STAKEHOLDER ANALYSIS IN THE DYNAMIC AND COMPLEX ENVIRONMENT OF MEGAPROJECTS

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Stakeholder Analysis in the Dynamic and Complex Environment of Megaprojects

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Certificate of Originality

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Abstract

A megaproject is typically characterized as having a huge investment scale, a complicated organizational structure, high technical difficulty, and a profound impact on national and regional socioeconomic development. With greater project complexity compared to the traditional projects, the success of megaprojects depends on the active collaboration of the stakeholders. The stakeholder structure in megaprojects is dynamic and complex. On the one hand, megaprojects have long-term project duration, so stakeholder participation varies in such a dynamic environment. In particular, these stakeholders continuously join or withdraw at different stages of a megaproject. On the other hand, a large number of stakeholder interactions occur in this complex project environment as they are deeply involved in various associated issues in these megaprojects. Therefore, understanding the stakeholder interactions in the dynamic and complex environment of megaprojects is essential in achieving better stakeholder management.

The primary aim of the current study is to develop robust approaches with which to analyze stakeholder interactions in the dynamic and complex environment of megaprojects. To achieve the research aim, this study breaks down the research objectives step by step as follows:

(1) propose an analytical approach to evaluate stakeholder dynamics in the

megaprojects;

(2) propose an analytical approach to evaluate stakeholder complexities in the megaprojects; and

(3) propose an analytical approach to evaluate stakeholder performance in the dynamic and complex environment of megaprojects.

To achieve these research objectives, a comprehensive review of the development of stakeholder analysis and promising research techniques was conducted. A topic modelling approach, a classical text-mining based method, was further developed to address the dynamic stakeholder analysis in megaprojects. Then, a traditional network modelling approach was upgraded to analyze the longitudinal patterns of stakeholder complexity in various phases of megaprojects. Furthermore, an integration model was designed based on the NK organizational simulative model, along with a two-mode network model to evaluate the stakeholder performance while considering the dynamic and complex environment of megaprojects.

The research findings can be grouped into three parts. First, the proposed dynamic stakeholder-associated topic model provides a text-mining based method, which can analyze the stakeholder dynamics by exploring the knowledge from large quantities of unstructured project documents. Second, the proposed longitudinal stakeholder-associated network model provides a systematic method, which can analyze the stakeholder complexities based on the classical two-mode network model. Third, the proposed Network-NK model provides a simulative method to evaluate the stakeholder performance under the dynamic and complex environment of megaprojects.

This study has three theoretical contributions to the literature. First, by using longitudinal text data from the official project documents, the proposed dynamic stakeholder-associated topic model fills the gap related to the lack of data on the analysis of stakeholder dynamics. Second, the proposed longitudinal stakeholder-associated network model fills the gap regarding the lack of longitudinal network studies, which provide a full picture of stakeholder complexities in the whole lifecycle of a megaproject. Third, the proposed Network-NK model introduces the complex adaptive system modeling technique into the evaluation of stakeholder performance, thus providing a simulative method that would allow us to better understand the stakeholder evolution and resilience in the dynamic and complex environment of megaprojects.

Meanwhile, the practical research contributions are summed into three aspects. First, by exploring knowledge from unstructured official project documents, the proposed dynamic stakeholder-associated topic model provides a method by which decision makers can perform dynamic stakeholder management in megaprojects. Second, the proposed longitudinal stakeholder-associated network model can help researchers and decision makers learn about critical stakeholder issues, stakeholder relationships, and management strategies from the complex stakeholder structures in the historic megaprojects. Finally, the proposed Network-NK model is beneficial for decision makers as they forecast and review stakeholder performance in the development of megaprojects by detecting the weaknesses of stakeholder performance and assessing the relevant issues with poor resilience for each project stakeholder.

Publications

Journal papers

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2. Xue, J., Shen, G. Q., Yang, R. J., Zafar, I. & Ekanayake, E. 2020. Dynamic Network Analysis of Stakeholder Conflicts in Megaprojects: Sixteen-Year Case of Hong Kong-Zhuhai-Macao Bridge. *Journal of Construction Engineering and Management,* 146, 04020103.

3. Xue, J., Shen, G. Q., Li, Y., Wang, J. & Zafar, I. 2020. Dynamic Stakeholder-Associated Topic Modeling on Public Concerns in Megainfrastructure Projects: Case of Hong Kong–Zhuhai–Macao Bridge. *Journal of Management in Engineering,* 36, 04020078.

4. Xue, J., Shen, G. Q., Yang, R. J., Wu, H., Li, X., Lin, X. & Xue, F. 2020. Mapping the Knowledge Domain of Stakeholder Perspective Studies in Construction Projects: A Bibliometric Approach, *International Journal of Project Management*, 38, 313-326.

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Approach, *Journal of Construction Engineering and Management* (Accepted)

6. Shen, G. Q., **Xue, J.** 2021. Managing stakeholder dynamics and complexity in mega infrastructure projects, *Frontiers of Engineering Management,* 8, 148–150, https://doi.org/10.1007/s42524-020-0149-6.

