and creative" development path to continuously enhance the bridge brand influence, which not only brings more financial benefits but accumulated several achievements with core technologies and independent intellectual property rights. Intellectual property was promoted and transformed Through close cooperation between owners and market players. The experience has been effectively applied in megaprojects such as Daxing Airport, Shenzhong Tunnel, Second Humen Bridge, and Qiongzhou Strait Bridge.

7.4 Discussion

This chapter systematically sorted out the practical challenges, IKS strategies, and innovation capability enhancement in the HZMB project. Besides, the owner's role in governing multi-stakeholder IKS collaboration during the preliminary, construction, and operation stages was also revealed. It provides important value for further improving megaproject innovation and strategy theory.

7.4.1 Mechanism linking practical challenges, IKS strategies, and innovation capability enhancement in megaprojects

Following the "Scenario-Process-Outcome" framework and based on the longitudinal case study of the HZMB project, this chapter proposes a four-layer framework and analyzes the dynamic coupling relationship between IKS scenarios (practical challenges), IKS strategies, innovation capability enhancement, and project owner's roles, as shown in Figure 7.3.



Note: the figure was created by the author

Figure 7.3 The four-layer framework of IKS for the innovation capability enhancement in megaprojects

First, scenarios reflect the core problems in megaprojects and trigger IKS, mainly including *environmental variability, uncertainty of needs, complexity of objects, and cognitive ambiguity.* Second, the process depicts the methods and paths of IKS in megaprojects. The IKS process in the three project stages delivery is depicted as *IKS in tactic and IKS in operation*. Third, innovation capabilities are the IKS outcomes to solve problems in megaprojects creatively. Four types of organizational innovation capabilities are improved through IKS during distinct project stages, including *institution, business, technology, and management innovation capabilities.*

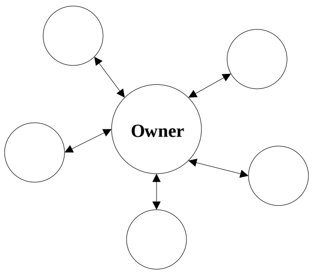
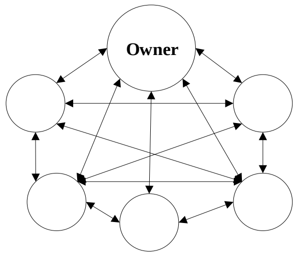
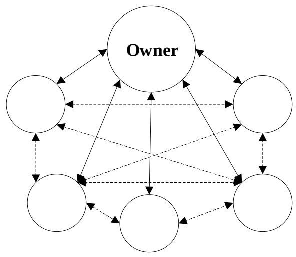
Fourth, in different project stages, the owner's role in managing multi-stakeholder IKS collaboration continuously changes, reflecting the internal mechanism that facilitates IKS in megaprojects. From the preliminary, construction, and operation stages, the project owners have experienced role changes from "*leader*" to "*coordinator*" to "*supporter*", which will be specifically elaborated on in the next section. This chapter forms an independent and original research framework by reviewing and systematically analyzing megaproject practice.

7.4.2 The role of the owner in guiding IKS in different project stages

This chapter expands the megaproject governance model research by revealing the changing roles of megaproject owners in IKS governance (Bendoly et al., 2021; Dessaigne and Pardo, 2020; Diriker et al., 2022), as shown in Table 7.1.

1) In the preliminary stage, the HZMB project owner played a "*leader*" role in IKS governance and led several IKS activities, including special studies on project feasibility analysis and preliminary design. In the above process, a *Hub-and-spoke* governance mode is depicted where the megaproject owners occupy an overall leading role and undergo non-linear changes (Bridoux and Stoelhorst, 2022), which is in line with the non-linear changes in the conflict level in releasing the interest demands of all MSOs. This matching is beneficial for avoiding potential problems caused by the linear and rapid convergence of construction goals. The dominance of the government reaches its peak in the central government coordination decision-making stage. As a result, project objectives were identified to avoid falling into a disordered state, reduce cognitive ambiguity, and enhance innovation capabilities through continuous demonstration and reflection.

Table 7.1 The evolution of the owner's role in different project stages of megaprojects

Project stage	Megaproject owner role
Preliminary stage	*Leader (Hub-and-spoke governance*): the owner plays a "*leader*" role in coordinating and guiding IKS activities in megaprojects to build a common vision and goal, which depicts a *Hub-and-spoke* governance mode. 
Construction stage	*Coordinator (Polycentric governance):* the owner plays a "*coordinator*" role in facilitating the contractors and other MSOs to jointly conduct IKS activities to solve key technical and management problems, which presents a *polycentric governance* mode. 
Operation stage	*Supporter* (Shared governance): the owner plays a "supporter" role in attracting IKS activities to realize mixed project operation mode where the core business is independently operated by the owner itself and the other parts are resorting to the market to decrease operation costs, which presents a *shared governance* mode. 

NOTE: Solid arrows in the network diagram represent strong governance relationships; dashed arrows represent weak governance relationships.

2) In the construction stage, the HZMB project owner played a "*coordinator*" role in IKS governance. Under this mode, the business advantages of the contractors and other MSOs were fully activated through jointly conducting IKS activities to tackle key issues, solidify technology and management standard systems, and degrade complex objects. The collaborative modes of stakeholder synergy in the megaproject IKS network show a *polycentric mode* emphasizing the important driving role of key entities (Bridoux and Stoelhorst, 2022). As a result, the government and the market are both driven. Megaprojects can effectively realize the optimal allocation of business resources, reflecting the reciprocal relationship between the government and the market to promote technological breakthroughs and management upgrades jointly.

3) In the operation stage, the role of the market has been significantly improved. The HZMB project owner played a "supporter" role in facilitating IKS. The collaborative model suitable for this stage is the *shared* mode emphasizing the platform support and advocacy role of key entities (Bridoux and Stoelhorst, 2022). As a result, a mixed operation mode was adopted to realize the symbiosis between the government and the market, where the core technology module is independently operated while other parts resort to the market to decrease operation costs. The market greatly contributed to realizing the project's economic and social value and better adapting to the development and changes of future needs.

7.5 Chapter Summary

Megaprojects are typical complex giant systems involving multiple MSOs, multi-source integration of technologies, and close coupling of sub-projects. MSOs (e.g., owners, contractors, and suppliers) have to form a *megaproject innovation alliance* (MIA) to conduct IKS to obtain cross-border knowledge resources to enhance innovation capability and improve project performance. Based on the ground theory, this chapter conducts a longitudinal case analysis of the Hong Kong-Zhuhai-Marco Bridge (HZMB) project to explore two research questions and conclude several essential results. For RQ 7.1, the practical challenges stimulating IKS in MIA were summarized as VUCA scenarios, including *environmental variability, the uncertainty of needs, the complexity of objects, and cognitive ambiguity*. Two typical IKS strategies are found, *IKS in tactic and IKS in operation,* to enhance organizational innovation capabilities in four aspects: *institution, business, technology, and management*. For RQ 7.2, the project owners respectively play the role of "*leader*", "*coordinator,*" and "*supporter*" from the preliminary, construction, and operation stages of megaproject delivery. This chapter provides insights into how to promote innovation capability through IKS and help MSOs cope with technical and management challenges by achieving a leap in innovation.

CHAPTER 8 CONCLUSIONS AND RECOMMENDATIONS

8.1 Introduction

In this chapter, the research objectives were reviewed, and the findings of this study were summarized. Furthermore, this chapter highlighted the contributions of the research, encompassing both theoretical contributions and practical implications. The study’s limitations were identified and addressed, and potential avenues for future research were proposed.

8.2 Review of Research Objectives and Conclusions

IKS has become an important strategy for MSOs to drive high performance and innovation in megaprojects. However, a series of problems impede the highly efficient implementation of IKS in megaprojects, including a lack of efficient knowledge guidelines, unmatched IKS mechanisms, insufficient understanding of IKS antecedents, lack of stakeholder synergy strategies, and the unclear relationship between IKS and innovation capability enhancement. This research aims to develop an integrated framework for MSOs to identify and facilitate IKS and enhance innovation capability. The specific research objectives are established to achieve this aim, shown as follows:

1. To categorize knowledge shared in megaprojects and map proper IKS mechanisms from Socio-technical perspectives

2. To explore complex interrelationships between factors and their joint effects on the IKS efficiency in megaproject

3. To identify the stakeholder power in megaprojects IKS network and propose stakeholder synergy strategies

4. To explore the evolution path of innovation capability enhancement by IKS in megaprojects

The research design for each objective and the research methods are shown in Chapter 3. The findings and conclusions of each objective are shown in Chapters 4-7. The main conclusions of each objective are summarized in the following.

Objective 1: Chapter 4 was crafted to delve into the less-explored realm of the matching between knowledge categorization and IKS mechanisms. Qualitative data were collected from both primary sources, such as semi-structured interviews, and secondary sources, including published books and project documents, to ensure the triangulation of research findings. Four distinct categories of knowledge—namely, *real-time project status, innovative managerial experience, cutting-edge technical skills,* and *integrated technical guidelines*—were identified based on their inherent characteristics, specifically knowledge tacitness and heterogeneity. Subsequently, a four-dimensional framework of IKS mechanisms was established—comprising large-scale interorganizational events, small-scale offline interactions, instant online communication, and document synthesis and summarization. These dimensions were combined to form a comprehensive configuration, tailored to facilitate IKS in various scenarios. The research findings presented in Chapter 4 contribute a novel framework for examining the sharing of diverse knowledge types among MSOs and devising targeted strategies for the governance of IKS.

Objective 2: The Bayesian network (BN) method was employed in Chapter 5 to establish an IKS-BN model to measure the effects of various factors related to knowledge, organizational, and context characteristics on IKS efficiency based on literature reviews, expert knowledge, and questionnaire surveys. The findings revealed that the top influential factors were interorganizational trust, project incentive mechanisms, communication infrastructure, organizational distance, absorptive and sharing capacity, and tacitness of knowledge. Besides, the joint effect of controlling various factors on improving the efficiency of IKS was greater than the simple factor, achieving the highest probability (74%) of good IKS efficiency among all five-factor scenarios and 88% among six-factor scenarios. Three basic factors should be carefully controlled among joint scenarios: interorganizational trust, sharing, and absorptive capacity. Scenarios combined with multiple-dimensional factors could lead to a high level of IKS efficiency. The proposed IKS-BN model provides effective decision support techniques to improve IKS efficiency in megaprojects.

Objective 3: From a value-focused thinking and network-based perspective, the benefits of IKS between two MSOs could be qualified as KVF, which further consists of KVF cycles (i.e., KVF loops beginning from and ending with the same stakeholder) and KVF network. Different MSOs own different knowledge resources and power. A key challenge for governing IKS is to form corresponding strategies to facilitate stakeholder synergy in the KVF network. Based on the design structure matrix approach, chapter 6 first identifies and quantifies crucial KVFs to construct a KVF network in the context of megaprojects through a novel stakeholder value network (SVN) analysis approach. Then, all KVF cycles across MSOs are searched out. The results denote that KVF cycles are mostly generalized exchanges and show a dominant pattern of negative skewed distribution. Next, three types of stakeholder power (value, exchange, and integrated advantages) were defined in the IKS network, based on which MSOs were classified into four types (powerful, central, wealthy, and powerless) and proposed corresponding internal strategies for promoting stakeholder power (exchange, value, integrated, and adaptive strategies). Finally, the top seven restricted and generalized exchanges are analyzed to propose two external strategies (power incongruence and knowledge broker) for improving IKS collaboration to achieve value co-creation. This chapter makes great contributions to bridge IKS and value co-creation in megaprojects.

