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Exploring Decision-Making Complexity in Major Infrastructure Projects: A Case Study From China

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Abstract

The goal of this study is to identify, classify, explore, and understand decision-making complexity elements in major infrastructure projects (MIPs). This article puts forward systematic definitions of decision making, decision-making quality, and decision-making complexity. Based on literature reviews and an in-depth case analysis of Hong Kong-Zhuhai-Macao Bridge (HZMB), a comprehensive framework of decision-making complexity is developed, which divides the elements into six dimensions: technical, social, financial, legal, organizational, and time. The links between different dimensions are also illustrated. This article is expected to deepen our current understanding of decision-making complexity and to provide a fundamental point of reference in the front-end phase of MIPs.

Keywords

decision making, complexity, major infrastructure projects, case study

Introduction

As the construction of major infrastructure projects (MIPs) continues to spread at high speed across the world, the complexity of MIPs typically attracts a high level of interest among both project practitioners and researchers due to its significant and far-reaching impact on the regional socioeconomic environment (Salet et al., 2013). The MIPs referred to in this article cover different kinds of infrastructure, such as long bridges, subways, and railways, and are usually large-scale construction projects with long life cycles, multi-stakeholder participation, and complex environmental conditions (Salet et al., 2013; Sheng, 2018b). Decision making in MIPs is a difficult and important issue in project management, wherein making decisions adequately could account for the differences between success and failure (Jato-Espino et al., 2014). Therefore, the question of identifying and characterizing decision-making complexity becomes increasingly important. Whereas an increasing amount of literature focuses on project complexity, attention to decision-making complexity is lacking.

In practice, it is not uncommon to find that neglecting the overall and systematic analysis of decision-making complexity has led to unfulfilled functions and objectives of MIPs, and furthermore, has posed great danger to socio-economic and natural environments (Sheng, 2018c). For instance, in the decision making with regard to the reservoir water level in the case of the Sanmenxia Dam of China, complex interdependencies with sedimentation problems upstream were overlooked, resulting in sediment accumulation that caused severe flooding of the Wei River upstream (Wang et al., 2005). Another example is the Karakum Canal, in the former Soviet Republic of Turkmenistan, which is seen as a major factor contributing to widespread soil salinization problems, including the Aral Sea environmental disaster, mainly because of deficient understanding of the Amu River's diversion efforts (Glantz et al., 1993). These examples illustrate that there is an unfulfilled practical need for the systematic and exhaustive identification, classification, and understanding of decision-making complexity, as this will be able to provide a fundamental reference for decision makers to avoid irreversible consequences.

Over the past few decades of academic research, considerable efforts have been devoted to project complexity, predominantly focusing on project complexity definition, identification, classification, sources, assessment, and management (Dao et al., 2017; Shi et al., 2018). However, the increasing importance of decision making appeals to the emphasis on refining project complexity

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into specifically decision-making complexity (Dimitriou et al., 2012; Samset & Volden, 2016; van Marrewijk et al., 2008). Decision making in MIPs, particularly the unstructured, macro-level decision-making issues, such as project approval, financial mode selection, construction scheme selection, and so on, are a type of complex and core management activity with important strategic and overall significance (Hu et al., 2015; Priemus et al., 2008). This complex decision making involves multiple factors and complex relationships between elements, with the characteristics of deep uncertainty and multi-scale complexities. In fact, decision making is becoming more challenging than ever due to the continuously increasing scale of construction, dynamic environments with many stakeholders, increasing legislation, and technical complexity of MIPs (Bosch-Rekveldt et al., 2011; de Miranda Mota et al., 2009; Thomas & Mengel, 2008). One of the reasons for project failure would be the increasing complexity of decision making, or a lack of systematic and long-term strategic views on decision-making complexity. However, previous studies on decision-making complexity are fragmented, and are generally inclined to select a limited number of decision-making complexity elements for analysis, rather than attempting systemic classification and analysis. Decision-making complexity has been treated as a sort of black box; the definition and the factors that increase decision-making complexity have not been further detailed. Hence, traditional complexity theory, which focuses on the conceptual framework of project complexity (Chapman, 2016; Maylor et al., 2008; Sinha et al., 2006), is faced with a theoretical gap or tension with regard to describing decision-making complexity in the context of project complexity.

This article aims to propose a comprehensive framework to identify, classify, explore, and understand decision-making complexity in MIPs. Additionally, the aim of the article is to highlight the imperative that project investors and managers need to understand and pay closer attention to decision-making complexity. The goal was achieved by attaining two specific objectives: (1) clarifying the conceptual background of decision making, decision-making quality, and decision-making complexity; and (2) identifying the numerous interdependent elements that contribute to decision-making complexity, as well as classifying these into different dimensions. The study of decision making in MIPs needs to be carried out from a comprehensive point of view, taking dynamic evolution and development into account. We intend for the framework proposed in this article to be used as descriptive guidance for decision makers in MIPs. Rather than describing the elements of decision-making complexity, this article emphasizes the links and development between complexity dimensions, and analyzes decision-making complexity in stages, providing a comprehensive analysis method for academic research. The contribution of this article is to fill the gap in existing research that confuses decision-making complexity with project complexity, to focus more on the complexity of decision making in MIPs, to extend project complexity into decision-making complexity, and to enrich the theoretical context of complexity and decision making, as well as to provide a reference value for the front-end decision-making phase of MIPs. The comprehensive framework will provide a solid foundation for researchers and practitioners in related topics and fields.

Conceptual Background

Decision Making

In the development of behavioral decision theory, Simon (1956) pointed out the nature of its needs and environment creates a very natural separation between "means" and "ends." Based on that viewpoint, we consider decision making as a broad and comprehensive concept, which comprises more than simply making a selection from a list of alternatives (Rolstadås et al., 2015). More synthetically, decision making is a combination of process and outcome, which refers to the process when, after identifying problems, analyzing, developing, assessing, and choosing, the final scheme comes into being (Bakht & El-Diraby, 2015; Rolstadås et al., 2014, 2015). In the field of project management, decision making implies the process of making choices on issues related to project planning, bidding, construction, operation, and so forth, as well as the generated outcome, which is influenced by integrated consideration in the process. Therefore, this article defines decision making in MIPs from the perspective of a combination of process and outcome, with a focus on the hierarchical mega decisions. The elaborated definition for decision making in MIPs, as used in this article is:

> the interactive process in which integrated considerations lead to long-term strategic and short-term operational choices on essential issues in the front-end phase of MIPs, which have a profound influence on the whole life cycle of the MIP. The outcome selected from multiple alternatives is the decision-making scheme in MIPs, which consists of decision objectives, variables, values, measures, and criteria. The decision-making outcome is the final "product" of the decision-making process, which has a strong dependence on the decision-making process.