7. Zafar, I., Shen, G. Q., Zahoor, H., **Xue, J.** & Ekanayake, E. 2020. Dynamic Stakeholder Salience Mapping Framework for Highway Route Alignment Decisions: China Pakistan Economic Corridor as a Case Study. *Canadian Journal of Civil Engineering,* 47(11), 1297-1309

8. Zafar, I., Wuni, I. Y., Shen, G. Q., Zahoor, H. & **Xue, J.** 2020. A Decision Support Framework for Sustainable Highway Alignment Embracing Variant Preferences of Stakeholders: Case of China Pakistan Economic Corridor. *Journal of Environmental Planning and Management,* 63, 1550-1584.

9. Zafar, I., Wuni, I. Y., Shen, G. Q., Zahoor, H., & **Xue, J.** 2020. Dynamic Decision Support Framework for Stakeholder Engagement in the Selection of Optimal Highway Alignment. *Group Decision and Negotiation* (under review)

Conference papers

1. Xue, J., Shen, G. Q., Li, Y., Wang, J., Yu, J. & Yang, Y. Dynamic Analysis on Public Concerns in Hong Kong-Zhuhai-Macao Bridge: A Topic Modelling Approach, *Construction Research Congress 2020*, The American Society of Civil Engineers, March 8-10, 2020, Arizona, United States (Best paper award)

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Chapter 1 Introduction

1.1 Research background

Why focusing on the megaprojects?

Megaprojects usually have huge investment scale, high technical difficulty, and complex environment, and have a profound impact on national and regional economic and social development (Mok et al., 2015). China is a major engineering country and is currently carrying out the world's largest scale of megaprojects (Xila et al., 2005), such as South-to-North Water Transfer, West-East Gas Transmission, West-East Power Transmission, Beijing-Shanghai High-Speed Railway, and Hong Kong-Zhuhai-Macao Bridge. In recent years, under the guidance of the "Belt and Road" initiatives, a large number of mega overseas construction projects, especially mega infrastructure projects, have been gradually launched. On November 17, 2015, Premier Li Keqiang pointed out in the "Thirteenth Five-Year Plan" preparation work meeting that we must clearly and effectively grasp the focus of megaproject development through the implementation of a number of megaprojects, to seize the commanding height of national competitiveness strategy. It can be seen that the construction management of megaprojects has risen to the height of the national policy.

Why is stakeholder analysis essential in megaprojects?

With the trend of project complexity, the success of megaprojects increasingly depends on the active collaboration of stakeholders and the adaptability of stakeholders, including the adaptability to the external environment and the coordination of internal members (Shen et al., 2009). The American Project Management Association pointed out: "Stakeholders refer to individuals or institutions actively participating in the project, or their interests are positively or negatively affected during project execution or after success" (Pmi, 2013). The project stakeholders are the direct participants and affected people of the project, and their interaction and process directly affect the completion of the entire project (Liu et al., 2016a)

The failure stakeholder management has caused significant losses in various stages of megaprojects (Jia et al., 2011), which calls for the systematical stakeholder analysis to analyze stakeholder interactions in the project duration. For instance, in the planning stage, the stakeholder conflicts occurred in the Western bypass route (Route 29) in the USA, causing the project defunded (Doyle, 2016). In the pre-contract stage, the stakeholder conflicts caused by contract negotiations were a critical factor of project delays in large international construction projects in Vietnam (Maemura et al., 2018). In the construction stage, external stakeholder conflicts have led average delay of 3.6 years and cost overruns of 290 percent in large construction projects in Korea (Lee et al., 2017b).

The significant loss of failure stakeholder management is mainly due to a large number of interacting project stakeholders in megaprojects. The differences in stakeholder perceptions of interests and goals, cultural background, and institutional logic (Shi et al., 2016) have raised the difficulties on the interaction and coordination process of project stakeholders in the project duration (Xue et al., 2012, Tang and Shen, 2015). Therefore, there is an essential need for effective methods to accurately analyze the stakeholders of megaprojects and coordinate the stakeholder interactions in various project phases.

Why is the stakeholder analysis under a dynamic and complex environment in need?

Megaprojects can be regarded as a "complex system" with the complex project organization structure and dynamic organization interactions (Holland, 2000). The complex environment of megaprojects is mainly reflected in a large number of project stakeholders and the intricate interaction between the stakeholders. While the dynamic environment is reflected in the continuous changes of stakeholders and the external environment as the project progresses at different stages. Namely, various project stakeholders will join or withdraw from this "complex system" at different stages.

The dynamic and complex environment of megaprojects raises the challenges of traditional stakeholder analysis methods. In conventional construction projects, project managers generally use traditional stakeholder analysis methods to analyze project stakeholders, such as stakeholder strategy models (Mitchell et al., 1997), stakeholder salient models (Rowley, 1997), etc., mainly through evaluation by critical stakeholders to identify, assess, and manage the relevant stakeholder issues.

These static analysis perspectives gradually show their deficiencies as the dynamics and complexity of the project increases in megaprojects (Mok et al., 2015). On the one hand, project managers are limited by their own management experience and insights to evaluate the stakeholder performance in the complex and dynamic environment (Di et al., 2015). On the other hand, due to the increase in complexity and dynamics of megaprojects, it also increases the difficulty of identifying stakeholders and analyzing their relationships in various project phases (Yang et al., 2009c). Therefore, it is still waiting for new methods of stakeholder analysis under the dynamic and complex environment in megaprojects.