Objective 4: Based on the ground theory, this chapter conducts a longitudinal case analysis on the Hong Kong-Zhuhai-Marco Bridge (HZMB) project to explore how MIA enhances its innovation capability through IKS following the *Scenario-Process-Outcome* framework and what is the owner's role in governing the MIA in different project stages to conduct IKS. Several essential results are concluded. The practical challenges stimulating IKS in MIA were summarized as VUCA scenarios, including *environmental variability, uncertainty of needs, complexity of objects, and cognitive ambiguity*. Besides, two typical IKS strategies are found, *IKS in tactic and IKS in operation,* to enhance organizational innovation capabilities in four aspects: *institution, business, technology, and management*. Last, the project owners respectively play the role of "*leader*", "*coordinator,*" and "*supporter*" from the preliminary, construction, and operation stages of megaproject delivery. This chapter provides insights into how to promote innovation capability through IKS and help MSOs cope with technical and management challenges by achieving a leap in innovation.

8.3 Research Contributions

8.3.1 Theoretical Contributions

8.3.1.1 Study 1 Knowledge categorization and IKS mechanism mapping in megaprojects

This study has contributed significantly to the theoretical landscape in several ways. *Firstly*, while knowledge categorization is commonly based on knowledge characteristics, the criteria for such categorization are not standardized across the literature (Pian et al., 2019). Existing approaches often focus on a single knowledge characteristic (Balle et al., 2019; Iftikhar and Ahola, 2022), and there is limited exploration of theoretical models that integrate multiple knowledge characteristics (Bendoly et al., 2021). In response to this gap, the study has introduced a novel knowledge categorization framework based on two-dimensional knowledge characteristics—knowledge tacitness and knowledge heterogeneity, as shown in Table 4.1. The framework includes typical examples drawn from empirical data, as illustrated in Figure 4.2. This innovative approach offers a systematic blueprint for understanding essential knowledge flows shared across MSOs and can serve as a foundation for future empirical quantitative research on measuring IKS.

Secondly, this study challenges and advances the conventional wisdom that technicalization and socialization mechanisms for IKS should be selected solely based on knowledge tacitness (Aaltonen and Turkulainen, 2018; Lawson et al., 2009; Le Dain et al., 2020; Naeem, 2019; Oesterreich and Teuteberg, 2019; Vijver et al., 2011). The study argues that knowledge heterogeneity should also be considered when MSOs choose appropriate IKS mechanisms (Balle et al., 2019; Gomes et al., 2018). This is because knowledge heterogeneity can resonate with socialization mechanisms and significantly moderate the performance of IKS (Tsai, 2018). In response to the broader call to govern projects, particularly the knowledge management aspect in the project context, from the socio-technical perspective (Elia et al., 2021; Malhotra et al., 2021; Zhou, 2019), this research has established a four-dimensional IKS mechanisms framework based on the degree of socialization and technicalization, as presented in (i.e., Table 4.2). This framework offers a nuanced approach for organizations to tailor their IKS strategies to the specific characteristics of the knowledge they aim to share.

Thirdly, this research provides valuable insights for IKS governance by suggesting a configuration of multiple IKS mechanisms, as outlined in Table 4.3. This approach challenges the traditional one-to-one matching model, which relies on utilizing a single mechanism to facilitate the sharing of a specific category of knowledge (Fang et al., 2013; Loebbecke et al., 2016). The study reveals that employing a primary mechanism in conjunction with multiple secondary mechanisms effectively facilitates sharing each category of knowledge. This configuration represents a strategic complementarity of technicalization and socialization in the IKS governance framework.

Finally, while most previous studies on knowledge sharing in projects focus on dyadic interactions at the individual, team, or intra-organizational level (Sang et al., 2019; Sun et al., 2019), there has been limited exploration of multi-organizational interactions among MSOs at the interorganizational level (Roehrich et al., 2020). Furthermore, within the limited research on IKS in megaprojects, quantitative research has dominated, often examining the frequency and efficiency of IKS through social network analysis (Imam, 2021; Ni et al., 2018; Senaratne et al., 2021; Williams et al., 2015). This research addresses these gaps by conducting empirical qualitative research on IKS in projects. It identifies and describes the nature of knowledge itself (i.e., the types of “skills and expertise”) and the corresponding IKS mechanisms at the interorganizational level in megaprojects.

8.3.1.2 Study 2 Exploring the antecedents of IKS through Bayesian network analysis

The primary contribution of this study resides in exploring the joint effects of multiple factors on IKS efficiency in the context of megaprojects. The study has culminated in creating a simulation model that effectively visualizes the joint effects and the cause-effect relationships among the factors, as illustrated in Figure 5.1. Extant organization research scholars mostly explored the effects of single or few factors and rarely assessed their joint effects on MSOs’ IKS behavior. Although extant studies systematically reviewed the factors influencing the IKS performance through qualitative methods (Abdelwhab Ali et al., 2019; Iftikhar and Lions, 2022; Zhou et al., 2022), more quantitative approaches should be utilized to figure out the most influential factors and make corresponding strategies.

Second, this study offers an innovative approach to quantifying the efficiency of IKS under diverse scenarios by applying a simulation methodology. In the current dynamic context, what-if scenarios are essential for organizations to understand how certain changes in projects would affect their states of certain behaviors and resist risks. Extant quantitative studies, system dynamic approach (Liu et al., 2021), multi-layer decision-making approach (Amoozad Mahdiraji et al., 2022), set-theoretic approach (Bakker et al., 2011), analytic model and numerical analysis (Ma et al., 2020; Wang and Shi, 2019), and structural equation modeling analysis (Ren et al., 2018), hardly measure the level of IKS efficiency under what-if scenarios. Furthermore, built upon the machine learning of collected data, the BN simulation approach employed in this study can effectively minimize errors and biases associated with expert judgments during model development, distinguishing itself from conventional BN methods.

Third, this research verified and echoed extant empirical research on the effects of a single or a few factors on the organizations' IKS performance. This study concluded that interorganizational trust, project incentive mechanisms, communication infrastructure, organizational distance, sharing and absorptive capacity, and tacitness of knowledge were the top influential factors impeding the enhancement of IKS efficiency, supporting extant empirical research (Amoozad Mahdiraji et al., 2022; Hsiao et al., 2017; Philsoophian et al., 2022; Ren et al., 2020, 2018; Sun et al., 2019). Besides, the joint effect of controlling multiple factors was proposed, specifically over five factors, including interorganizational trust, sharing, and absorptive capacity, which could improve the probability of high-level efficiency of IKS up to more than 70% greater than simple scenarios (Chen et al., 2022; Luo et al., 2020).

8.3.1.3 Study 3 Stakeholder synergy in megaproject IKS network

This study makes several theoretical contributions. *First*, Maylor et al. (2018) indicate the importance of bringing the process to the table to improve operations in projects. It is an important topic but has received surprisingly little attention in project studies (Geraldi and Söderlund, 2018). This chapter adds insights for understanding IKS in megaprojects from a *value-focused-thinking* and *network-based* perspective. Prior studies focus on either the IKS process (Arora et al., 2021; Iftikhar and Ahola, 2022) or knowledge value creation (Gaimon and Ramachandran, 2021; Zhu et al., 2018) in inter-organizational settings. However, based on the social exchange theory, the utility function is rarely used to identify and quantify the multiple-dimensional benefits of IKS (e.g., economic and social value). Besides, prior management studies set a focal organization ad hoc (Gaimon and Ramachandran, 2021; Roehrich et al., 2014; Sharma et al., 2020) to explore the interactive *restricted exchanges* between the *focal organization* and its stakeholders (e.g., *linear* or *hub-and-spoke* model in Figure 6.1), as such studies focus on the supply base or the ego network that depicts a centralized and hierarchical feature (Gualandris et al., 2021), not a shared network. The SVN analysis method utilized in this chapter is established on a systematic *network-based* model (Figure 6.1c) that considers indirect and multiple KVFs across a series of stakeholders (i.e., *generalized exchanges*). Furthermore, SVN studies were developed to analyze other stakeholders' status other than only on the focal organizations (Hein et al., 2017; Pereira et al., 2018; Zheng et al., 2021) by conducting SVN analysis on the stakeholders in the whole IKS network.

Second, this chapter provides a paradigm to understand how stakeholders benefit from IKS from business and social aspects by utilizing utility theory. The stakeholder synergy theory plays an important role in characterizing the value co-creation in complex systems. However, the existing approach remains qualitative and is often case-specific. In this study, a series of indicators (i.e., *value, exchange, and integrated* advantages) could provide the reference for measuring *stakeholder power* in the IKS network (Al-Busaidi and Olfman, 2017; Desai, 2018), which is an important aspect in the IKS studies (Roome and Wijen, 2006). Moreover, distinct types of stakeholder power are designed and calculated to classify MSOs into four types (i.e., *powerful, wealthy, central*, and *powerless*). Different internal strategies are proposed to help each type of stakeholder enhance their power in the IKS network.

Third, the characteristics of IKS network is depicted in this study. Most KVF cycles in the IKS network are found to be generalized exchanges, and their length demonstrates a dominant pattern of *negative skewed distribution*. This framework guides the optimization of the design and implementation of the exchange processes across MSOs. The relative importance (power) between the two stakeholders was also found to be asymmetric.

Fourth, external strategies are formulated through analyzing the top restrictive and non-restrictive KVFs to help MSOs collaborate with partners to reach the reciprocal goal and achieve joint IKS benefits maximally. The study reveals that complementary knowledge resource advantages between knowledge-sending and knowledge-receiving organizations are conducive to maximizing the value co-creation through IKS. Non-powerful organizations should collaborate more with powerful organizations, engaging in IKS to enhance knowledge influence and value co-creation. Additionally, the study finds that triadic relationships are advantageous for enhancing the circulation of IKS networks. Non-powerful organizations can enhance their IKS with other organizations by the bridging of powerful organization.

8.3.1.4 Study 4 Link IKS and innovation capability enhancement in megaprojects

Several theoretical contributions could be reached, shown as follows.

First, this research expanded extant research on IKS in the context of a general project or permanent enterprise. Different from IKS in permanent enterprise organizations, IKS among the temporary MSOs recently attracted much research interest. However, unlike general construction projects, IKS in megaprojects, which are special projects with huge investments and long periods and delivered by multiple MSOs so that IKS among MSOs is essential for their successful delivery, was less explored (Argote et al., 2003; Sohi and Matthews, 2019; Waisberg and Nelson, 2018). Most of these rare studies only focused on a single stage of megaprojects (e.g., preliminary, construction, or operation stage) and lacked systematic analysis of IKS in the entire life cycle of megaprojects delivery (Lin et al., 2006; Mai et al., 2018; Tan et al., 2018). Besides, existing research on IKS or interorganizational collaboration were always conducted through quantified methods (e.g., social network analysis through patent data) (Azadegan et al., 2008; Ritala et al., 2022; Wang and Hu, 2020; Wang et al., 2014). This research conducted a qualitative analysis of multi-source data from the literature, typical cases, scientific research reports, and industrial market surveys.