Subsequent research in the article is all related to this definition.

Decision-Making Quality

System identification of decision-making complexity can enable decision makers to reduce decision-making mistakes. This reflects the awareness of decision-making quality. Traditional product quality refers to the physical properties and the durability and stability of the direct use function of the product. The product of decision making for MIPs refers to the decision-making outcome; in other words, the final selected decision-making scheme. The decision-making scheme is a manufacturing process that leads to a result. Meanwhile, originating from Simon's definition of decision making, we treat decision-making quality from two perspectives based on the behavioral decision theory, namely the quality of the process that is applied to create the decision-making scheme and the decision-making scheme quality itself. That is, decision-making quality could be perceived from the perspective of a combination of process and outcome (Froschauer, 2010; Sheng, 2018c). The quality of the decision-making process involves the decision-making organization, procedures, hierarchical principal-agent relationship between decision makers, and behavioral norms, all of which refer to whether the decision-making process is legal, open, transparent, and enabling public and expert participation, and whether there is information loss, information monopoly, and behavior variation. The quality of the decision-making outcomes is reflected in the robustness of the decision-making scheme regarding the changes and evolution of construction scenarios (Sheng, 2018c). Regarding the evaluation of decision-making quality, under the premise of paying attention to the actual objective function and effect of the decision scheme when solving the decision problem, the decision makers' degree of satisfaction and values and intentions can be considered. Even if the decision-making scheme has been formed and has met with the satisfaction of decision makers, some hidden and potential problems are still likely to emerge. This indicates that the evaluation of the decision-making quality—that is to say, whether the decision scheme is reasonable and effective, whether it is stable in the whole process, whether it satisfies the needs of the people, and whether the degree of satisfaction is sufficient—should be derived from the practical test.

Decision-Making Complexity

With the increase of complexity of major infrastructure projects (MIPs), complexity analysis and management have become a focal point in the field of major infrastructure management research (Bakhshi et al., 2016; He et al., 2015; Lee et al., 2018; Qazi et al., 2016). Researchers also argue that complexity should be considered as integral to the decision-making process (De Bruijn & Leijten, 2007; Giezen, 2013), which also means that the consideration of complexity should be at the heart of decision making (Giezen, Bertolini, et al., 2015; Giezen, Salet, et al., 2015). Given the significant importance of decision making in MIPs, identifying and exploring the decision-making complexity is crucial to improving the decision-making quality.

Decision-making complexity is the complexity of decision-making activities, which is an extension of project complexity. Unlike project complexity, decision-making complexities refer to a set of features within the decision context that make the decision-making complex. More accurately, decision-making complexities are assumed to comprise the uncertainties and ambiguities, as well as the difficulty and confusion in dealing with various influencing factors and complex interrelationships in wide-range and high-level decision-making issues (Sheng, 2018a). On the one hand, in the front-end phase of MIPs, decision-making issues are usually characterized by various wide-range, high-level influencing factors and complex interrelationships (Jato-Espino et al., 2014; Książek et al., 2015), increasing the complexity with regard to making decisions. On the other hand, the decision-making process should be understood as a behavior chain of a self-adaptable organization that is composed of multiple subjects and a complex system, rather than a set of activities comprised of normative and procedural steps. This means that the decision-making process is composed of numerous decision-making complexities (Sheng, 2018c). Moreover, as Simon (1972) indicates, decision makers are rationally bound by incomplete information; decision-making complexity can be perceived as the rational boundary and as the obstacle that prohibits formally rational (i.e., optimizing) decision making. That is to say, when decision makers feel it is difficult to state the issue clearly, analyze thoroughly, and predict accurately, and are unable to propose a solution to solve these issues, the attribute of the complex understanding on the rational boundary and decision context can be perceived as decision-making complexity. In order to minimize the effect of bounded rationality on making long-term decisions, this study will identify the sources and elements of decision-making complexity as much as possible.

As Daniel and Daniel (2018) pointed out, the project management literature looks at complexity from two perspectives: deterministic and non-deterministic. They also divided complexity into structural complexity and dynamic complexity, based on systems theorists. Similar to Daniel and Daniel (2018), Hertogh and Westerveld (2010) used the distinction in detail and dynamic complexity to describe deterministic and non-deterministic features of project management. Our research focuses on decision making in MIPs, with decision making as a combination of process and outcome, which is not only a static notion, but also a dynamic notion (Chapman, 2016; Luo et al., 2017). It is possible to distinguish between a static and a dynamic perspective with regard to decision-making complexity, using two attributes for decision making. Detail complexity describes the deterministic complexity of decision making, and often has more influence on decision-making outcome. Dynamic complexity describes the evolutionary and non-deterministic complexity, and often has more influence on the decision-making process. More specifically, detail complexity refers to the number of components with a high degree of interrelatedness, which is mainly associated with the physical and information features of a project, such as project size, number of stakeholders, location, and environment. Detail complexity is complicated, but it is always describable, knowable, and predictable. It depends on project scope, objectives, and characteristics (Zhu & Mostafavi, 2017). Dynamic complexity refers to situations where cause and effect are subtle, and where the effects of interventions are changing over time (Hertogh & Westerveld, 2010). In MIPs, dynamic complexity is mainly related to the non-predictable, non-linear, and interactive nature of projects, which changes over time and cannot be evaluated in the beginning of decision making (Zhu & Mostafavi, 2017).