1.2 Scope of the research

This research focuses on megaprojects. The megaproject is widely defined by its vast project cost, which is usually over 1 billion USD (Flyvbjerg et al., 2003), involved by various project stakeholders with divergent interests (Mok et al., 2015). Compared to the traditional construction projects, megaprojects are faced with the complicated contractual relationship, the dynamic project organization structure, and the uncertain project environment (De Meyer et al., 2002, Holland, 2000), which requires stakeholders to have better management strategies.

This research focuses on project stakeholders and their relevant issues. The concept of project stakeholders in this research not only includes the project members within the project (i.e., owner, consultant, contractor, suppliers) but also involves members from the project environs. (i.e., government, local community, public media). The stakeholder issues refer to the stakeholder-associated events which exert influence on the stakeholder interests and behaviors. The project stakeholders are either directly or indirectly affected by stakeholder issues, which considers the concept of stakeholder issues as a primary research target for analyzing stakeholder positions in the megaprojects.

This research focuses on the dynamic and complex project environment of megaprojects. The dynamic project environment consists of the longitudinal information of stakeholder issues in the long-term project duration. The term 'dynamic' in this research reflects the situation changes with time-series stakeholder information in various project phases, including planning, construction, and handover stage. The stakeholder analysis will be made with the dynamic model to present how stakeholder interactions with the changeable project environment in the timeline. The complex project environment contains the wide-range interactions between stakeholders and relevant issues in the project duration. The term 'complex' represents the non-linear and inter-dependency nature between stakeholders and related issues. A network model will be established to present and evaluate the stakeholder complexity by prioritizing the management factors in the complicated stakeholder structure under the complex environment of megaprojects.

1.3 Research aim and objectives

The primary research aim is to develop robust approaches to analyze stakeholder interactions in dynamic and complex environment of megaprojects.

The specific research objectives are as follows.

(1) To propose an analytical approach to evaluate stakeholder dynamics in the megaprojects.

(2) To propose an analytical approach to evaluate stakeholder complexities in the megaprojects.

(3) To propose an analytical approach to evaluate stakeholder performance in dynamic and complex environment of megaprojects.

Objective 1 is to seek the analytical approach for exploring the chronological features of project stakeholders and their relevant events in various project phases, which realizes the dynamic stakeholder management in the megaprojects.

Objective 2 is to explore the analytical approach for evaluating the complexities of stakeholders and their relevant issues in the project duration, which prioritizes the critical factors for stakeholder management in the complex environment of megaprojects.

Objective 3 is to develop the analytical approach for analyzing the stakeholder performance in both considerations of stakeholder dynamics and complexities in the project, which understands the evolution and resilience of stakeholders in the development of megaprojects.