Second, extant studies on IKS in a project context often emphasize the overall VUCA scenarios in which MSOs are embedded but do not elaborate on them in detail (Cousins, 2018; Wang et al., 2021). This research specialized megaproject VUCA features in multiple aspects, such as the surrounding environment, organization structure, and technical applications, and identified the difference between *ambiguity, complexity, variability, and uncertainty*.

Then, prior research on the IKS process mostly focused on the dual IKS model (i.e., exploratory, and exploitative IKS) (Bakker et al., 2011; Guo et al., 2020; Im, 2006; Shi et al., 2019). From the project perspective, this research further introduces a new dual IKS model (i.e., IKS in tactic and IKS in operation) and extracts corresponding practical IKS activities under each process in the HZMB project, which bridges project management with knowledge management. *IKS in tactic and IKS in operation* have their focuses and complement each other. The former focuses on building the vision, goals, and planning system from the cognitive level (Crupi et al., 2020), while the latter focuses on exploring and solving specific technical and management problems from the behavioral level (Al-Busaidi and Olfman, 2017; Balle et al., 2019; Wanberg et al., 2017). Combining the two enables MSOs to better cope with *environmental variability, uncertainty of needs, complexity of objects, and cognitive ambiguity.*

Next, this research proposes an effective path for MSOs to enhance innovation capability through IKS. The innovation capability enhancement is mainly reflected in four aspects through the retrospective analysis of the fragments of IKS in the HZMB project: *institutional, business, technical, and managerial*. This research expands the classification system of existing enterprise organizational innovation and condenses the concrete manifestations of the improvement of four types of innovation (Cantarelli and Genovese, 2021; Iddris, 2016; Najafi-Tavani et al., 2018; Saunila et al., 2012; Saunila and Ukko, 2012; Zawislak et al., 2012). Rooted in the long-term project practice of the HZMB project, this chapter enriches the theoretical system of IKS and innovation. Finally, this chapter expands the megaproject governance model research by revealing the changing roles of megaproject owners in IKS governance (Bendoly et al., 2021; Dessaigne and Pardo, 2020; Diriker et al., 2022).

8.3.2 Practical Implications

8.3.2.1 Study 1 Knowledge categorization and IKS mechanism mapping in megaprojects

This study has several crucial managerial implications. *Firstly*, the knowledge items derived from semi-structured interviews with practitioners and experts provide valuable guidance to project managers. This information aids project managers in understanding the types of knowledge they should share with counterparts from interdisciplinary organizations. It also assists in clarifying their responsibilities and obligations within the project's knowledge supply chain. *Secondly*, the study proposes practical IKS mechanisms for project managers. These mechanisms can serve as a foundation for developing targeted strategies to promote various categories of IKS across organizational boundaries, fostering interdisciplinary knowledge collaboration (Zhang and Ng, 2012). For instance, promoting communities of practice is encouraged in future megaprojects to enhance IKS in technical skills. Additionally, establishing partnerships through social mechanisms is recommended to facilitate the exchange of managerial experience. These insights can guide project managers in adopting effective strategies for promoting knowledge sharing in diverse project contexts.

8.3.2.2 Study 2 Exploring the antecedents of IKS through Bayesian network analysis

The IKS-BN model developed in this study is useful for managing IKS in megaprojects. The managerial implications were concluded as follows. First, the proposed model could deepen project practitioners' understanding of the interrelationships among factors influencing IKS efficiency and raise their awareness about the importance of the interactions. For example, "Reciprocity→Organizational distance→Efficiency of IKS" is an essential influence chain to enhance IKS efficiency. Long organizational distance between MSOs harms facilitating IKS in projects. Cultivating the reciprocity between MSOs should be a supportive measure to enhance IKS efficiency by establishing regulation systems to form partnerships among MSOs (Ren et al., 2020).

Second, this study helps project managers predict the real efficiency of IKS under different scenarios and underpin the design of interventions in megaprojects. The decision-making evidence was furnished by comparing various scenarios and establishing a knowledge management benchmark, wherein influencing factors are controlled at levels conducive to the successful implementation of IKS. Determining the most effective scenario can prove challenging at times due to variations in the effort required (such as time and cost) to optimize factors, contingent on each organization's specific context. Nonetheless, the introduced IKS-BN model empowers practitioners to assess different scenarios. The model enables practitioners to customize and implement the model following the specific prevalent conditions by permitting adding or removing variables without impacting the overall network structure. When practitioners obtain insights into which influencing factors ought to be managed, they can refer to previous research to search for targeted strategies to regulate the states of specific factors, ultimately enhancing overall IKS efficiency (Chan et al., 2020).

8.3.2.3 Study 3 Stakeholder synergy in megaproject IKS network

Two essential managerial implications are also reached in this study. *First,* this work offers practical insights for governing megaprojects in improving stakeholder power in value creation by IKS. Wealthy stakeholders should take a more networked view by exploiting the broker's role to balance stakeholders' exchange advantages. In addition to maintaining communication channels, central stakeholders should invest more time and effort into customizing and tailoring values for projects, particularly at the front end of project development programs (Liu et al., 2019). Reaping greater benefits from knowledge exchanges, powerless stakeholders could simultaneously take an integrated strategy to cope with the exchange and value disadvantages. To maximize the value co-creation within the IKS network, powerful stakeholders could adopt adaptive strategies to promote a collectivistic and supportive culture (Gualandris et al., 2021) and balance the exchange and value advantages to accommodate other stakeholders' situations.

Second, two external strategies were formed to facilitate stakeholder collaboration in IKS by analyzing the top seven restricted and generalized KVF cycles in the IKS network. The incongruent power status between the knowledge sender and the recipient is beneficial for non-powerful stakeholders to sharply fill in their power gap with powerful stakeholders so that the reciprocal value co-creation of IKS can be maximized efficiently. Triads are considered building blocks for understanding the complex interactions in a network, especially the balanced role of the broker. This chapter denotes those powerful stakeholders should be encouraged to work as *brokers* for non-powerful stakeholders. These managerial implications could provide useful suggestions for interorganizational knowledge collaboration, value co-creation, and governance mechanisms for delivering knowledge-intensive megaprojects.

8.3.2.4 Study 4 Link IKS and innovation capability enhancement in megaprojects

This chapter has important practical significance for IKS and innovation capability enhancement in megaprojects.

(1) To cope with *cognitive ambiguity*, the project owner needs to first conduct *IKS in tactic* to gradually clarify the project boundary, vision, and goals. Then, *IKS in*

operation should be implemented to obtain best practices across fields and industries to form an overall planning and management plan matching the project vision and goals.

(2) To cope with *object complexity* and *environmental variability*, the project owner needs to first conduct *IKS in tactic* to tackle key problems by degrading engineering systems, encouraging independent innovation, integrating global business resources, and facilitating the synergy of the entire industry chain. Then, *IKS in operation* refers to setting up flexible bidding and contract models (e.g., large bidding sections management) according to the project conditions, such as risk level and environmental factors, cultivating partnerships, and facilitating resilient organization.

(3) To cope with the *uncertainty of needs,* under the principle of "adaptive is optimality", a *need-oriented IKS process* in *strategy and business* was proposed to match the *social and technical needs.* To avoid the out-of-control phenomenon that "the contractors ultimately control the owners", it is necessary to balance the relationship between "government-market" by implementing the mixed operation business model.

(4) Based on the situational characteristics of megaprojects at different stages, different IKS activities in strategy and business promote organizational innovation capability enhancement in institutional, business, technical, and managerial.

8.4 Limitations and Future Research

Inevitably, this chapter suffers from some limitations prompting future research.

8.4.1 Study 1 Knowledge categorization and IKS mechanism mapping in megaprojects

First, the empirical data in this study was collected from semi-structured interviews with experts who were organization members of primary and internal core stakeholders participating in the delivery of megaprojects. Future research could conduct interviews with experts from the external or secondary stakeholders, such as the public and electromechanical sub-contractors. Besides, a single case-study longitudinal research method could be employed in future studies to obtain the peculiarity of a specific case and further validate and clarify the bounded conditions of the IKS mechanisms in complex project settings. *Second*, the sample of this study is limited to China's megaprojects (e.g., the Hong Kong-Zhuhai-Macao Bridge). The sampling technique chosen limits the generalizability of the research findings. As such, in the future, this study could be extended to conduct parallel analyses using sample data from other megaprojects in other industries, such as aerospace, and in different countries or regions. *Third*, this study categorized knowledge categories and developed different IKS mechanisms for matching. Some qualitative methods, such as questionnaire surveys, are needed to verify the one-to-one matching relationship or develop multiple governance mechanisms in a one-to-many way. Finally, extant research has found that effective IKS could greatly contribute to value creation (Martinsuo et al., 2019; Möller and Svahn, 2006). Future research could explore the effects of distinct categories of shared knowledge on value creation in megaprojects.

8.4.2 Study 2 Exploring the antecedents of IKS through Bayesian network analysis

Certain methodological limitations merit discussion in this study. *Initially*, the IKS-BN model in this study is established on survey data collected from all megaprojects in China. Although previous studies also regarded megaprojects as the ideal data collection resource to explore IKS in megaprojects (He et al., 2023; Iftikhar and Wiewiora, 2020). More data could be collected in the future from other industries, such as manufacturing (Lawson and Potter, 2012), health care (Lim et al., 2015), and IT service (Zhao et al., 2015), to make cross-validation of the research findings in this study. *Second*, to simplify the established model, the main influencing factors were selected from three aspects (i.e., knowledge, organizational, and context characteristics) by literature reviews to establish the IKS-BN model. More factors could be included and examined in future studies. For example, recent studies explored the effects of MSOs' network characteristics on their IKS efficiency (Jenke and Pretzsch, 2021; Milagres and Burcharth, 2019; Linzhuo Wang et al., 2023). *Last*, the mutual information observed in this study tends to be relatively modest, a trend that is consistent with findings from previous research (Chan et al., 2020; Sun et al., 2023). Other quantitative methods, such as agent-based modeling (ABM) and Fuzzy-set Qualitative Comparative Analysis (fsQCA), could be further employed to verify the results under what-if scenarios.

8.4.3 Study 3 Stakeholder synergy in megaproject IKS network

This study paves the way for three main research streams. *First*, the traditional design-bid-build approach is still prevalent in delivering megaprojects globally, including in China (Zheng et al., 2019a), Europe (Eriksson et al., 2017b), and the US (Park and Kwak, 2017). The SVN was established based on the design-bid-build delivery system. Future studies can adopt a similar SVN approach based on other delivery systems, such as Design-Build (DB) model and Engineering, Procurement, and Construction (EPC) model. *Moreover*, the seven major MSOs in the current model are primarily organizations directly involved in the megaproject delivery. Future research could include external or secondary organizations (such as the public or subcontractors) to broaden the study's findings. *Last*, by referring to the research design of previous SVN studies (Hein et al., 2017; Pereira et al., 2018; Zheng et al., 2021), the primary data were collected from a series of semi-structured interviews and questionnaire surveys. In this study, the KVFs consist of important tasks across different project stages. Future studies can collect longitudinal data and reveal the trajectories of SVN in project implementation.