Research Methodology

In order to develop a comprehensive framework to identify, classify, explore, and understand decision-making complexity in MIPs, both an inductive literature review and a deductive case study were used to investigate decision-making complexity and gain new insights with regard to complexity theory, through systematically analyzing and classifying the elements of decision-making complexities, linkages, and interactions between complexity dimensions. The research steps are as follows: First, a literature survey was performed in which the dimensions of decision-making complexity were analyzed and the corresponding elements were gathered that are assumed to contribute to decision-making complexity. Second, a case study of Hong Kong-Zhuhai-Macao Bridge (HZMB) in China was introduced, identifying the decision-making complexity elements from the interview, document analysis, and observation. In particular, the interviewees were not aware of the literature analysis results, which can strengthen the empirical evidence (Bosch-Rekveldt et al., 2011; Yin, 2013). The decision-making complexity elements gathered from HZMB were refined to make it suitable, universal, and applicable to general MIPs. The case study was mainly used to identify and validate the dimensions and elements of decision-making complexities and then explore the relationships between the different dimensions of decision-making complexities. Next, the results from the literature analysis and case study were used to develop a comprehensive framework of decision-making complexity. Therefore, our research intends to enrich the theoretical context of complexity and decision making based on the philosophical lens of instrumentalism.[1]

A search for relevant publications was performed in the literature review, using several web-based academic databases, (e.g., Web of Science, Science Direct, Scopus, and Google Scholar). Sufficient attention was paid to the reputable journals in the field of project management, such as the *International Journal of Project Mangement*, *Project Management Journal®*, *Journal of Management in Engineering*, *Journal of Construction Engineering and Management*, among others. The reviews focused predominantly on articles published in the past 20 years and those that have been cited most frequently. Our research questions were broken down into three key phrases, including decision making, complexity, and major infrastructure project. As the literature closely related to this topic is limited, the key terms were extended to inlcude decision, project, and complexity, which were then searched for in pairs in the academic databases.

A case study approach can take an exploratory view, conduct an in-depth examination of the contextual information, and uncover a new topic from an original perspective (Wu et al., 2016); therefore, a case study method was adopted for this research (Eisenhardt, 1989; Yin, 2013). Our case study focuses on the Hong Kong-Zhuhai-Macao Bridge (HZMB) in China. This case was introduced to help establish and validate the decision-making complexity framework, followed by an exploration of the relationships between the different dimensions of decision-making complexities. Why was the HZMB project chosen? The HZMB project is the largest bridge with the highest investment to date in China. As such, this project provides a wealth of new details with regard to complexity. In addition, this project is the first MIP to be developed jointly by the three regional governments under the policy of: "one country, two systems." Thus, decision making in HZMB is complex in the cross-border context, especially where policy making, finance, and legislation intersect, which could gain new insights into and understanding of decision-making complexity. The case selection meets the requirement of: "If it is valid for this case, it is valid for all (or many) cases" (Flyvbjerg, 2006).

Methods for data collection included semi-structured narrative interviews, document analysis, as well as the authors' observations. The three co-authors worked on one of the largest consulting teams for HZMB from 2007 to 2016. And two co-authors devoted themselves to the fundamental theory research of project complexity over the past 10 years. The authors have a comprehensive and profound understanding of the specific case of HZMB, as well as complexity theory, while a large amount of project data and information has been collected for this study. Face-to-face interviews were conducted with 10 experts who were involved with the decision-making process of HZMB. Two of them have over 20 years of bridge construction and management experience, three of them have 15 to 20 years of management experience, and the remaining five experts have 10 to 15 years of management experience. Ten interviewees are all senior managers in the HZMB organization, who have played an important role in the construction phase (as planning manager, contract director, etc.). The interviews focused on stories and recounting of past events, especially focusing on what crucial complexities had been encountered in the front-end phase of the project. The topics covered timeline, critical issues, influencing factors, complexity elements, and interactions. The information gathered from these interviews was subsequently fortified by means of detailed document analysis, including feasibility reports, annual memorabilia, monographic research reports from professional institutes, official letters and email messages, public records, news and trade publications, and more.

The deductive data analysis was then used in the case study. We conducted our analysis in four steps. In the first stage of our analysis, the decision-making process of HZMB was sorted out and distinguished into four rounds, starting and ending with main events, in accordance with the bridge memorabilia and rounds model (Teisman, 2000). The rounds were validated by the approval of the director and the planning manager. During the next stage, we conducted an in-depth gather and extracted decision-making complexity elements in each round from interviews and documents, which were then classified into six dimensions and distinguished based on detail and dynamic attributes. Next, the linkages of the complexity dimensions were illustrated and theorized based on the detailed case of

Table 1. Project Complexity Frameworks

Author(s), Year	Dimensions
Baccarini (1996)	Organizational complexity, Technical complexity
Girmscheid and Brockmann (2008)	Overall complexity, Task complexity, Social complexity, Cultural complexity
Hertogh and Westerveld (2010)	Technical complexity, Social complexity, Financial complexity, Legal complexity, Organizational complexity, Time complexity
Wood and Ashton (2010)	Organizational, Planning and management, Operational and technological, Environmental, Uncertainty
Bosch-Rekveldt et al. (2011)	Technical complexity, Organizational complexity, Environmental complexity
Geraldi et al. (2011)	Structural complexity, Uncertainty, Dynamic, Pace, Socio-political complexity
Dunović et al. (2014)	Structural complexity, Uncertainty, Constraints
Nguyen et al. (2015)	Socio-political complexity, Environmental complexity, Organizational complexity, Infrastructural complexity, Technological complexity, Scope complexity
Chapman (2016)	Finance complexity, Context complexity, Management complexity, Site complexity, Task complexity, Delivery complexity

HZMB. And finally, the results were reported back to the interviewees and validated by their approval.

Dimensions of Decision-Making Complexity

Decision-making complexity dimensions stem from different sources of decision context, and each dimension has its own features. For example, let us look at the Channel Tunnel project, which is a railway tunnel connecting Britain and France. As the world's second longest undersea tunnel and longest seabed railway tunnel, its size and seabed safety design place high requirements on technical experience, making decision making in technical issues complex. In addition, financial problems have also become key to implementation. The use of private capital has made the coordination of market operations and the administrative management of government departments difficult. In order to guarantee the legal context for cross-border decision making, the governments of Britain and France signed the Treaty of Canterbury. As MIPs would be facing technical, financial, organizational, legal, and other complexities in decision making, the dimensions and corresponding elements needed to be explored.

Previous studies on decision-making complexity are fragmented, with most studies focusing on a framework of project complexity. This article compares a number of existing, most recognized frameworks with regard to project complexity dimensions, as shown in Table 1. Based on these studies, the dimensions and characteristics of complexity in different types of MIPs have been analyzed by some authors, such as in transportation projects (Chapman, 2016; Favari, 2012; Nguyen et al., 2015) and city-level multiprojects (Li et al., 2015).