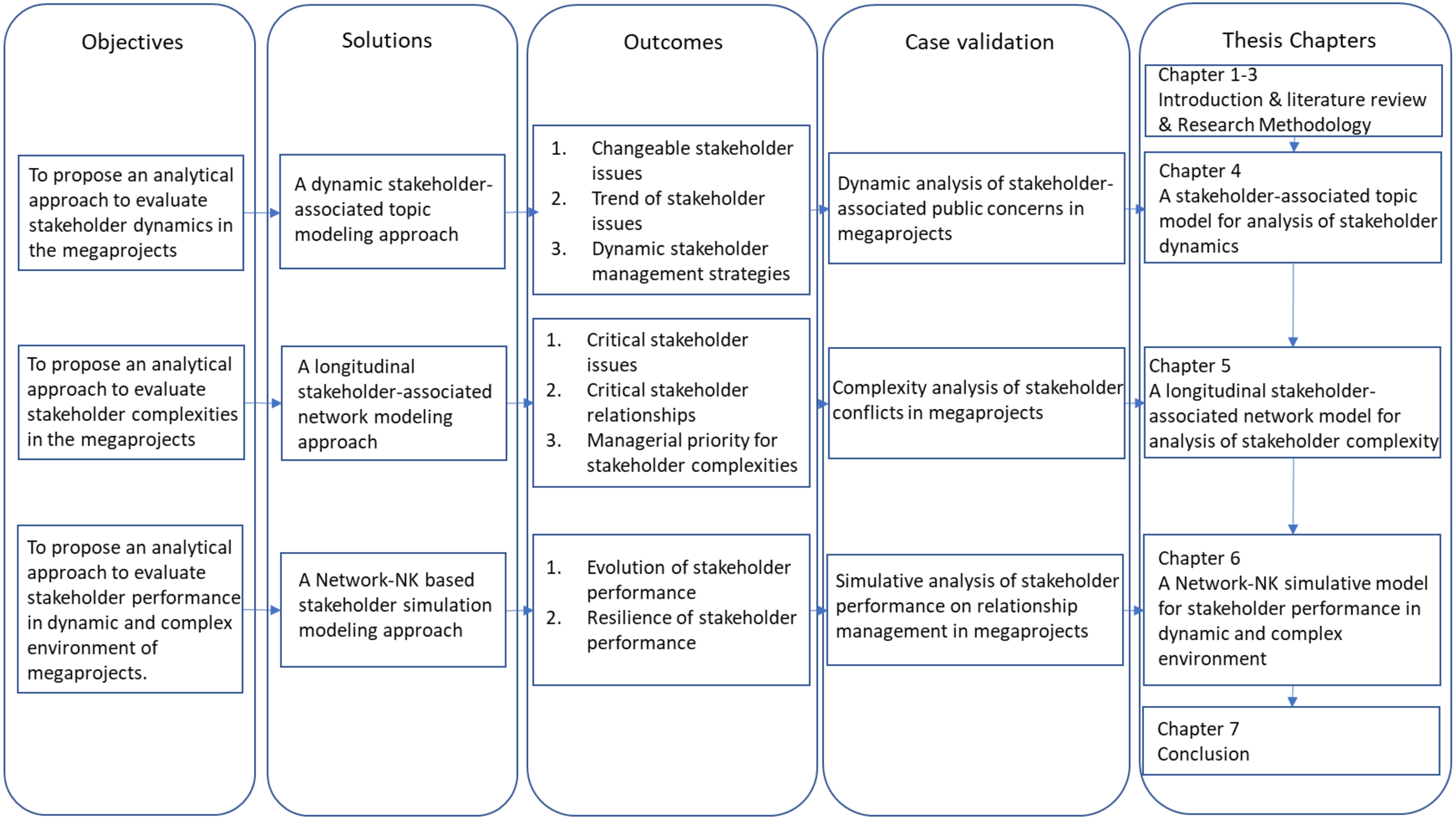

Figure 1.1 Overall framework of the thesis

1.4 Research design

The research design is mainly composed of three parts (shown in Figure 1.1). Each section is corresponding to one research objective.

First, the research initiates with introduction, literature review, and research methodology. The introduction part identifies the research objective and significance. The literature review summarizes the development of stakeholder analysis and points out the knowledge gaps in the research field. Moreover, the research methodology part elaborates the promising analytical approaches that have the potential to address the identified knowledge gaps.

Second, the research is around the objective of proposing the analytical approach to evaluate stakeholder dynamics in the megaprojects. In this part, the dynamic stakeholder-associated topic model is proposed. This model realizes the automated knowledge exploration for dynamic stakeholder management from large quantities of unstructured text project documents. The model identifies the changeable stakeholder issues, tracks the trend of stakeholder issues in the timeline, and presents the dynamic stakeholder management strategies in different project phases. The model is validated by a case of stakeholder-associated public concerns in the megaproject.

Third, the research is around the objective of proposing the analytical approach to evaluate stakeholder complexities in the megaprojects. A longitudinal stakeholder-associated network model is developed. This model prioritizes the critical factors for stakeholder management in the complex environment composed of stakeholders and their relevant issues. The model not only identifies the critical issues of stakeholder but also detects the key stakeholder relationships in the various stages of the megaprojects. Besides, the managerial priority for addressing stakeholder complexities is also derived by the model to guide the stakeholder management in the view of complex stakeholder networks. The model is validated by a case of stakeholder conflicts in the megaproject.

Fourth, the research focuses on the objective of proposing the analytical approach to evaluate stakeholder performance in both dynamic and complex environment of megaprojects. In this part, a Network-NK based stakeholder simulative model is proposed. The model requires the influence of stakeholder strategies and the two-mode stakeholder-issue networks as the inputs for the model processing. Then, the evolution and resilience of stakeholder performance are predicted and evaluated in the various project phases as two critical outputs according to the results of the simulative model. Finally, the model is validated by a case of stakeholder performance on relationship management in the megaproject.

Fifth, the research findings are summarized in the conclusion part. The research contributions are discussed in both theoretical and practical aspects. The limitations of the proposed models are also presented for future studies.

1.5 Significance of the research

First, the proposed dynamic stakeholder-associated topic model fills the gap of lacking data for dynamic stakeholder analysis by using longitudinal text data from official documents relevant to the project. The model offers a text-mining based method to identify, evaluate, and manage the stakeholder issues by exploring the knowledge from large quantities of unstructured documents relevant to the project. The automated analytical model will provide useful guidelines for future megaprojects in the view of stakeholder management.

Second, the proposed longitudinal stakeholder-associated network model is beneficial to analyze the stakeholder complexity throughout the whole project duration, beginning from the planning stage to the construction and handover stage. The model fills the gap of lacking longitudinal network studies to provide a full picture of stakeholder complexities in the whole lifecycle of megaprojects. The model upgrades the traditional network analysis in the domain of construction management by systematically providing a series of methods to prioritize criticalness of stakeholder issues, affected stakeholder relationships, and stakeholder management strategies.

Third, the proposed Network-NK based stakeholder simulative model is useful to simulate the stakeholder performance under the dynamic and complex environment in megaprojects. The model introduces the complex adaptive system modeling technique into the evaluation of stakeholder performance. The model deepens the understanding of stakeholder evolutions in the project life cycle. Furthermore, it gives birth to a new concept termed "stakeholder resilience," which reflects the stakeholder capability when faced with unpredictable challenges in the megaprojects.

1.6 Structure of the thesis

Chapter 1 is a general introduction to the thesis. It includes the research background, research scope, research aim and objectives, research design, research significance, and the thesis structure.

Chapter 2 reviews the literature in the domain of stakeholder management to summarize the previous research findings and present the knowledge frontier of current studies, which lead to the research gaps of this study.

Chapter 3 presents the methodologies to achieve research objectives. Three analytical modeling approaches that have the potential to be introduced into the stakeholder analysis are elaborated, including the topic modeling, network analysis, and NK modeling.