8.4.4 Study 4 Link IKS and innovation capability enhancement in megaprojects

Case studies are suitable for exploring the inquiry process, i.e., the "what", "how," and "why" questions. A longitudinal case study of the HZMB project, a typical representative of world-class megaprojects, was conducted to obtain and promote its best practices in IKS. However, the case study method is weak in exploring "to what extent" questions, which need further quantification. Following the "Scenario-Process-Outcome" framework, this chapter discussed the relationship between IKS and innovation capability enhancement and revealed the changing roles of owners in the above process. During the data analysis process, it was found that different types of MSOs often form temporary strategic alliances to conduct IKS activities, deal with specific problems, and achieve innovation. Future scholars can quantitatively analyze the IKS process in megaprojects from the network perspective. Specifically, research questions such as "What are typical characteristics of IKS networks in megaprojects," "Why does the IKS network evolve in different project stages," and "How to provide governance strategies to facilitate value co-creation of the IKS network".

8.5 Chapter Summary

This chapter has provided a comprehensive review of the research objectives and presented a summary of the findings obtained in the course of the whole study. Additionally, the chapter has highlighted the contributions made by this research, encompassing both theoretical advancements and practical implications. The identified limitations of this study have been duly acknowledged and addressed. Lastly, the chapter concludes by outlining potential avenues for future research.

APPENDICES

Appendix A. Questionnaire design and reliability and validity check

No	Psychosocial hazard	Question (factor loading >0.4)	Reliability and validity indicators	Goodness-of-fit indices
1	Tacitness (Guo, 2018)	We often share blueprints, instructions, and handbooks with other organizations.	CR: 0.814 AVE: 0.659 Coefficient H: 0.89	Not able to be calculated with three items
		We often share managerial experience and technical expertise with other organizations.		
		We often share manuals and procedures to guide other organizations.		
2	Ambiguity (Lawson and Potter, 2012)	We are clear about the context of our shared knowledge.	CR: 0.891 AVE: 0.673 Coefficient H: 0.93	Not able to be calculated with three items
		We are clear about the causes and effects related to our shared knowledge.		
		We could easily obtain feedback on our shared knowledge from other organizations.		
3	Complexity (Kim et al., 2013)	We need to share a large body of interdisciplinary knowledge.	CR: 0.795 AVE: 0.705 Coefficient H:0.86	Not able to be calculated with three items
		We need to combine existing knowledge to create new knowledge.		
		We need to integrate a large body of knowledge from different project periods.		
4	Heterogeneity (Guo, 2018)	We have more managerial knowledge to share than other organizations.	CR: 0.799 AVE: 0.649 Coefficient H: 0.91	Not able to be calculated with three items
		We have more technical knowledge to share than other organizations.		
		We have more market knowledge to share than other organizations.		
5	Absorptive capacity (Lawson and Potter, 2012)	We must integrate our existing knowledge with new knowledge from other organizations.	CR: 0.825 AVE: 0.628 Coefficient H: 0.93	CFI: 0.965 IFI: 0.952 TLI: 0.929 RMSEA: 0.099 SRMR: 0.038
		We need the capability to exploit the new integrated knowledge into concrete applications.		
		We need the capability to formulate internal routines to analyze the knowledge obtained from other organizations.		
		We need the capability to identify, value, and import external knowledge from other organizations.		
6	Sharing capability (Zhao et al., 2015)	We can identify the value of the knowledge we own for collectors	CR: 0.801 AVE: 0.634 Coefficient H: 0.90	Not able to be calculated with three items
		We can perceive what knowledge is needed for collectors.		
		We can transfer knowledge using channels (e.g., written text, graphics, video, face-to-face communication) convenient for collectors.		
7	Reciprocity (Ren et al., 2020)	We are willing to help and cooperate with other organizations mutually	CR: 0.882 AVE: 0.712 Coefficient H: 0.92	CFI: 0.980 IFI: 0.976 TLI: 0.945 RMSEA: 0.108 SRMR: 0.047
		We are willing to pay back when other organizations help us out.		
		We believe that we will get a return if we lend a hand to other organizations.		
		We believe that it is worthwhile to assist other organizations mutually.		

No	Psychosocial hazard	Question (factor loading >0.4)	Reliability and validity indicators	Goodness-of-fit indices
8	Interorganizational trust (Ren et al., 2020)	We believe that other organizations are reliable	CR: 0.869 AVE: 0.705 Coefficient H: 0.91	CFI: 0.990 IFI: 0.987 TLI: 0.945 RMSEA: 0.076 SRMR: 0.029
		We believe that other organizations are honest.		
		We believe that other organizations will not harm our benefits.		
		We believe that other organizations will keep their promises.		
9	Geographical distances (Ren et al., 2020)	In our projects, project organizations are geographically close.	CR: 0.795 AVE: 0.683 Coefficient H: 0.87	Not able to be calculated with two items
		In our projects, project organizations are geographically concentrated.		
10	Organizational distance (Hsiao et al., 2017)	We have a similar organizational structure to other organizations	CR: 0.820 AVE: 0.559 Coefficient H: 0.88	Not able to be calculated with three items
		We have similar business practices and operational mechanisms with other organizations.		
		We have a similar corporate culture and management style to other organizations.		
11	Project temporary nature (Ren et al., 2018)	In our projects, we disband or leave after project completion.	CR: 0.901 AVE: 0.644 Coefficient H: 0.94	CFI: 0.976 IFI: 0.958 TLI: 0.961 RMSEA: 0.099 SRMR: 0.030
		In our projects, we start working on new projects after project completion.		
		In our projects, the duration is rather short-term oriented.		
		In our projects, we are integrated from other projects at project initiation.		
12	Project time constraints (Ren et al., 2020)	In our projects, the schedule is tight	CR: 0.876 AVE: 0.719 Coefficient H: 0.96	CFI: 0.988 IFI: 0.948 TLI: 0.934 RMSEA: 0.067 SRMR: 0.037
		In our projects, we are generally under time pressure.		
		In our projects, the schedule is frequently checked by clients.		
		In our projects, we spent much time on the construction and had little spare time.		
13	Project culture (Ren et al., 2020)	In our projects, the atmosphere is tolerant and open	CR: 0.817 AVE: 0.625 Coefficient H: 0.89	CFI: 0.995 IFI: 0.986 TLI: 0.977 RMSEA: 0.046 SRMR: 0.049
		In our projects, inter-project and cross-functional information exchange are encouraged.		
		In our projects, sharing knowledge among employees is advocated.		
		In our projects, top managers pay attention to knowledge sharing.		
14	Project incentive mechanisms (Wang and Shi, 2019)	In our projects, we will receive monetary rewards when sharing knowledge with other organizations	CR: 0.833 AVE: 0.616 Coefficient H: 0.91	CFI: 0.957 IFI: 0.942 TLI: 0.949 RMSEA: 0.051 SRMR: 0.028
		In our projects, we will receive additional points for promotion when sharing knowledge with other organizations.		
		In our projects, we will be respected by others when sharing knowledge with other organizations.		
		In our projects, we will be praised by superiors when sharing knowledge with other organizations.		

No	Psychosocial hazard	Question (factor loading >0.4)	Reliability and validity indicators	Goodness-of-fit indices
15	Communication infrastructure (Zhou et al., 2022)	In our projects, we have a mature meeting system to support our knowledge-sharing with other organizations	CR: 0.849 AVE: 0.672 Coefficient H: 0.93	CFI: 0.982 IFI: 0.912 TLI: 0.909 RMSEA: 0.058 SRMR: 0.035
		In our projects, we have widely applied information technology tools to support our knowledge sharing with other organizations.		
		In our projects, we have smooth communication channels to support our knowledge sharing with other organizations.		
		In our projects, we have a convenient document exchange system to support our knowledge sharing with other organizations.		
		In our projects, we have training sessions and workshops to support our knowledge sharing with other organizations.		
16	Market competition (Harmancioglu et al., 2020)	The market is so competitive	CR: 0.871 AVE: 0.599 Coefficient H: 0.94	Not able to be calculated with three items
		Contract price wars often occur.		
		We have to fight to hold onto our share of the market aggressively.		
17	Efficiency of knowledge transfer (EKT) (Ren et al., 2018)	We increased knowledge stock by conducting IKS with other organizations	CR: 0.876 AVE: 0.586 Coefficient H: 0.90	CFI: 0.965 IFI: 0.929 TLI: 0.923 RMSEA: 0.072 SRMR: 0.014
		We solved problems by conducting IKS with other organizations.		
		We improved the technology level by conducting IKS with other organizations.		
		We promoted members' capability by conducting IKS with other organizations.		
		We enhanced work efficiency by conducting IKS with other organizations.		

Note: CR = composite reliability (>0.7); AVE = average variance extracted (>0.5); Coefficient H (>0.8); CFI = comparative fit index (>0.9); IFI = incremental fit index (>0.9); TLI = Tucker–Lewis index (>0.9); RMSEA = root mean square error of approximation (<0.1), and SRMR = standardized root mean square residual (<0.05);.

Appendix B. Questionnaire on the two attributes of KVF

Distinct KVFs were associated with different types of organizations. Thus, there are seven sets of questionnaires in total. Each set of questionnaires included two parts. (Note: This is the general presentation of the questionnaire design and does not involve specific code content.)

Part I: Please fill in the blank and place a tick “ √ ” at the most appropriate option.

Items	Options
Personal information	
Education background	□ Bachelor □ Master □ Doctor □ Others
Work experience in large inter-organizational construction projects (in years)	□ ≤ 5 □ 6-10 □ 11-15 □ 16-20 □ >20
Involved project information (Please select a **recently participated megaproject** as the reference for finishing the surveys.)	
Project name	________________________
Your position in this project	□ Project manager □ Project director □ Department/operation manager □ Technical director □ Other (Please specify)__________
The role your organization played in the project	□ Owner □ Designers □ Consultants □ Contractors □ Government □ Project Supervisors □ Suppliers □ Other (Please specify)__________
Project investment (1 billion RMB, around 0.154 billion US dollars)	□ < 1 □ 1-5 □ 6-10 □ Above 10
Project period (Months)	□ < 24 □ 24-36 □ 37-48 □ 49-60 □ Above 60

Part II: Please read the rules for characterizing knowledge-sharing activities.

1. Satisfaction with the knowledge-sharing process	
Q1: To what extent are you satisfied with the knowledge-sharing process from other project partnering organizations?	
Satisfaction scale	**Description**
a	Would be pleased with the knowledge-sharing process and would not regret the noncompliance
b	Would be pleased with the knowledge sharing
c	Would be pleased with the knowledge-sharing process and would certainly regret the non-compliance
d	Knowledge-sharing process is important, and the non-compliance would be regrettable
e	Knowledge-sharing process is extremely essential, and the non-compliance would be regrettable

2. Importance of knowledge for meeting the project working needs	
Q2: How important do you think each knowledge value flow from other project participating organizations is to your project work?	
Importance scale	**Description**
A	Not important – I do not need this shared knowledge to accelerate my project work
B	Slightly important – It is acceptable that this shared knowledge accelerates my project work
C	Important – It is preferable that this shared knowledge accelerates my project work
D	Very important – It is highly desirable that this shared knowledge accelerates my project work
E	Extremely important –This shared knowledge is indispensable in accelerating my project work

Part III: Please evaluate the relative satisfaction and importance of each KVF in the list.