Some scholars have attempted to identify the sources of decision-making complexities. Flyvbjerg et al. (2002) and Meyer (2014) proposed the optimism bias of the decision makers as a source for decision-making complexities, leading to poor decision making. Altshuler and Luberoff (2004) considered that only few decision-making schemes made an impact on the surrounding economy and environment. Short and Kopp (2005) pointed out that the opacity of information was one of the main causes of decision-making complexities. Also, some scholars have further attempted to summarize the dimensions of decision-making complexities. Based on a study of 60 cases, Miller et al. (2001) summarized that decision-making complexities stem from technical, market related, political, social, economic, and other aspects. Priemus (2010) concluded there are six pitfalls in decision making, identifying them as lack of problem analysis, lack of project scheme, ambiguous objective, flawed process architecture, vague functional requirements, and dissemination of contested information. And Jankovic et al. (2010) proposed a model of decision-making complexity that comprises four aspects: objectives, process, environment, and transformation. Sheng (2018a) presented four aspects of the origination of management complexity: social economic environment, multi-agent construction, deficient synthetic ability of subject resources, and integration of construction.

Based on these reviews of decision-making complexity, and adapted from the research of Hertogh and Westerveld (2010), this article proposes six dimensions of the decision-making complexities: the technical, social, financial, legal, and organizational dimensions, as well as the dimension of time.

Technical Complexity

Technology is identified as an important source of decision-making complexities. The technical aspect includes many factors contributing to decision-making complexity, including mega-sized products (scope); uncertainties about geology and innovations (Hertogh & Westerveld, 2010); lack of technology experience or decisional capacity (Baccarini, 1996; He et al., 2015); diversity of decision-making issues and tools (Jato-Espino et al., 2014); interdependency between decision-making issues, teams, and technology (Baccarini, 1996; Lu et al., 2015); different technical standards; technical issues innovation (Vidal & Marle, 2008); lack of appropriate decision-making schemes (Priemus, 2010); approval of unproved technologies; controllability of technology (Li et al., 2015); technology uncertainty, such as underground construction; and extreme weather conditions (Li et al., 2015).

Social Complexity

Social complexity is the dominant and central complexity within MIPs (Hertogh & Westerveld, 2010). It refers to the complexity originating from different interests and preferences of a large number of stakeholders and the complex and dynamic context in which a project operates, as well as inconsistent cultures and changing financial requirements (Priemus, 2010; Wideman, 2004). Many scholars have proposed various elements of social complexity in managing projects. First, the decision making involves multiple stakeholders with different perspectives and conflicts of interests (Arroyo, 2014; Shan & Yai, 2011), therefore, the opinion divergence and different objectives tend to increase decision-making complexity (Jankovic et al., 2010; Książek et al., 2015).

Second, the decision-making issues are often multidisciplinary, making them too complex for decision makers to solve. One of the most important elements that affect decision-making complexity is difference in experience among decision makers, as well as their leadership skills, working background, and coordination skills (Jankovic et al., 2010; Lu et al., 2015). In addition, the elements of social complexity also include complex project location (Bosch-Rekveldt et al., 2011), uncertain interaction of different cultures (Girmscheid & Brockmann, 2008; He et al., 2015), conflicting and shifting preferences of stakeholders, changing environment and major impact on environment, transportation, and local society (Li et al., 2015).

Financial Complexity

Financial complexity in MIPs is related to cost calculation, financial control, management and accountability, and value for money (Hertogh & Westerveld, 2010). Through reviewing, we have found that financial complexity stems from high financial requirements (Hertogh & Westerveld, 2010), various investment sources (tax, appropriation, loan, bond, and private capital; Li et al., 2015), inadequate balancing of scarce resources, such as trade-off between cost and quality (Elonen & Artto, 2003), competition between investment demand and resource distribution (Kabir et al., 2014), inconsistent and changing financial requirements (Li et al., 2015), different calculation methods and difficulty of determining and managing the project costs and benefits (Hertogh & Westerveld, 2010), and optimistic/pessimistic bias (Flyvbjerg et al., 2002; Meyer, 2014).

Legal Complexity

The legislation and rules of the country have a significant influence on decision making in MIPs. It thus follows that legal complexity stems from lacking or immature laws and regulations (Hertogh & Westerveld, 2010); inconformity of laws and administrative powers between different decision makers; large numbers of laws and regulations; changing, nonexistent, and conflicting laws; difference in interpretation of legislation; and rules on the content and processes (Li et al., 2015).

Organizational Complexity

The decision-making complexity in MIPs is also manifested by organizational complexity. Organizational complexity does not only have to do with structuring the internal organization of the decision-making organization, but also, most importantly, with the division of responsibilities and positioning of the organization with regard to its principal and/or parent organization (Hertogh et al., 2008). As this is one of the most important elements of decision-making complexity, many scholars have paid it increased attention, putting forth several views on organization complexity, which encompass the following characteristics of complexity: organizational structure complexity (He et al., 2015; Li et al., 2015) and information complexity (Elonen & Artto, 2003; Jankovic et al., 2010).

Time Complexity

Compared to the other five types of complexity, time complexity is more abstract. It originates from the long duration of project planning and construction. Decision-making management may introduce numerous aspects of time complexity, such as long timeframe with continuous changes, uncertain impact of decision making because of changing society and environment, uncertainty about future selections, small fault tolerance (Hertogh & Westerveld, 2010), tight schedule and huge pressures from societal expectations (Li et al., 2015), and large numbers of concurrent issues (Bosch-Rekveldt et al., 2011; Hertogh & Westerveld, 2010).