Chapter 4 proposes the stakeholder-associated topic model for analysis of stakeholder dynamics. The analytical model is based on the topic model, which could automatically detect the dynamic patterns of stakeholder issues from large quantities of unstructured text documents relevant to the project.

Chapter 5 proposes the longitudinal stakeholder-associated network model for analysis of stakeholder complexity. The longitudinal network model could assist decision-makers in comprehensively understanding the stakeholder complexity from perspectives of critical stakeholder issues, key stakeholder relationships, and the management strategies of stakeholder issues in various phases of the project.

Chapter 6 proposes the Network-NK simulative model for stakeholder performance in dynamic and complex environment. The model is based on the integration of the NK organizational evolution model and the two-mode network model, which could simulate the general trend of stakeholder performance under various management strategies dealing with stakeholder issues. As a result, the stakeholder evolution and resilience are analyzed according to the simulation results of the proposed Network-NK simulative model.

Chapter 7 summarizes the research findings. Through the review of the research objectives, the research contributions are highlighted in both theoretical and practical aspects. Besides, the research limitations and future directions are also discussed to guide the subsequent studies.

1.7 Summary of the Chapter

In this chapter, the comprehensive description of the research is made from six parts, including research background, research scope, research aim and objectives, research design, research significance, and the thesis structure.

Chapter 2 Literature Review[1]

2.1 Introduction

This chapter reviews the previous stakeholder studies in construction projects and points out the research frontiers when traditional stakeholder analytical methods extend to stakeholder analysis in megaprojects. First, it introduces the development of the stakeholder concept. Second, it overviews stakeholder analysis from perspectives of stakeholder identification, assessment, and management. Third, the existing analytical methods on stakeholder dynamics, complexity, and performance are reviewed with revealing critical limitations. Fourth, three knowledge gaps are summarized based on the limitations of current stakeholder analytical methods facing the dynamic and complex environment of megaprojects.

2.2 Stakeholder concept

In terms of stakeholder concepts, the noticeable definition of stakeholders came from the famous book "strategic management" written by Freeman (1984), in which a clear definition of stakeholder was first suggested: "any group or individual who can affect or is affected by the achievement of the firm's objectives." The definition set the foundation of stakeholder management and was furtherly interpreted by Cleland and

[1] This chapter is relevant to the publication:
Xue, J., Shen, G. Q., Yang, R. J., Wu, H., Li, X., Lin, X. & Xue, F. 2020. Mapping the Knowledge Domain of Stakeholder Perspective Studies in Construction Projects: A Bibliometric Approach. International Journal of Project Management, 38, 313-326.

Kerzner (1986), who listed eighteen project stakeholders, bringing the stakeholder concept from corporation management into the project management. In the next year, Morris and Hough (1987) first pointed out the multi-organizational management is one of the determinants to achieve the success of large complex projects, indicating the importance of the stakeholder concept in the construction project management domain. After that, the terms like "group and individual" and "affect and affected" developed by Freeman (1984), were finally incorporated and translated into the project stakeholder concept defined by PMI (Institute, 1987) as "those individuals and organizations who are actively involved in a project or whose interests may be affected as a result of project execution or completion." Based on the Freeman and PMI's definition, the stakeholder concept was furtherly defined by various categories: external/internal (Atkin and Skitmore, 2008), direct/ indirect (Lester, 2006), proponents/opponents (Bonke and Winch, 2002), core and fringe (Hart and Sharma, 2004).

2.3 Overview of stakeholder analysis

2.3.1 Stakeholder identification

The "power, legitimacy, urgency" model proposed by Mitchell et al. (1997) set the principles to insightfully identify the critical stakeholder by its influence level on organizational activities. The model is the influential work to identify critical stakeholders by their attributes, which is the basis of a series of critical stakeholder identification methods. Generally, there were three classical tools developed from the "power, legitimacy, urgency" model. First, the power/interest matrix was first proposed by Scholes et al. (2002) in the corporate management, then Olander and Landin (2005) introduced this identification tool into the project management by mapping the stakeholders and their influences in two construction projects. Second, the stakeholder circle was designed by Bourne and Walker (2005) to visualize the power and influence of stakeholders in the project. Third, the Olander (2007) developed the stakeholder impact index by integrating the stakeholder attribute model (Mitchell et al., 1997), stakeholder position theory (Mcelroy and Mills, 2000), power/interest matrix (Scholes et al., 2002). The index identification tool was furtherly enhanced by Nguyen et al. (2009) with supplementing the perspective of stakeholder knowledge. However, all the attributes-based models are static identification tools, which cannot reflect the stakeholder dynamics as the levels of attributes often vary over time through the development of construction projects (Yang et al., 2009c). Besides, the series of stakeholder identification tools much relied on the cognitive information of project managers, which was lack of efficiency when employed in the complex construction projects (Yang et al., 2009c).