Form	End	Knowledge category	Code	Q1 (a-e)
Designers	Government	Real-time project status	D1G	
	Contractors		D1C	
	Owner		D1O	
	Government	Innovative managerial experience	D2G	
	Contractors		D2C	
	Owner		D2O	
	Government	Cutting-edge technical skills	D3G	
	Contractors		D3C	
	Owner		D3O	
	Consultants		D3CS	
	Suppliers		D3S	
	Government	Integrated technical guidelines	D4G	
	Contractors		D4C	
	Owner		D4O	
	Consultants		D4CS	
	Suppliers		D4S	
Government	Designers	Real-time project status	G1D	
	Project Supervisors		G1PS	
	Contractors		G1C	
	Owner		G1O	
	Designers	C	G2D	
	Project Supervisors		G2PS	
	Contractors		G2C	
	Owner		G2O	
	Designers	Cutting-edge technical skills	G3D	
	Project Supervisors		G3PS	
	Contractors		G3C	
	Owner		G3O	
	Designers	Integrated technical guidelines	G4D	
	Project Supervisors		G4PS	
	Contractors		G4C	
	Owner		G4O	
Project Supervisors	Government	Real-time project status	PS1G	
	Contractors		PS1C	
	Owner		PS1O	
	Contractors	Innovative managerial experience	PS2C	
	Owner		PS2O	
	Contractors	Cutting-edge technical skills	PS3C	
	Owner		PS3O	
	Contractors	Integrated technical guidelines	PS4C	
	Owner		PS4O	
Suppliers	Contractors	Real-time project status	S1C	
	Contractors	Integrated technical guidelines	S2C	
	Owner		S2O	
	Designers	Cutting-edge technical skills	S3D	
	Contractors		S3C	
	Owner		S3O	
	Contractors	Integrated technical guidelines	S4C	
	Owner		S4O	

Form	End	Knowledge category	Code	Q1 (a-e)
Contractors	Designers	Real-time project status	C1D	
	Government		C1G	
	Project Supervisors		C1PS	
	Owner		C1O	
	Contractors		C1CS	
	Suppliers		C1S	
	Designers	Innovative managerial experience	C2D	
	Project Supervisors		C2PS	
	Owner		C2O	
	Consultants		C2CS	
	Designers	Cutting-edge technical skills	C3D	
	Government		C3G	
	Project Supervisors		C3PS	
	Owner		C3O	
	Consultants		C3CS	
	Suppliers		C3S	
	Government	Integrated technical guidelines	C4G	
	Project Supervisors		C4PS	
	Owner		C4O	
	Contractors		C4CS	
	Suppliers		C4S	
Owner	Designers	Real-time project status	O1D	
	Government		O1G	
	Project Supervisors		O1PS	
	Contractors		O1C	
	Contractors		O1CS	
	Designers	Innovative managerial experience	O2D	
	Government		O2G	
	Contractors		O2C	
	Contractors		O2CS	
	Suppliers		O2S	
	Contractors	Cutting-edge technical skills	O3C	
	Consultants		O3CS	
	Suppliers		O3S	
	Designers	Integrated technical guidelines	O4D	
	Government		O4G	
	Project Supervisors		O4PS	
	Contractors		O4C	
	Contractors		O4CS	
Consultants	Contractors	Real-time project status	CS1C	
	Owner		CS1O	
	Contractors	Innovative managerial experience	CS2C	
	Owner		CS2O	
	Designers	Cutting-edge technical skills	CS3D	
	Contractors		CS3C	
	Owner		CS3O	
	Designers	Integrated technical guidelines	CS4D	
	Contractors		CS4C	
	Owner		CS4O	

Part IV: Please evaluate the relative satisfaction of each knowledge-sharing activity in the list.

Form	End	Knowledge category	Code	Q2 (A -E)	Form	End	Knowledge category	Code	Q2 (A -E)
Designers	Government	Real-time project status	D1G		Contractors	Designers	Real-time project status	C1D	
	Contractors		D1C			Government		C1G	
	Owner		D1O			Project Supervisors		C1PS	
	Government	Innovative managerial experience	D2G			Owner		C1O	
	Contractors		D2C			Contractors		C1CS	
	Owner		D2O			Suppliers		C1S	
	Government	Cutting-edge technical skills	D3G			Designers	Innovative managerial experience	C2D	
	Contractors		D3C			Project Supervisors		C2PS	
	Owner		D3O			Owner		C2O	
	Consultants		D3CS			Consultants		C2CS	
	Suppliers		D3S			Designers	Cutting-edge technical skills	C3D	
	Government	Integrated technical guidelines	D4G			Government		C3G	
	Contractors		D4C			Project Supervisors		C3PS	
	Owner		D4O			Owner		C3O	
	Consultants		D4CS			Consultants		C3CS	
	Suppliers		D4S			Suppliers		C3S	
Government	Designers	Real-time project status	G1D			Government	Integrated technical guidelines	C4G	
	Project Supervisors		G1PS			Project Supervisors		C4PS	
	Contractors		G1C			Owner		C4O	
	Owner		G1O			Contractors		C4CS	
	Designers	C	G2D			Suppliers		C4S	
	Project Supervisors		G2PS		Owner	Designers	Real-time project status	O1D	
	Contractors		G2C			Government		O1G	
	Owner		G2O			Project Supervisors		O1PS	
	Designers	Cutting-edge technical skills	G3D			Contractors		O1C	
	Project Supervisors		G3PS			Contractors		O1CS	
	Contractors		G3C			Designers	Innovative managerial experience	O2D	
	Owner		G3O			Government		O2G	
	Designers	Integrated technical guidelines	G4D			Contractors		O2C	
	Project Supervisors		G4PS			Contractors		O2CS	
	Contractors		G4C			Suppliers		O2S	
	Owner		G4O			Contractors	Cutting-edge technical skills	O3C	
Project Supervisors	Government	Real-time project status	PS1G			Consultants		O3CS	
	Contractors		PS1C			Suppliers		O3S	
	Owner		PS1O			Designers	Integrated technical guidelines	O4D	
	Contractors	Innovative managerial experience	PS2C			Government		O4G	
	Owner		PS2O			Project Supervisors		O4PS	
	Contractors	Cutting-edge technical skills	PS3C			Contractors		O4C	
	Owner		PS3O			Contractors		O4CS	
	Contractors	Integrated technical guidelines	PS4C		Consultants	Contractors	Real-time project status	CS1C	
	Owner		PS4O			Owner		CS1O	
Suppliers	Contractors	Real-time project status	S1C			Contractors	Innovative managerial experience	CS2C	
	Contractors	Integrated technical guidelines	S2C			Owner		CS2O	
	Owner		S2O			Designers	Cutting-edge technical skills	CS3D	
	Designers	Cutting-edge technical skills	S3D			Contractors		CS3C	
	Contractors		S3C			Owner		CS3O	
	Owner		S3O			Designers	Integrated technical guidelines	CS4D	
	Contractors	Integrated technical guidelines	S4C			Contractors		CS4C	
	Owner		S4O			Owner		CS4O	

Appendix C. The process of searching all of the KVF cycles

This appendix describes the process of utilizing the design structure matrix method to search all of the KVF cycles among primary MSOs. Firstly, a simplified example is shown as follows, including three steps to make it more understandable.

Step I: Constructing a design structure matrix M

Figure C.1 is an example multidigraph that depicts all value flows (a, b, c, d, e, f, g, and h) between four stakeholders, A, B, C, and D, based on which a design structure matrix *M* is constructed **(Figure C.2**). The element (A, D) in matrix M is “h”, which means a value flow “h” is existed from stakeholder “A” to “D”.

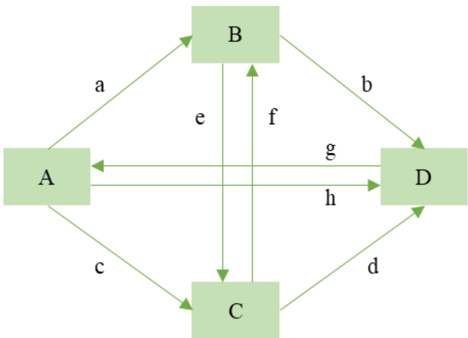


Figure C.1 Multidigraph of the example

Start \ End	A	B	C	D
A		a	c	h
B			e	b
C		f		d
D	g			

Figure C.2 Design structure matrix M of the example

Step II: Multiplying design structure matrix M through Danielson’s algorithm to search all of the KVF cycles

According to Danielson’s algorithm, simple cycles[10] with a length of k could be obtained through the k-time multiplication (ordinary matrix product) of the design structure matrix, a utility weightings matrix V could be obtained by multiplying matrix M. To enumerate KVF cycles in length (n), the matrix M was multiplied n times (as

[10] A simple cycle exactly represents the standard form of *generalized exchange* and has been taken as the basic units to measure the impacts of stakeholder relationships in the network, and no stakeholder except the focal organization is visited more than once along the value cycle

shown in the Equation below) to get a matrix V. The matrix V ensures that each stakeholder (excluding the start or end stakeholder) is only visited once (Feng, 2013) along each KVF cycle, and all possible KVF cycles (see the diagonal elements of the matrix V) can be found for any stakeholder.

$$V = \sum_{i=1}^{n} M^i, 2 \leq n \leq \text{a}, \text{x} \in \text{z}$$

where n is an integer not more than the number of stakeholders (a) in the network.

In this example, various design structure matrix V could be obtained by multiplying M different times (i.e., M^2, M^3, M^4, see **Figure C.3**) to enumerate KVF cycles with different lengths (i.e., length-2, length-3, and length-4). The diagonal elements of the matrix V show all possible KVF cycles for any stakeholder.

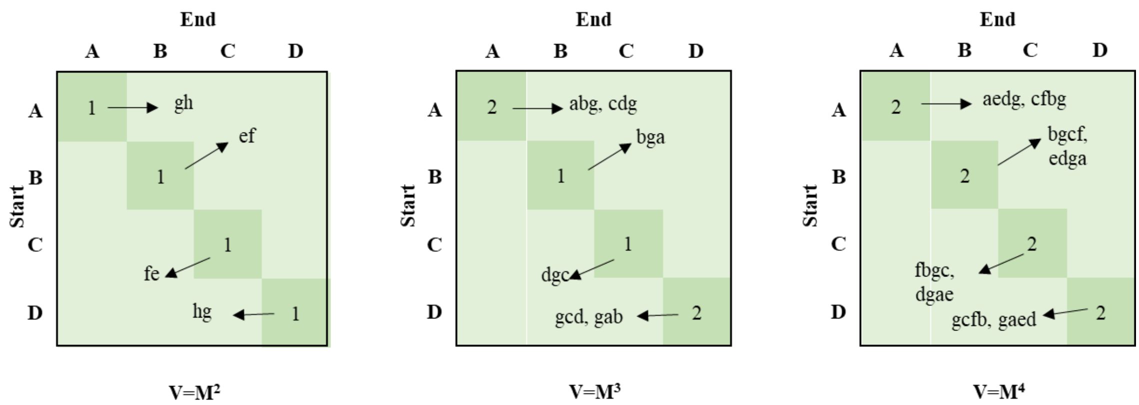


Figure C.3 Multiplied design structure matrix V for M^2, M^3, M^4

Step III: Summing up the number of KVF cycles in various length

Finally, KVF cycles in various lengths are summed up for further analysis, as shown in **Figure C.4**.