Case Study: The Hong Kong-Zhuhai-Macao Bridge

Project Description

The Hong Kong-Zhuhai-Macao Bridge (HZMB) is one of the largest infrastructure projects in the world, connecting Hong Kong, Zhuhai, and Macao, three major cities in the region of the Pearl River Delta in China. The project aim was to increase land transportation between the western region of the Pearl River and Hong Kong, thereby promoting sustainable long-term economic growth of the Pearl River Delta. The HZMB consists of three major parts: the offshore main bridge; the boundary crossing facilities (BCFs) at Hong Kong, Zhuhai and Macao; and the link roads in these three regions. The combined total length of the offshore main bridge and tunnel is about 35.6 km, of which 6 km is in Hong Kong territory and 29.6 km is in the territory of Guangdong. The project adopted a scheme using a bridge-and-tunnel combination, of which the tunnel section was approximately 6.7 km long, and the bridge section was approximately 22.9 km. The HZMB was designed to have a service life of 120 years. The capital budget of the offshore main bridge (price level 2008) was US$2.25 billion, which was approximately 42% of the total cost of the main bridge. The capital was 100% publicly invested, jointly by mainland China (including Central People's Government support, US$1.0 billion), the Hong Kong Special Administrative Region (US$0.96 billion), and Macao Special Administrative Region (US$0.28 billion). The remaining 58% would be financed by loans.

Decision-Making Rounds in the Front-End Phase

In the case of the HZMB, a variety of crucial events happened that should be considered. This article distinguishes four institutional periods, starting and ending with main events:

Round 1—The Initial Plan of the Lingdingyang Bridge (1983–1998)

The cross-border bridge connecting Hong Kong and Zhuhai was first proposed by a businessman in 1983. Subsequently, the Zhuhai People's Government initiated the bridge's construction plan. The aim was to add a cross-sea passage between Zhuhai and Hong Kong. The Zhuhai People's Government was proactive in communicating and coordinating with the Hong Kong Government after the Engineering Feasibility Research Report had been finished by Zhuhai. The idea for the bridge was shelved after some time, partly because of a negative opinion that was eventually formed by the Hong Kong Government. At that time, Hong Kong was still under the rule of the United Kingdom, and the consultants engaged by the government suggested to consider the plan 20 years hence. Eventually, the first round was terminated due to the 1997 Asian financial crisis. However, the work with regard to the Lingdingyang bridge had laid a solid foundation for the eventual construction of the HZMB.

Round 2—Re-Proposing and Preliminary Planning of HZMB (2002–2004)

A second round was started in 2002. Under the supervision of the central government of China, the Guangdong Provincial Government, the Hong Kong Special Administrative Region Government, and the Macao Special Administrative Region Government, the construction of the HZMB was proposed again. This round aimed to comprehensively evaluate the macro-political, economic, and social benefits of the project, draw conclusions on the importance and necessity of the HZMB project, and make decisions on technical issues. In order to speed up decision making, the HZMB Pre-Coordinating Group was founded in 2003 to carry out research. In late 2004, the preliminary engineering feasibility research report of the HZMB was finished. The report focused mainly on technical issues, such as a traffic volume survey and analysis, project content and the main technical standards, construction conditions, bridge site selection, ports and facilities, environmental impact assessment, investment and financing programs, among others. During this round, many schemes were proposed for comparison. As the temporary recommended decision-making scheme of port setting was "one region, three custom inspections," the main stakeholders were more willing to adopt a BOT (build-operate-transfer) financing method than government financing.

Round 3—Chaos in Managing Conflicts of Opinions and Interests (2004–2006)

Near the end of round 2, a number of important decision-making schemes had been proposed. However, different stakeholders held different opinions on the decision-making issues. Especially, further research had gradually been used to investigate the impact of legal, financial, and environmental problems on decision making. As a result, a third round was started, aiming to deepen the study. The HZMB pre-coordinating group delegated a professional institution to carry out the survey. Among other things, this resulted in the establishment of the HZMB pre-coordinating group, which was tasked with investigating alternatives and proposing the best solution for the jurisdiction on April 2005. As a result, the understanding of important decision-making issues was becoming clearer, including the understanding of issues such as landing points, bridge route, and port setting. During the sixth meeting of the Pre-Coordinating Group, which was held on 14 July 2006, the landing points and bridge route were selected as follows: "The east landing point was San Shek Wan in Hong Kong, the west landing point was Gongbei in Zhuhai/Pearl in Macao, the bridge route was the combination of bridge and tunnel for the north line from San Shek Wan in Hong Kong to Gongbei in Zhuhai/Pearl in Macao" (HPDI, 2006). The port setting was finally selected as "three regions, three custom inspections," which was approved by each actor. The end of this round marks the breakthrough that made the project possible.

Round 4—Reaching an Agreement (2006–2009)

By the end of 2006, the HZMB Task Force led by the National Development and Reform Commission was founded, which represented the start of the fourth round. The aim was to solve the controversial issues by using the authority of the central government of China, which facilitated the efficiency and effectiveness of decision making. During this round, the interests of all parties came under the guidance of the central government in order to expedite the construction progress of the HZMB and propel further implementation of the HZMB project. Therefore, the engineering feasibility research report was approved formally by the state council of the People's Republic of China on 28 October 2009, which meant the decision-making issues in the front-end phase had now all been solved.

Based on previous reviews and interviews, the key complexity elements that played a part in each round are summarized in Table 2.

Table 2. The Decision-Making Complexity Elements in Each Round of HZMB

Dimensions		Round 1	Round 2	Round 3	Round 4
Technical	Detail	Scope size, first cross-sea bridge to be proposed	Scope of project (total length is approx. 50 km, tunnel section is approx. 6.75 km), high-quality requirements, different technical standards among three regions, technical innovation needed	Lack of technology experience on construction in core zone of nature reserve, lack of optimal decision-making schemes	High technology level required, lack of experience with protecting marine life
	Dynamic	Uncertainty of the feasibility of innovations toward regulations	The impact of multiple construction conditions (meteorological, hydrological, navigable conditions, high aviation limit, topography, etc.), interdependency between decision-making issues (landing points and bridge route)	Interaction between Sousa chinensis* protection issue and bridge route decision, managing adverse impacts of construction on the environment (especially on Sousa chinensis protection)	Interaction between port setting and bridge route decision, approval of technologies on "adjusting the functional zoning of Sousa Chinensis National Nature Reserve temporarily, carrying out eco-compensation"
Social	Detail	Number of different countries involved (mainland China, United Kingdom, and Portugal), complicated project location and environment	Number of different stakeholders (Zhuhai, Hong Kong, and Macao), complicated project location and environment	Number of different stakeholders (Zhuhai, Hong Kong, and Macao), complicated project location and environment	Number of different stakeholders (Zhuhai, Hong Kong, and Macao), complicated project location and environment
	Dynamic	Conflict of interests, opinion divergence and different objectives (disinterest of Hong Kong Government)	Political influence (under the policy of "one country, two systems"), major impact on local society, uncertain interaction of different cultures	Difference in experience and management skills among decision makers, different preferences among decision makers, uncertain interaction of different cultures and political systems	Difficult to reach an agreement among stakeholders, adverse impact of project on environment (such as Sousa chinensis protection), uncertain interaction of different cultures and political systems
Financial	Detail	Lack of willingness to invest	Difficulty with evaluating project's economic benefits	High investment requirements (total investment would be more than US$10.42 billion), different investment calculation methods, different project economic evaluation methods	Different calculation methods, various investment sources
	Dynamic	Impact of financial crisis, difficulty calculating all individual elements	Inconsistent and changing financial requirements	Different financing ideas on public projects among three regions, difficult to allocate costs and benefits among three regions, economic risk identification, strategic misinterpretation of optimistic and pessimistic bias	Competition between investment demand and resource distribution, comparison of financing methods