2.3.2 Stakeholder assessment

In terms of stakeholder assessment, two significant methods were raised. One is the critical success factors (CFS) approach first identified by Sanvido et al. (1992) in the construction industry, since when CSFs and its related survey-based method have become an essential part of stakeholder analysis research. The Sanvido et al. (1992) claimed that the various stakeholders (owners, designers, and contractors) had common and unique CSFs in the construction projects, which was worthwhile to be clearly explored for achieving the project's success. Then, the significance of CSFs was emphasized by Cleland (1999) on stakeholder management as it was essential for the project team to know whether the project stakeholders were managed successfully or not. The CSFs of stakeholder management were dug out by Yang et al. (2009a) in the construction projects, which were composed of stakeholder identification, stakeholder assessment, decision-making, act and evaluation, and continuous support. The identified CSFs of stakeholder management was furtherly applied by Oppong et al. (2017b) to guide the strategies for the improvement of stakeholder management performance. As CSFs are significantly related to the management performance, the assessment of CSFs preference of project stakeholders attracted a group of stakeholder analysis researches in a broad theme, such as green buildings and Public-Private Partnership projects (Osei-Kyei and Chan, 2017, Liang et al., 2015).

Another assessment tool is network analysis, which was comprehensively presented by one book written by Wasserman and Faust (1994). The book introduced the social network analysis (SNA) as a relational measure to systematically assess the interactions among various organizations. Later, Rowley (1997) made an analysis of stakeholder influence by SNA, which first combined the methodology of SNA with a stakeholder-related study. After that, the SNA technique was introduced by Yang et al. (2009c) to analyze the stakeholder relationship in construction projects as it was useful to visualize and examine various project stakeholders as a system rather than a group of independent focal organizations with the dyadic ties presented by Freeman (1984). The SNA approach was furtherly recommended by Mok et al. (2015) for stakeholder analysis on the complexities in mega construction projects. Currently, there are two kinds of SNA approaches in stakeholder assessment. One is to evaluate the relationship between project stakeholders (Mok et al., 2017a). Another is to assess the interactions of stakeholder-associated issues in the projects (Mok et al., 2017c). Both approaches provide the researchers with a robust assessment tool to understand the stakeholder positions in construction projects.

2.3.3 Stakeholder management

The key stakeholder management skills were recognized by Atkin and Skitmore (2008) as stakeholder identification, management and engagement. Since then, a group of stakeholder management focused on three aspects: stakeholder management process, strategies, and performance. First, focused on the stakeholder management process, Olander and Landin (2008) revealed five influential factors: analysis of stakeholder concerns and needs, communication of benefits and negative impacts, evaluation of alternative solutions, project organization, and media relations. Second, for the effective stakeholder management strategies, Aaltonen et al. (2008) identified the strategies to increase stakeholder salience in the aspect of resource building, coalition building, conflict escalation, creditability building, communication, and so forth. Third, to improve stakeholder management performance, 15 critical factors were identified by Yang et al. (2010), among which social responsibilities were regarded most important for managing stakeholders. These stakeholder management theories eventually formed the foundation to establish the stakeholder management framework in construction projects proposed by Yang and Shen (2014), which included four major components, including stakeholder identification, stakeholder assessment, decision-making process, and stakeholder management actions.

2.4 Analysis of stakeholder dynamics

Stakeholder dynamics reflect the changes of stakeholders' position in the project duration (Aaltonen et al., 2015), which leads to the changeable attitudes and actions of stakeholders in various stages of the construction projects (Rowley, 1997). The previous studies analyze the stakeholder dynamics from three aspects: stakeholder attributes identification, stakeholder influence assessment, stakeholder management strategies

(De Schepper et al., 2014, Aaltonen et al., 2015, Olander and Landin, 2005). In terms of stakeholder attributes identification, the “power, legitimacy, urgency” model has been tailored to analyze the stakeholder dynamics from the attributes of stakeholder power and urgency in four large Public-Private-Partnership projects (De Schepper et al., 2014). However, the stakeholder dynamics is assessed as a general indicator in the research without specifying various stakeholder groups. The stakeholder influence has been claimed to change over time in the project duration (Olander, 2007). The previous research introduces the mapping technique into assessing the influence of stakeholders in each project phase (Bourne and Walker, 2005, Bonke and Winch, 2002). The mapping technique clearly shows the stakeholder dynamics in a nuclear waste repository project by considering stakeholder salience and stance (Aaltonen et al., 2015). Moreover, the dynamics of stakeholder management strategies is analyzed qualitatively. For instance, various management strategies are discussed to match the dynamic stakeholder positions in the project, including collaboration, defending, monitoring, informing, and involving (Olander and Landin, 2005).

Despite the contribution of prior studies to stakeholder dynamics, the existing research still lacks a comprehensive approach to analyze stakeholder dynamics from identification to assessment and management (Aaltonen and Kujala, 2010). Besides, few studies analyze the stakeholder dynamics at the level of stakeholder issues (Luoma-

Aho and Vos, 2010), which limits the dynamic stakeholder management in the practice (Yang et al., 2009c). The bottleneck comes from the data availability (Mok et al., 2017c). The traditional stakeholder attributes model is a static model which relies on the cognitive information provided by involved stakeholders (Yang et al., 2009c). As the megaproject is long-term and complex (Mok et al., 2015), it is difficult to trace the changes of stakeholder issues in the dynamic environment through questionnaire surveys as required a large number of samples for statistical evaluation (Xue et al., 2020b) . Hence, it calls for an advanced approach to realize the analysis of stakeholder dynamics in megaprojects.