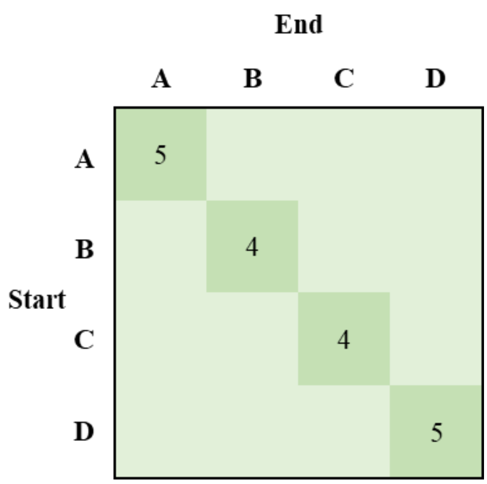


Figure C.4 Statistics of KVF cycles in different lengths

Secondly, following the above steps, the KVF cycles among primary MSOs could be enumerated. In this study, the stakeholders mapped in step I constitute the system elements of matrix M, and its off-diagonal cells consist of KVF among the stakeholders, as shown in **Table C**. According to Danielson's algorithm, different utility weightings matrices V were obtained by multiplying matrix M to enumerate all KVF cycles with different lengths.

Table C Design structure matrix M of the SVN model

	D	G	PS	C	O	CS	S
D	/	G1D G2D G3D G4D		C1D C2D C3D	O1D O2D O4D	CS3D CS4D	S3D
G	D1G D2G D3G D4G	/	PS1G	C1G C3G C4G	O1G O2G O4G		
PS		G1PS G2PS G3PS G4PS	/	C1PS C2PS C3PS C4PS	O1PS O4PS		
C	D1C D2C D3C D4C	G1C G2C G3C G4C	PS1C PS2C PS3C PS4C	/	O1C O2C O3C O4C	CS1C CS2C CS3C CS4C	S1C S2C S3C S4C
O	D1O D2O D3O D4O	G1O G2O G3O G4O	PS1O PS2O PS3O PS4O	C1O C2O C3O C4O	/	CS1O CS2O CS3O CS4O	S2O S3O S4O
CS	D3CS D4CS			C1CS C2CS C3CS C4CS	O1CS O2CS O3CS O4CS	/	
S	D3S D4S			C1S C3S C4S	O2CS O3CS		/

Note: "C" represents Client, "G" represents Government, "CS" represents Consultants, "PS" represents Project Supervisors, "C" represents Contractors, "S" represents Suppliers, and "D" represents Designers.

Appendix D. Evaluated results for all knowledge value flows

The detailed information of 81 knowledge value flows is shown in Table D.

Table D Knowledge value flows in megaprojects

Code	U_f	Code	U_f	Code	U_f
D1G	0.21	PS1G	0.48	O1C	0.76
D1C	0.28	PS1C	0.47	O1CS	0.85
D1O	0.48	PS1O	0.41	O2D	0.43
D2G	0.23	PS2C	0.49	O2G	0.52
D2C	0.47	PS2O	0.77	O2C	0.85
D2O	0.26	PS3C	0.44	O2CS	0.76
D3G	0.24	PS3O	0.45	O2S	0.55
D3C	0.49	PS4C	0.49	O3C	0.83
D3O	0.39	PS4O	0.53	O3CS	0.61
D3CS	0.55	C1D	0.29	O3S	0.37
D3S	0.35	C1G	0.43	O4D	0.43
D4G	0.19	C1PS	0.48	O4G	0.39
D4C	0.41	C1O	0.79	O4PS	0.46
D4O	0.42	C1CS	0.69	O4C	0.77
D4CS	0.38	C1S	0.42	O4CS	0.82
D4S	0.28	C2D	0.27	CS1C	0.58
G1D	0.44	C2PS	0.43	CS1O	0.85
G1PS	0.31	C2O	0.85	CS2C	0.84
G1C	0.26	C2CS	0.86	CS2O	0.83
G1O	0.25	C3D	0.47	CS3D	0.49
G2D	0.42	C3G	0.55	CS3C	0.82
G2PS	0.27	C3PS	0.44	CS3O	0.87
G2C	0.48	C3O	0.83	CS4D	0.56
G2O	0.51	C3CS	0.85	CS4C	0.83
G3D	0.49	C3S	0.54	CS4O	0.79
G3PS	0.23	C4G	0.33	S1C	0.32
G3C	0.47	C4PS	0.75	S2C	0.51
G3O	0.46	C4O	0.62	S2O	0.33
G4D	0.44	C4CS	0.71	S3D	0.45
G4PS	0.21	C4S	0.47	S3C	0.77
G4C	0.38	O1D	0.47	S3O	0.49
G4O	0.49	O1G	0.47	S4C	0.55
		O1PS	0.44	S4O	0.44

Note: "C" represents Client, "G" represents Government, "CS" represents Consultants, "PS" represents Project Supervisors, "C" represents Contractors, "S" represents Suppliers, and "D" represents Designers.

Appendix E. Robustness tests

Robustness Test 1. Using a non-linear scale to calibrate the two attributes of each KVF.

Table E.1: The Non-linear Scale for KVFs Calibration

		U_f (importance)				
		a = 0.11	**a = 0.19**	**a = 0.33**	**a = 0.57**	**a = 0.98**
	A = 0.11	0.11	0.02	0.04	0.06	0.11
	B = 0.19	0.02	0.04	0.06	0.11	0.19
U_f **(satisfaction)**	**C = 0.33**	0.04	0.06	0.11	0.19	0.32
	D = 0.57	0.06	0.11	0.19	0.32	0.56
	E = 0.98	0.11	0.19	0.32	0.56	0.96

Table E.2: Value Advantage Scores of Seven Types of Organizations

Organizations	D	G	PS	C	O	CS	S
Value advantage	0.101	0.082	0.063	0.225	0.283	0.198	0.048
Value advantage level	Low	Low	Low	High	High	High	Low

Note: C = contractors, CS = consultants, D = designers, G = government, O = owner, PS = project supervisors, S = suppliers

Table E.3: Integrated Advantage Scores of Seven Types of Organizations

Organizations (focal organizations)	D	G	PS	C	O	CS	S
D→ D	**1.000**	0.655	0.496	0.954	0.905	0.689	0.415
G→G	0.833	**1.000**	0.506	0.935	0.927	0.715	0.476
PS→PS	0.762	0.695	**1.000**	0.922	0.914	0.637	0.408
C→C	0.821	0.613	0.506	**1.000**	0.965	0.743	0.412
O→O	0.803	0.582	0.527	0.973	**1.000**	0.716	0.485
CS→CS	0.824	0.541	0.442	0.931	0.958	**1.000**	0.438
S→S	0.865	0.501	0.435	0.967	0.944	0.597	**1.000**
Integrated advantage	**0.844**	**0.655**	**0.559**	**0.955**	**0.945**	**0.728**	**0.519**
Integrated advantage level	**High**	**Low**	**Low**	**High**	**High**	**Low**	**Low**

Note: C = contractors, CS = consultants, D = designers, G = government, O = owner, PS = project supervisors, S = suppliers

Robust Test 2. Using the "quadratic" aggregation rule for calculating the KVF cycles

Table E.4: Integrated Advantage Scores of Seven Types of Organizations

Organizations (focal organizations)	D	G	PS	C	O	CS	S
D→ D	**1.000**	0.737	0.483	0.962	0.958	0.780	0.397
G→G	0.811	**1.000**	0.558	0.970	0.965	0.709	0.320
PS→PS	0.746	0.719	**1.000**	0.984	0.970	0.680	0.284
C→C	0.747	0.660	0.485	**1.000**	0.959	0.767	0.351
O→O	0.750	0.665	0.482	0.962	**1.000**	0.777	0.333
CS→CS	0.768	0.644	0.453	0.970	0.969	**1.000**	0.313
S→S	0.844	0.611	0.399	0.985	0.972	0.659	**1.000**
Integrated advantage	**0.809**	**0.719**	**0.551**	**0.976**	**0.970**	**0.767**	**0.428**
Integrated advantage level	**High**	**Low**	**Low**	**High**	**High**	**Low**	**Low**

Note: C = contractors, CS = consultants, D = designers, G = government, O = owner, PS = project supervisors, S = suppliers

Appendix F. Qualitative triangulation through interviews

	Interview Clips
Value advantages	• **High (Consultants):** ◆ A series of experiment data of innovative technologies created by the research team from Tongji University, such as the deep-inserted steel cylinder rapid island construction technology, provide a critical reference for our project design and construction. (O1) ◆ Knowledge is our foundation. We (TEC, Tunnel Engineering Consultants with extensive experience in risk management for bridge and tunnel projects) submitted six consultancy reports highlighting the risk of tunnel flooding and pointing out the significant impact of sea level rise due to climate change from the end of 2008 to September 2011. (CS1) • **Low (Project supervisors):** ◆ Their (project supervisors) responsibility is to provide all-around supervision on project creation, design, and construction to promote project performance. However, it is common that they have limited professional technical knowledge and experience in participating such complex interorganizational construction projects, such as steel structure manufacturing and immersed tube tunnel construction, which are necessary for successful project delivery. (C1) ◆ Our (project supervisors) main task is quality supervision and safety hazard detection. Our work is more of a routine nature to discover flaws in quality, safety, etc. It is not our duty to involve in project decision making or problem solving. We have limited expertise in these aspects. (PS1)
Flow advantages	• **High (Designers):** ◆ Due to the complexity and interdisciplinary of our project, project design tasks are assigned to different designers based on professional segmentation. In each section, such as steel box girder structure design, steel-composite girder structure design, immersed tube tunnel design, and bridge deck pavement design, we (owner) encourage them (designers) to establish close collaboration with world-class consultants and contractors. There are lots of knowledge flows among them. (O2) ◆ We (designers) often participated in complex hospital construction projects and encountered the most complicated and trivial design and communication tasks there. For example, continuous knowledge sharing with the owner is required to confirm the changing building function design. A large amount of information regarding medical equipment was provided by suppliers. Information and knowledge of mechanical & electrical design need to be accurately shared with the contractors. (D1) • **High (Government):** ◆ On the one hand, large infrastructure projects are usually funded and delivered by the government (i.e., the owner). On the other hand, they are also closely supervised by related government departments (i.e., government). We (the owner) need to report different types of project-related details timely and obtain responses during the whole project period, such as feasibility studies and environmental impact assessments. (O3) ◆ We (government officials) not only supervise a specific project but also

	Interview Clips
Integrated advantages **Flow strategy**	direct the construction industry by piloting some policies or regulations on the typical large complex construction projects, such as BIM application, environment protection, and project delivery model promotion. All participating organizations (e.g., contractors, consultants, suppliers, and designers) should provide their opinions to optimize our policy-making. (G1) • **Low (Suppliers):** ◆ In general construction projects, suppliers' knowledge is usually limited and mostly related to the basic updated parameters about their supplied materials or equipment because they have to protect their core technologies and business secrets. Sometimes, this phenomenon in complex projects is improved. For example, we (contractors) need collaboration and exchanging knowledge and opinions to tackle some technical problems jointly. But this case is not universal. (C3) ◆ We (suppliers) primarily maintain connections with designers and contractors to provide support with materials and equipment. We have limited interest in establishing connections with other project organizations. (S1) • **High (Owner):** ◆ The construction project is eventually delivered to the owner, so the owner's needs and evaluation are vital to us. We have frequent knowledge and opinion exchange during the whole life cycle of project delivery to update project status and obtain timely feedback. (C3) ◆ We are the information and knowledge hub to connect all project participants. Each connection also creates huge value for successful project delivery. For example, we promoted the "on-site design + headquarters support" mode in the design stage: the design plan can be quickly delivered to the constructors; construction problems can be fed back to the designer in time; the headquarters support ensures the technical reliability and professionalism of the design. (O2) • **High (Contractors):** ◆ Due to the project's complexity and limited experience in similar projects, we took on extra tasks in those complex projects compared with general projects, such as participating in design tasks. For example, the on-site linkage of design and construction was encouraged in the island tunnel project to share insights and experience. We (contractors) creatively proposed the "L-shape" factory locating scheme instead of "the linear shape", which greatly helps designers optimize their design. (C3) ◆ Insufficient technical data on the construction of immersed tube tunnels in the offshore environment, inadequate estimation of the project environment, and technical difficulties caused "hard" challenges for successful project delivery in our projects. The contractor connected and facilitated consultants conducting scientific experiments, surveys, and simulations to obtain missing data and establish an efficient knowledge-sharing channel. (CS2) ◆ We (consultants) are the "think tank" of the owner and bring new and creative ideas to address technical and managerial challenges. However, limited interactions with organizations impede our knowledge contribution