(Continued)

Table 2. Continued

Dimensions		Round 1	Round 2	Round 3	Round 4
Legal	Detail	Without general law and regulation to deal with problems under different political systems	Vacancy laws to deal with cross-border issues	Immature or vacancy laws and regulations to deal with jurisdictional issues, strict legal constraints (whether the bridge could go through the nature reserve)	Large number of laws and regulations need to follow
	Dynamic	Inconformity of laws and administrative powers between different stakeholders	Different legal systems in three regions, difficulty in cross-border construction, management, operation	Differences in legal context (such as whose laws should be obeyed with regard to tender, foreign exchange, tax, concession), changing, nonexistent, and conflicting laws	Differences in interpretation of legislation and rules on the content and processes, need to find solutions within the legal framework
Organizational	Detail	Numerous communication and coordination requirements	Numerous contracts needed, blurred interfaces, complicated information transfer	Numerous communication and coordination requirements; numerous contracts needed; complicated division of responsibilities, mandates, and tasks; complicated information transfer	Special arrangements for cross-border issues, numerous communication and coordination requirements, numerous contracts needed, complicated division of responsibilities, mandates and tasks, complicated information transfer
	Dynamic	Ever-changing dynamics of stakeholder relationships	Ambiguity at hierarchal relationships	Ambiguity at hierarchal relationships, temporary organizations with frequently changing research institutions and experts, complex communication and coordination relationships	Ambiguity at hierarchal relationships (which country dominates the project), ever-changing dynamics of stakeholder relationships, temporary organizations with frequently changing research institutions and experts (foundation of new teams), complex communication and coordination relationships (multiple organization levels, long chains of communication)
Time	Detail	Huge pressures from societal expectations	Tight schedule and huge pressures from societal expectations, large number of concurrent tasks	Tight schedule, large number of concurrent tasks	Tight schedule and huge pressures from societal expectations, small fault tolerance of Sousa chinensis protection issue, large number of concurrent tasks
	Dynamic	Uncertainty about future selections	Long timeframe with continuous changes, uncertainty about future selections	Long timeframe with continuous changes, uncertain impact of the decision making on the society and environment	Long timeframe with continuous changes, uncertain impact of the decision making because of changing society and environment, uncertainty about future selections, changes of project objectives and plans caused by enormous factors (such as central government was willing to invest)

[a]Sousa chinensis (aka, Chinese white dolphins) is an endangered species of dolphins living in the South China Sea.

Analysis of Complexity Linkages in Relation to Decision Making

From Table 2, we find that the six dimensions of complexity embrace all complexities that were observed in the HZMB. Each dimension of decision-making complexity was present at each round, though showing different characteristics at each round. The relationship between these dimensions also needs to be emphasized.

> The HZMB spans the entire Lingdingyang Bay and has a complex technical environment. It requires high investment amount for the whole project. Due to the needs of the navigation channel, a tunnel scheme should be adopted in the case of the HZMB. However, the construction cost of the tunnel will be higher than that of the bridge, which further increases the investment amount. (Assistant director)

Actually, the project type, location, and bridge routes were the key decision-making issues for the HZMB in the early stage. However, the scale of the project is huge, certain technical experience is lacking, and a large number of technological innovations are required. The overall investment needed for the project will be impacted by the considered different project types, such as the full-bridge scheme, or the island-tunnel combined scheme, as well as different bridge routes, such as avoiding or crossing ecologically sensitive areas.

As indicated by the assistant director of the HZMB Authority, the construction cost of the island-tunnel combined scheme is much higher than that of the full-bridge scheme. This would lead to a hugely uncertain return on investment (ROI) of the BOT model with a payback period that would potentially be too long, making it difficult for HZMB to find suitable financiers. Therefore, technical complexity impacts financial complexity. And, furthermore, the financial complexity had also aggravated social complexity. In order to reduce the impact of financial crisis, stimulate domestic demand, and promote economic stability in Hong Kong and Macau, the central government of China was willing to contribute a larger investment to the project's main bridge to promote the construction of HZMB. As a result, the financing decision was further coordinated by the central government, which also triggered the organizational complexity.

> In the decision-making process of landing points, the Macao government initially did not oppose … choosing Bei'an plan as its landing point. However, as the bridge route scheme was further clarified, it emerged that three bridges would be crossed by the HZMB if it were to land in Bei'an, and then the Macao government strongly opposed this scheme. (Planning manager)

The decision making on landing points and bridge routes would have an important impact on local traffic patterns. The Hong Kong side initially only recommended the North Lantau Island scheme, and opposed the Tuen Mun and South Lantau Island schemes, whereas the Macao side had changed its decision making from not opposing the Bei'an scheme to fully opposing the Bei'an scheme. Therefore, the technical decision-making complexity involved the interests and objectives of all subjects and then triggered social complexity. Moreover, the decision-making process of the bridge routes was very complex, which is closely related to transportation planning, geological hydrology, ecological protection, and so forth. This means that a large number of research institutions participated in the decision making, such as the Zhongjiao Highway Planning and Design Institute, the Institute of Comprehensive Transportation of National Development and Reform Commission, CHELBI Engineering Consultants, Inc., among others. More than 250 researchers and experts took part in the early stages of decision making for the HZMB. Thus, high technical complexity added complexity to the organization structure, to the information transmission, and to communication, thus increasing organizational complexity.