2.5 Analysis of stakeholder complexity

As the construction projects are more and more complicated, the analysis of stakeholder complexity plays an important role in stakeholder studies (Mok et al., 2017a). The stakeholder complexity refers to the complicated interdependencies between stakeholders and their relevant issues in various project phases (Yang et al., 2009c, Mok et al., 2017b, Mok et al., 2017a). The stakeholder analysis studies concentrated on the complexity of stakeholder concerns since the project complexity was intensified by the conflicting concerns among stakeholders (Atkin and Skitmore, 2008). The research of stakeholder concerns was started by Li et al. (2012a), which emphasized the criticalness of exploring the conflicts and consensus from the multiple stakeholder concerns. The stakeholder concerns were furtherly considered as one aspect of stakeholder complexity by Mok et al. (2017a), which recommended the network analysis approach to analyze the complex interactions of stakeholder concerns. The network-based approach was explicitly introduced to reduce the stakeholder complexity by identifying the critical position of stakeholder concerns with theoretical network indicators (Mok et al., 2017c). Then the stakeholder complexity studies extended from stakeholder-associated concerns to various kinds of stakeholder-associated issues. With the prioritization of stakeholder issues by network analysis, a group of project risks and challenges were detected from stakeholder perspectives in a variety of projects, including the infrastructure projects (Mok et al., 2017c), urban-redevelopment projects (Yu et al., 2017), and prefabricated housing projects (Luo et al., 2019).

Megaprojects became a hotspot of stakeholder studies with complex stakeholder interdependencies (Mok et al., 2017b). In 2015, Mok et al. (2015) followed this trend and wrote an influential review paper on stakeholder studies in mega construction projects. That paper provided a national culture analysis, a life-cycle analysis, a social network analysis, and an establishment of the database as four major directions for stakeholder analysis research facing the complexity in megaprojects (Mok et al., 2015). Following the trend, the stakeholder investigations of megaprojects were undertaken under various national cultural contexts to understand the stakeholder management measures in different countries (Di Maddaloni and Davis, 2018, Yang et al., 2018, Park et al., 2017). Moreover, social network analysis was employed to visualize the stakeholder complexity and manage the stakeholder relationship in megaprojects (Mok et al., 2017b). There are still limitations remained. First, although the stakeholder management studies of long-term megaprojects were conducted to explore the stakeholder performance in the complex project environment (Eskerod and Ang, 2017, Park et al., 2017), it still lacks the systematic discussions on interdependencies of stakeholder and relevant stakeholder issues in the current life-cycle analysis of megaprojects. Second, the existing network-based stakeholder analysis does not provide the longitudinal evidence of stakeholder complexities in various project phases (Mok et al., 2017b). Third, the reliable dataset is still waiting to be built to study on stakeholder complexity instead of traditional survey samples usually collected in a given timepoint, which is feasible to reflect the continuous longitudinal complex environment of megaprojects (Xue et al., 2020d).

2.6 Analysis of stakeholder performance

Stakeholder performance refers to the achievement level of stakeholder's objectives and interests (Wang and Huang, 2006, Hu et al., 2016). The previous study proves that enhancing stakeholder performance is essential for the project success (Wang and Huang, 2006). Besides, the stakeholder performance influences the performance of project management in a wide range of aspects, such as cost, schedule, safety management (Doloi, 2013, Braeckman and Guthrie, 2016, Wang et al., 2017b). The traditional analysis of stakeholder performance is followed by three steps (Oppong et al., 2017a, Roumboutsos et al., 2013). First, a group of stakeholder's objectives are explored. Second, the critical success factors (CSFs) for achieving stakeholder's objectives are detected. Third, a key performance index (KPI) is established based on the identified CSFs to evaluate the stakeholder performance in the project. The major deficiency of the traditional analytical method is to neglect the features of dynamics and complexity in megaprojects (Xue et al., 2020b, Mok et al., 2017a). In terms of complexity, the stakeholder structure is complicated in megaprojects due to the wide interactions between stakeholders and stakeholder issues (Mok et al., 2017b, Mok et al., 2017a). Hence, each stakeholder's objective varies on various stakeholder issues in different timepoints of the project. However, the traditional method sets the stakeholder's objective in a general way not specifying stakeholder issues (Roumboutsos et al., 2013). In the aspect of dynamics, for one stakeholder issue, each stakeholder performance is interrelated, since one stakeholder's behavior would be influenced by other relevant stakeholders (Westhoff et al., 1996, Weaver, 2007, Co and Barro, 2009). The classical CSFs and KPI cannot reflect the influence of dynamic stakeholder interactions on stakeholder performance. In summary, the traditional analytical method is a static approach. If it is required to trace the changes of stakeholder performance in megaprojects with a dynamic and complex environment, the classical method needs to assess the stakeholder performance repeatedly towards various stakeholder issues in the timeline, which is inefficient in the practice. Therefore, it is still waiting for the development of a new analytical approach to measure stakeholder performance in dynamic and complex environment of megaprojects.

2.7 The knowledge gap of stakeholder analysis

Gap 1: Lacking empirical data for analyzing stakeholder dynamics

As stakeholder dynamics is a primary feature of the project management, the stakeholder studies require the effective approaches to analyze the dynamics of stakeholder interactions (De Schepper et al., 2014). The classical static approaches require the upgrade to improve the adaptability tackling with the dynamic environment of megaprojects (Xue et al., 2020b). The classical methods require the empirical data to make stakeholder analysis, which are often obtained in a given time point through questionnaire survey and critical participant interview (Mok et al., 2017c). Therefore, it has inborn deficiencies for the traditional methods to reflect the dynamic patterns of interactions between stakeholders and their relevant issues, since these interactions vary in the development of megaprojects. Since the classical stakeholder identification approach has been criticized with the shortcoming of reflecting stakeholder dynamics in the literature review of the section 2.4, it calls for the robust approach to explore the stakeholder dynamic patterns from the reliable dataset covering timestamped stakeholder information in megaprojects, which furtherly achieves the stakeholder identification, assessment, and management in the timeline with the development of megaprojects.