	Interview Clips
Value strategy	to other project organizations. Suppose the owner could establish an efficient and easy-to-use knowledge sharing sociotechnical system (such as systems, regular or specialized seminars). In that case, we think we could provide more practical insights for other organizations to optimize their decision-making and prevent critical risks in project delivery. (CS2) ◆ The prominent challenge of complex inter-organizational construction projects is the integration of design and construction. We (designers) have established connections with other organizations (e.g., owners, contractors, consultants, and suppliers). It is not enough. Our effort should focus on response to their concerns, fitting to needs, and establishing partnerships to support the implementation of the design solution during the construction stage. (D2) ◆ Megaprojects are usually commissioned by governments. We (the government) have coordinated and monitored the project delivery process. However, more extensive and profound interactions with different organizations should be developed next to help us understand each project organization's needs and concerns and immerse ourselves in this VUCA era. (G2) ◆ We (project supervisors) make a vital effort in confirming project performance (e.g., controlling quality, cost, and safety). To bridge our technical knowledge gaps, we obtained all-around training from the designers, contractors, and quality management consultants during the construction preparation period to enhance our technical and project management capability. It is a real case to reflect our actions of "partnership" in our project. (PS1)
Integrated strategy	◆ To be honest, in general projects, we (suppliers) usually participate in knowledge sharing in the bidding stage to respond to tender specifications and have no motivation to donate our professional knowledge to the contractors or the owner afterward, although this kind of knowledge is essential for project performance. However, complex projects push us to establish collaboration with others (e.g., contractors and consultants). Ultimately, we found that our thoughts in general projects were wrong. Collaboration and partnership could bring us unexpected technical breakthroughs and market outlook. (S1) ◆ We (the owner) have invested a lot of effort in knowledge management. Large inter-organizational construction projects face complex challenges. We integrate different organizations to conduct research and solve technical and management challenges. In particular, we have developed cultural salons and created the project's magazine to promote knowledge sharing between organizations (O2).
Adaptive strategy	◆ During the implementation of large inter-organizational construction projects, we experience significant challenges that are difficult to anticipate during the project's planning stage. We maintain close interactions with the owner, designers, and consultants to cope with technical and managerial problems. The construction stage is the most concentrated stage of resource investment. We make great efforts to make joint innovation in the project delivery process. (C3)

Appendix G. Life-cycle IKS process in the HZMB project

Table G.1 IKS in Tactic

IKS Process	IKS Content	External Organizations
Project Vision & Goal Design	Project vision design	Chinese and foreign model projects (Three Gorges Dam, Brooklyn Bridge）
	Project goal design	
Overall Project Planning	Legal systems synergism	Cross-boundary and cross-sea bridges
	Investment and financing model selection	
	Bridge location and landing point design	
	Port mode planning	
	Chinese white dolphin protection	
Project Management Planning	High-quality bridge planning	Quality management principles (Deming)
	Bidding management planning	Large tender section management (High-Speed Rail)
	Information system design	Information system (Nuclear Power)
	Quality management planning	Lean manufacturing (Toyota)
	HSE management planning	HSE system (Petrochemical)

Table G.2 IKS in operation

IKS Process	IKS Content	External Organizations
Integration of Management Resources	Design of bidding contract mode for the island tunnel project	Hong Kong government project Oresund Tunnel (Denmark, Sweden) Jujia sea-crossing bridge (South Korea)
	Risk control of the island tunnel project	TEC (Netherlands)
	Multi-bid system integration of traffic engineering	High-speed rail (China)
	Bridge maintenance and rescue equipment configuration	Tsing Ma Bridge (Hong Kong China)
	Bridge health and cost optimization	Akashi Kaikyo Bridge (Japan)
	Cross-border collaboration	Cross-Border Project Operation Coordination (Singapore & Malaysia)
	Operation system establishment	Shanghai Yangtze River Tunnel and Bridge (China) Donghai Bridge (China) Hangzhou Bay Bridge (China) Taizhou Bridge (China) Humen Bridge (China) Sutong Bridge (China) Qinling Zhongnanshan Tunnel (China)
	Core business operation model	Mixed model (Highway, bridge, and tunnel project in Canada and USA) Self-operated model (Qinling Zhongnanshan Tunnel)
	Partnership cultural cultivation	Chesapeake Bay Bridge (USA)
	Brand building	Gwangan Bridge (South Korea)
Integration of Key Technologies	Island tunnel project: construction headquarters (Temporary project)	Haneda Airport (Japan)
	Island tunnel project: Immersed tube prefabricated framework production	Peri formwork (Germany)
	Island tunnel project: Jacking system	VSL technology (Switzerland)
	Island tunnel project: East-West artificial island fair-faced concrete buildings	Fair-Faced concrete (Japan)

IKS Process	IKS Content	External Organizations
	Island tunnel project: Standardized production of small components	Standardized prefabricated molds For small components (Japan)
	Island tunnel project: Rebar processing	Standardization of rebar processing (Japan)
	Island tunnel project: Final joint	Prefabricated final joint (Japan)
	Island tunnel project: Factory production of immersed tubes	Oresund Tunnel (Denmark, Sweden)
	Island tunnel project: Weather window settings	Ocean forecast (China)
	Island tunnel project: Deep sea docking	Aviation metrology (China)
	Bridge project: Intelligent manufacturing of steel box beams	Steel component processing and manufacturing equipment (Japan)
	Bridge project: Optimized steel box girder U-RIB design	Steel box girder design (Japan)
	Bridge project: GMA pouring asphalt technology	GA (Germany, Japan) and MA (UK) technology
	Bridge project: Rapid maintenance plan	Hanshin Expressway: Honshu-Shikoku Line (Japan)
Formation of Standard Institution and Management System	Guidelines for special design criteria (Special design guidance manual) Guidelines for special construction standards, quality inspection, and evaluation standards (Special construction and quality management manual) Guidelines for special operation and maintenance standards (Special operation and maintenance manual) The HZMB preliminary work coordination group office system The HZMB main project operation management system	Policies and regulations of the Mainland, Hongkong, and Macau; British Standard; West Skelt Tunnel (Netherlands)

Appendix H. IKS and innovation capability enhancement in HZMB projects

Example description	Concepts		
	Level 1	**Level 2**	**Level 3**
"We are still confused about many issues, such as 'What is the value of the HZMB project?', 'Can it meet the social and economic development needs of the three places?', 'How much will this project cost? Can we get the expected benefits?'. There are no answers at present, and we need further exploration." (PR09/PUB01)	Cognitive ambiguity in project necessity	Cognitive Ambiguity	Practical challenges
" 'What environmental, economic, technological, resource, legal and other issues will the bridge encounter during its delivery?', 'As a large-scale project that spans 'one country, two systems, and three places, will the bridge have institutional and legal difficulties?', 'Is our current environmental, economic, and technological preparation feasible?', 'Can we deal with those problems that will arise?'. These problems are not clear in our cognition." (PUB01/PUB02)	Cognitive ambiguity in project feasibility		
"In the preliminary stage, the scope of the bridge project was very vague, the specialties were complicated, and the procedures were numerous. There were many organizational interfaces in each sub-project. Different specialties constituted a complex project sub-system. Inextricable links exist among sub-systems." (MG01/IL04)	Complexity in managing interfaces	Complexity of Objects	
"The HZMB project needs to solve too many technical problems, especially the 6.7-kilometer island tunnel project, which is the longest in the world, with the deepest buried under the sea, the largest single immersed tube volume, the longest designed service life, and the widest tunnel lane. Lots of technical challenges can be imagined." (PUB01)	Complexity in technical		

Example description	Concepts		
	Level 1	**Level 2**	**Level 3**
"The natural conditions of the Lingdingyang sea area where the bridge is located are variable and influenced by storms, tsunamis, fog, white dolphins protection, etc., which have added too much difficulty to the project construction. From 2011 to 2017, typhoon defense has accumulated 38 times, 33,000 people have been evacuated, and more than 1,800 ships have been evacuated." (PUB02)	Natural environment variability	Environmental Variability	
"As a super system, the HZMB project integrates the world's first-class construction resources, which brings dynamic changes in the cooperative relationship between the participating parties in solving different problems at different times and scenarios. The difficulty in interorganizational coordination is high...." (MG01/IL02)	Organizational environment variability		
"In the preliminary stage, the technology of new energy vehicles is immature, but in the operation stage, the demand for charging is increasing with the popularity of new energy vehicles. These technological developments are unpredictable, which brings great uncertainty and difficulty for bridge operation". (IN06/PR07/IL03)	Uncertainty of technical need development	Uncertainty of needs	
"Affected by cross-border traffic policies and the epidemic, the traffic flow of the HZMB Bridge was lower than expected. To increase operation incomes and obtain comprehensive development, we are mining its social value and building a world-class operating brand in tourism, cultural, and creative businesses." (IN04/ PR07)	Uncertainty of changes in social needs		
"We conform to project vision and goal through literature study and project inspection. For example, the Brooklyn Bridge is a world-famous bridge in the Bay Area, and Dujiangyan is a water conservancy project that has continued to function for over 2,000 years. These projects can help us clarify our project vision and goals..." (PR02)	Project vision and goal design	IKS in tactic	IKS strategies

Example description	Concepts		
	Level 1	Level 2	Level 3
"We conducted a series of on-the-spot legal investigations, participated in legal seminars, and introduced legal counsel to clarify potential legal issues and countermeasures. We designed multiple alternative schemes for each issue, such as bridge design blueprints, project financing schemes, project technical standards, and the design of port border inspection. We then picked the optimal one that met both the legal requirements of the three places and project feasibility and implementation efficiency". (PR07/IL03)	Overall project planning		
"Complex weather conditions such as typhoons, rainstorms, high temperatures, and torrents often occurred during the construction stage. Construction sites were in the protected area of the Chinese White Dolphin. In addition, construction projects include intensive high-altitude, water, flammable, and explosive operations. These objective conditions are common in the petrochemical industry. Therefore, we launched a project inspection and conducted IKS with consultants in the petrochemical industry at the beginning to obtain occupational health, safety, and environmental (HSE) management experience and build a high-standard HSE management system. The system plays an important role in preventing safety incidents and decreasing safety risks during construction. Besides, various forms of cultural salons and bridge lecture halls were also held to make everyone acknowledge that safety must go first in the project" (PR10/PUB06)	Project management planning		
"The problem of bridge deck paving is a long-standing problem in bridge construction. The widely used pouring concrete technologies worldwide include GA in Germany and Japan and MA in Britain, but these two technologies are rarely used in our country. After a series of project inspections, market research, and special research, we finally combined the advantages of MA and GA technology and innovatively applied the new technology of GMA pouring asphalt." "The final design joint of the bridge's immersed tunnel is based on Japan's overall prefabricated installation joint. Unlike Japanese technology passively using water pressure to achieve water-stopping, the HZMB project realizes compression and water-stopping through actively controlled jacks, realizing great innovation." (IN02/PR01/PR02/PR04/PR05)	Integration of management resources	IKS in operat ion	