> Unlike the cross-city and interprovincial bridges or highway projects, the HZMB is the first cross-border project and the first project developed jointly by the three regional governments under the policy of "one country, two systems." For this reason, legal issues need to be paid enough attention. Therefore, we have established a non-litigation dispute resolution mechanism in the Authority Regulations to deal with legal complexity. (Contract director)

In the decision-making process of the HZMB, the legal regulations caused some contradictions. For example, as the bridge routes went through the Pearl River Estuary Sousa Chinensis National Nature Reserve, more stakeholders had to participate in the decision-making process, aggravating social complexity. Under the guidance of the Ministry of Agriculture's Bureau of Fisheries, and with the participation of the Administration of Ocean and Fisheries of Guangdong Province and the Development and Reform Commission of Guangdong Province, the South China Sea Fisheries Research Institute was commissioned to conduct a monographic research study into the protection of the Chinese white dolphin, *Sousa chinensis*. This also increased organizational complexity. Similarly, the inconformity of laws and administrative powers of the three regional governments led to inconsistency of the decision-making process and power, which further triggered social complexity. Specifically, the principle of territorial jurisdiction was formulated to carry out project construction. The investment proportion of the main bridge was also negotiated on the basis of the principle of territorial sharing. Meanwhile, legal complexity also put forward new requirements for conflict coordination within the organization. The typical management method in the HZMB is the establishment of a non-litigation dispute resolution mechanism, forming a friendly negotiation method, arbitration method, and central ruling method.

> As time flows, the decision-making issues have become more and more complex, with management experience lacking. Due to the difficulties in foreseeing the impact of decision making on future developments and small tolerance, it was very difficult for us to select the scheme at that time. Therefore, the HZMB Pre-Coordinating Group, the HZMB Task Force, and the HZMB Authority were gradually established to promote coordination among the organization, which also provided strong support for decision making. (Vice planning manager)

In the front-end decision-making phase of the HZMB, its organizational structure featured a flexible feature. With the deepening and implementation of decision making, the contradictions and coordination between the three governments could no longer be solved by the Pre-Coordinating Group, whereas the establishment of the task force could provide a coordination platform for conflicts at the highest level, and also promote the decision making of financing issues. This indicates that social complexity is closely related to organizational complexity. The relationship between social and organizational complexity embodies the matching of "things" and "rights." This also indicates that the conflicts and contradictions among stakeholders can be dealt with through the establishment of a reasonable organizational structure. Meanwhile, time complexity turns out to be a different view related to changes that can occur, tied to each of the other five complexities.

The Framework of Decision-Making Complexity

The decision-making complexity framework is defined here as a structure that consolidates a series of influencing elements (drawn from the literature and empirical data). The framework describes the sources of complexity facing project decision making that may potentially affect project performance (Chapman, 2016). Overall, based on the literature reviews and case study, the framework of characterizing the dimensions and elements of decision-making complexity is shown in Figure 1. In summary, this framework places emphasis on the characteristics of multi-rounds, multi-dimensions, multi-attributes, multi-elements, and multi-interaction.

First, the importance of each dimension of decision-making complexity varies for each round. The case study shows a shift of dominant complexity in the decision-making rounds. In the initial phase of the project (round 1), which aims at putting forth the idea of project construction, a number of stakeholders propose to be involved. How to deal with different interests and preferences of a large number of stakeholders is of vital importance. Therefore, social complexity was dominant in round 1. Next, round 2, which is the preliminary planning phase of the project, focuses on investigating basic technical issues, such as a traffic volume survey and analysis, project content and the main technical standards, construction conditions, and so forth, so that technical complexity receives more attention in round 2. In the subsequent phase of deepening research (round 3), the interaction of critical influencing factors starts to emerge, which is manifested especially in financial and legal complexity. Eventually, round 4, which is the final phase of reaching agreements and forming decisions, places more emphasis on organizational and time complexity. The reason for this is that the difficulty of communication and coordination, as well as time pressure, increases in the stage of reaching a consensus. This is expected to be a general pattern, to be studied in future research.

Second, each dimension of decision-making complexity is closely related and influenced by other complexities. The core of social complexity lies in the different perspectives and interests of different stakeholders. The organization complexity is mainly shown as the challenges in dealing with coordination, information transfer, responsibility assignment, and changing relationships of involved stakeholders. Thereby, in this sense, organization complexity and social complexity are closely related. Besides, the arena of stakeholders and the temporary organization are influenced by technical, financial, and legal complexities. For example, different calculation methods from financial complexity and different technical standards from technical complexity trigger the conflicting and shifting preferences of stakeholders from social complexity, as well as numerous communication and coordination requirements from organizational complexity. Conversely, social complexity and organizational complexity can sometimes create or enhance the financial, technical, and legal complexities. For instance, a lack of trust, lack of common perspective/panorama, and an overly strong focus on self-interests can create or enhance all kinds of financial, technical, and juridical complexities. Moreover, time complexity affects the other five dimensions of complexity regarding to its nature of change.

Third, social complexity and organizational complexity are the two basic, dominant, and interrelated complexities in decision-making complexity, which is in line with the findings of Hertogh and Westerveld (2010). In addition, legal complexity cannot be overlooked. Sometimes, legal complexity is the most important factor in determining decision making. This is reflected particularly in the case of the HZMB, which is a major cross-border project.

Conclusions

Decision making in MIPs is increasingly complex. It is imperative to explore and understand decision-making complexity in MIPs. This study has identified, classified, explored, and understood decision-making complexity, and provided a comprehensive framework of decision-making complexity in MIPs, which provides a solid foundation to researchers and practitioners in related topics.

In doing so, several questions were addressed in this article. The first and second questions intended to explore new concepts of decision making, decision-making quality, and decision-making complexity in MIPs. By drawing lessons from previous literature, we contribute to providing a comprehensive

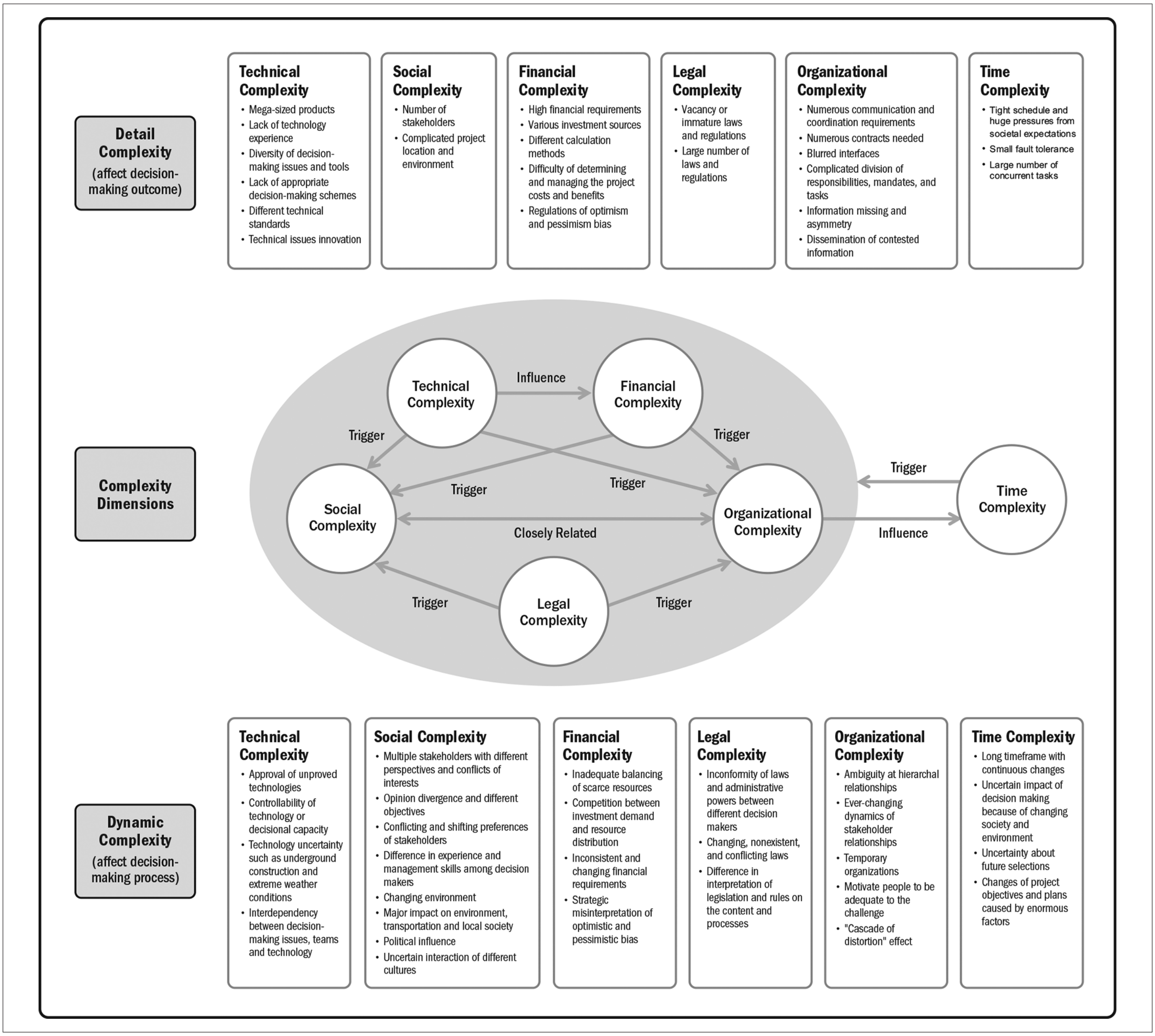

Figure 1. The framework of decision-making complexity.

concept of decision making in MIPs from a combination of process and outcome, which also indicates that decision making is not just a static notion, but a dynamic notion as well. Decision-making quality can also be perceived from two perspectives, process and outcome, making it different from project performance. Based on a literature review, we also present the understanding of decision-making complexity in MIPs, and emphasize its two attributes, detail complexity and dynamic complexity. The aim of the third research question was to avoid the fragmentation trap on the systemic classification and analysis of decision-making complexity. We have addressed this question by providing a structured and systematic framework of decision-making complexity in MIPs through both a literature review and a case study—thereby identifying six dimensions and 50 elements. Finally, we came to several findings, which can also provide related experiences to future practitioners.

The theoretical contribution of this study includes five aspects. First, this study provides a new perspective to understanding decision making and decision-making quality in MIPs, enriching decision-making theory. Second, there are still differences between decision-making complexity and project complexity, which is a neglected area of study. Existing research often confuses them, and this article intends to fill this gap. This study enriches complexity theory for MIPs from the perspective of decision-making complexity. We proposed a systematic framework of decision-making complexity through review and a typical case study of the HZMB from six dimensions (technical, social, financial, legal, organization, and time). This framework uses the classification of detail and dynamic complexity based on a static and a dynamic perspective, which also corresponds to the two dimensions of decision-making outcome and decision-making process. Third, this study analyzes the evolution and interaction of decision-making complexity dimensions, placing emphasis on its dynamic characteristic, which provides a panoramic and systematic perspective for decision-making complexity. Fourth, one of the contributions this article makes is the presentation of a decision-making complexity framework, which goes beyond existing project frameworks in that it considers the dynamic nature of decision making and human characteristics. That is to say, compared with project complexity, based on behavioral decision theory, we also consider the cognitive ability, psychological factors, behavioral characteristics, and information processing of decision makers in the establishment of a decision-making complexity framework. The proposed framework further expands the application of decision theory and complexity theory in MIPs, which represents a promising and intriguing step for the exploration of decision-making complexity. Fifth, the findings of this study also provide a fundamental reference, experience, and understanding for decision makers in MIPs for further improving decision-making quality and project performance.

Three limitations of this study should be noted. First, more interviews and case studies need to be conducted in the future to test and verify the integrity and replicability of the proposed framework. Second, the differences on project management (culture) between different countries may be considered in the future to verify the applicability of the framework. Third, as each element of decision-making complexity is investigated independently, further empirical studies are also needed to explore the critical elements contributing to the decision-making complexity and the interrelationship between multiple elements. Finally, this study is exploratory, and limited to an identification of dimensions and elements of decision-making complexities. It is also necessary to elicit an assessment model to measure and evaluate these critical decision-making elements in the future. These steps may help to lay a foundation for practitioners to deal with decision-making complexities in MIPs.

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Note

1. Instrumentalism, in the philosophy of science, is the view that the value of scientific concepts and theories lies in helping to make accurate empirical predictions or to resolve conceptual problems (Kilduff et al., 2011).

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