Example description	Concepts		
	Level 1	**Level 2**	**Level 3**
"To avoid the problem of *management fragmentation* caused by *transition split*, the bidding planning of the HZMB project is original from the experience of high-speed rail construction to conduct large bidding sections and prompt first-class designers and contractors to increase their resource investment. The idea of "Design-construction linkage, construction-driven design" is completely encouraged to realize the "design-construction cooperation" goal. Based on the dynamic project delivery model provided by the owner, the island tunnel project has achieved great success." (PR09/PR10/IL01/IL02/IL03)	Integration of key technologies		
"Our design standards are determined after investigating several typical projects around the world and fully absorbing the latest methodologies and standards worldwide. For example, we refer to the British standards and principles in bridge design, loads, prestressing, lighting, etc." (IN04/PR06/PR07/IL02)	Formation of the standard institution /management system		
"Through a series of inspections and screenings, we finally determined our project vision: bridging the Lingdingyang sea area of 'one country, two systems and three places' in economy, culture, and psychology, and promoting Hong Kong, Guangdong, and Macao becoming world-class regional centers. The construction goal is designed as 'building a world-class cross-sea passage, providing users with high-quality services, and becoming a landmark building'". These slogans indicate that we are conducting an extraordinary project. When everyone obtains the motivation and finishes their jobs well, the HZMB project is deemed successful..." (IN03/NR01)	Project vision and goal design capability	Institutional Innovation Capability	Innovation Capability Enhancement
"Three different administrative and legal systems are implemented in three regions of the same country, which makes the overall planning of the decision-making process of the HZMB project extremely complicated. By referring to similar megaprojects, a 'three-level governance system: task force (led by central government)—joint working committee of the three regions (led by local governments)—project legal (i.e., the HZMB Authority)' and the implementation plan of 'territorial division, joint investment, and unified construction' is established by the central government." (PUB04)	Project governance capability		

Example description	Concepts		
	Level 1	**Level 2**	**Level 3**
"The in-depth legal research in the early stage provided the governments of the three places with legal analysis opinions on the legal framework of the region where the HZMB project is located and the setting mode of the project management mechanism, which ensured the smooth progress of the HZMB project from the legal level and avoided invalidation and absence of investment and management." (PUB03)	Legal systems synergism capability		
"The bridge adopts the model that the governments of the three places jointly undertake the full funding. After several rounds of study and discussion, we compared the three mainstream investment and financing models (i.e., government investment, BOT, and PPP) to select the best solution." (PUB03)	Investment and financing model innovation capability		
"As for the division of bridge bids and the contracting model, we take measures to adapt to the actual situation and conditions in multiple aspects, such as risk situation, professional characteristics, and market conditions. For example, the traffic engineering sub-project adopts a comprehensive and integrated bidding and contract mode, and the bridge engineering sub-project adopts the separation of design and construction." (PUB04)	Flexible bidding and contract model innovation capability	Business Innovation Capability	
"to explore the operation and management mode of the HZMB project, we have comprehensively learned from the *market-based* commissioned operation management mode of Canadian highways and tunnels and the *self-operation* management mode of American highways and tunnels. The *market-based* mode could lead to the problem of 'the managers are ultimately controlled by the managers', while the *self-operation* management mode would increase the cost and bring poor efficiency. By view of how to keep the balance in the Qinling Zhongnanshan Tunnel, we make progress in confirming the core technology self-management and preventing potential management risks brought about by excessive marketization." (PR06/PR07)	Hybrid business operation capability		

Example description	Concepts Level 1	Level 2	Level 3
"Gwangan Bridge provides an excellent example for us in project commercial brand building where comprehensive development is carried out by maximizing the excavation and development of the bridge brand. Large-scale social events in Busan City (such as bicycle races and fireworks evenings) are often held at Gwangan Bridge. At the same time, The Guang'an Bridge is also an important tourist attraction during peak tourist seasons (such as the Busan Film Festival). Through the international operation of the bridge brand, the value of the bridge is being explored, and the relationship between the bridge and the public is also closer. The investment in the HZMB project is huge. On the one hand, by exploring the brand resources of the bridge for comprehensive development, such as tourism, exhibition, advertising, and cross-border logistics, the financial expenditure and burden of the three governments are reduced; on the other hand, based on the core technology and management experience in brand building accumulated in the HZMB bridge provides strong support for the future projects through technical consultation, which endows the HZMB project with more social value." (PR06/PR07/PR10/IL03)	Business brand building capability		
"the compacting sand pile technology is mature in Japan but has not been used in domestic projects. The HZMB project owner invited experts to share their experience and conduct training on parameter settings to adapt to environmental changes through pile tests. Finally, this technology was successfully applied and created a new record of 64 piles in a single day..." (PR08/PR09/ MG01)	Mature technology improvement capability	Technical Innovation Capability	
"The prefabrication of the immersed tunnel section of the bridge abandons the traditional and inefficient 'dry docking method' and draws on the experience of the Oresund Tunnel (the first project in the world to prefabricate the tunnel section by the factory method). The factory producing prefabricated immersed tubes is set on Guishan Island, 10km away. The production efficiency and quality of pipe in the proper indoor environment have been significantly improved. A breakthrough in the prefabrication technology of curved immersed tubes has been achieved for the first time, reaching the goal of a million cubic concrete without cracks and creating a project miracle forming a complete technical system for the construction of offshore immersed tunnels with independent intellectual property." (PR01/PUB07/MG01)	New technological breakthrough capability		

Example description	Concepts		
	Level 1	**Level 2**	**Level 3**
"The prefabrication of pipe sections in immersed tunnels is not a single technological innovation, but an integrated application of individual technologies and re-innovation. Developing many special supporting technologies and integrating these professional technologies that affect large-scale equipment is necessary." (IN01/PR03/NR01) "In terms of cross-border collaborative management, we draw on the experience of Singapore and Malaysia to utilize advanced technologies, such Internet of Things, big data, and artificial intelligence, to integrate multiple systems, such as passenger information and action record systems, self-check customs clearance systems, bubble detection systems, motorcycle biometric authentication automatic customs clearance systems. Hence, an intelligent operation and maintenance platform was built to improve the fast-moving capabilities of the three places, realize data and service sharing, and increase technology application experience." (PR08/AL01/IL01)	Multi-source technology integration capability	Managerial Innovation Capability	
"In the design stage, the excellent practices of other industries were referenced in advance to increase project management and planning capability to reach the goal of building a high-quality bridge through optimizing project quality management, information construction, bidding management, and HSE management'" (MG01/IL02)	Project Planning capability		
"The HZMB project appeared to top suppliers in the international market, formed cross-time and cross-regional IKS, and integrated their advantages in management or technology to avoid decision-making biases caused by cognitive limitations. Since some foreign companies with rich experience in megaproject management do not have the required qualifications, they cannot directly and dependently undertake consulting tasks. The consortium mode was creatively applied in the HZMB project, where multiple organizations could jointly participate in bidding and develop their strengths to cope with project complexity. For example, Shanghai Municipal Engineering Design and Research Institute established a consulting consortium with Dutch TEC Tunnel Engineering Consulting Company, TYLI International Group, and Guangzhou Metro Design and Research Institute in the island and tunnel project. Among them, Holland TEC Tunnel Engineering Consulting Company has rich experience in bridge and tunnel project risk management."	Global business resource integration capability		

Example description	Concepts		
	Level 1	**Level 2**	**Level 3**
"We invited engineering consulting companies with experience in engineering management and risk management from abroad to introduce the best risk management practices to the HZMB project. For example, from the end of 2008 to September 2011, TEC submitted six consultation reports to emphasize the risk of tunnel flooding and highlight the influence of sea level rise caused by climate change. Finally, a special design change consultation meeting was held in June 2014, based on which the height of the artificial island wave retaining wall was increased. The north side of the east island was adjusted from 6.2 to 8 m, and the south side from 7 to 8.5 m. The north side of the west island was adjusted from 6.5 to 8.5 m. and the south side from 8 to 9.5 m. The artificial island has withstood the test of super typhoons such as "Hato" in 2017 and "Mangosteen" in 2018." (MG01/IL02)	Project risk management capability		
"We have learned from the operation and management experience of the Chesapeake Bay Bridge and called for a lasting and dedicated work atmosphere and project culture. The Chesapeake Bay Bridge has maintained a stable organizational structure since its opening in 1964. There is little change in organization structures, from 167 persons at the beginning to 159 at present. Their intercom, lighting, ventilation, and other systems are checked 6 times a day, and backup power is checked once a month. The 50-year-old computer room is still kept clean and tidy. The tunnel's high-power ventilation and air quality inspection systems operate normally to keep the air quality well." (PUB03/IL01/IL03)	Project culture shaping capability		
"The owners of the HZMB fully study and practice the *partnership* based on the characteristics of the consortium, put forward the vision of 'openness, compatibility, pragmatism and innovation, harmony, and win-win', and constantly improve the communication mechanism, and set up an efficient communication platform to encourage organization member to express their opinions and advice fully..." "We thoroughly learned from and implemented the 'partnership' with others all the time. We tried to jump out of the traditional principle of *Party A's advantage* and adapt to the principle of fairness in the design of the selection scheme and the setting of the contract terms to allocate the project risks reasonably and leave the risks to the contracting party that is most conducive to risk management and control..." (PUB06/IL04)	Alliance and partnership cultivation capability		

Example description	Concepts		
	Level 1	Level 2	Level 3
"In the preliminary stage, the project owner, as the *leader* of the innovation alliance, crossing the river by feeling the stones, constantly learned from other industries and megaproject experience and fully absorbed external resources and information. A series of major issues such as the port model, investment and financing model, and protection of Chinese white dolphins have been reached among the three governments, which has accelerated the decision-making process of the project..." (IN06/IL02)	Lead IKS activities and conduct *Hub-and-spoke governance*	Leader	Role of Owner
"In the construction stage, the project owner plays the role of *coordinator* in the HZMB project innovation alliance, which is different from its strong position in the organization and cooperation in the early stage, to fully mobilize the enthusiasm and give more autonomy to other stakeholders, grasp the allocation of resources as a whole, and improve the overall project performance..." (IN03/IN05/IL04)	Coordinate IKS activities and conduct *polycentric governance*	Coordinator	
"At this stage, the HZMB owner has further weakened its advantages in the cooperation between the participating parties to be a *supporter* to respect the law of market competition and guide proper competition and cooperative relationship between the participating parties. Besides, the owner also advocates for sharing resources and information on the project, giving more autonomy to the market, supporting the integration of demand and demand suppliers in the market, and promoting the project's steady development." (IN05/MG01/IL02)	Support IKS activities and conduct *shared governance*	Supporter	

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