Gap 2: Lacking longitudinal network studies of stakeholder complexity in megaprojects

As stated in the section 2.5, the stakeholder analysis is heading for the complexity of stakeholders in megaprojects. The previous studies have proved it is feasible to tackle the challenges of stakeholder complexity by network analysis (Mok et al., 2017a). However, the current network-based stakeholder analysis is mainly according to the static network, which fails to reflect the change of complex stakeholder relationships in megaprojects (Mok et al., 2017c). To overcome the shortcoming, the combination of the network model and longitudinal data to conduct the longitudinal analysis is beneficial to understand the development of stakeholder networks in a complex project environment (Zheng et al., 2016). Furthermore, as critical success factors (CSFs) are useful for stakeholders to prioritize the critical issues for management stated in the section 2.3.2, the network model is waiting to be further upgraded to explore the critical stakeholder issues and relationships among a large number of stakeholder interactions for managing stakeholder complexities in various phases of megaprojects (Xue et al., 2020d).

Gap 3: Lacking measurement of stakeholder performance in dynamic and complex environment of megaprojects

As stated in the section 2.6, the previous measurement of stakeholder performance is based on the critical success factors and key performance index (Oppong et al., 2017a), which provides the overall evaluations of stakeholder performance in construction projects. The traditional measurement methods have two significant limitations. First, it is insufficient to consider the interdependencies of stakeholders and their relevant issues. Compared to the traditional construction projects, the megaprojects involve the complicated interacting stakeholder structures, which forms the complex environment of megaprojects (Flyvbjerg, 2014). The traditional method is incompetent to measure the influence of stakeholder interdependencies on stakeholder performance. Second, it lacks the adaptability to measure the stakeholder performance in the dynamic environment. The megaprojects are long-term projects experiencing the changeable environment in the project duration (Kardes et al., 2013). The previous measurement tool is relied on the empirical data to make the assessment. However, the data availability of longitudinal stakeholder information is a bottleneck for stakeholder analysis in the dynamic environment of megaprojects (Mok et al., 2017c, Xue et al., 2020b). Instead of the traditional empirical analysis, the simulative method would be an alternative to assess the stakeholder performance bypassing the requirement of large quantities of empirical data (Ganco and Hoetker, 2009). Since the simulative model is useful to evaluate the dynamics of project environment (Alzraiee et al., 2015), the integration of the network model and simulative model has the potential to analyze the stakeholder interactions in the changeable complex environment of megaprojects.

2.8 Summary of the Chapter

In this chapter, the classical literature of stakeholder studies are comprehensively reviewed from the stakeholder concept, identification, assessment, and management. Besides, the deficiencies of current stakeholder studies on stakeholder dynamics, complexity, and performance are analyzed. Finally, based on the limitations of previous analytical methods, three major research gaps are highlighted as follows.

First, there is a lack of data collection and analyzing tools for analysis of stakeholder dynamics. The gap leads to the first research objective that calls for an analytical approach to evaluate stakeholder dynamics in megaprojects.

Second, the current network-based analytical approach for stakeholder complexity has a deficiency in presenting the longitudinal complex environment of megaprojects. Based on the research gap, the second research objective is proposed to establish an analytical approach to evaluate stakeholder complexities in megaprojects.

Third, there is a lack of effective measurement tools to analyze the stakeholder performance in both considerations of dynamic and complex environment of megaprojects. To overcome the research gap, an analytical approach is waiting to be proposed for evaluating stakeholder performance in dynamic and complex environment of megaprojects, which is the third research objective of the study.

Chapter 3 Research Methodology

3.1 Introduction

This chapter presents the research methods of this study. First, it overviews the research methods towards each research objective. Second, each research method is elaborated to show the adaptiveness on how to achieve the corresponding research objective.

3.2 Overview of research methods

As Table 3.1 shows, the research methods consist of two parts, including analytical methods and validation methods. First, since the research aim is to develop approaches on stakeholder analysis in dynamic and complex environment of megaprojects, the design of analytical methods is the major task in the research. Hence, the analytical methods listed in the Table 3.1 show the promising approaches which have the potential to be upgraded for achieving research objectives. Second, the validation method is essential to examine the effectiveness of new proposed analytical methods.

Table 3.1 Overview of research methods in the study

Research objectives	Analytical Method	Validation Method
1. To propose an analytical approach to evaluate stakeholder dynamics in the megaprojects.	Topic Modeling Approach	Case Study
2. To propose an analytical approach to evaluate stakeholder complexities in the megaprojects.	Network Modeling Approach	Case Study
3. To propose an analytical approach to evaluate stakeholder performance in dynamic and complex environment of megaprojects.	NK Modelling Approach	Case Study

3.3 Topic modeling approach

Given the development of text-mining technology, topic modeling has been utilized as a robust tool to detect core concepts from a considerable amount of texts (Yao et al., 2016). Topic models are derived from probabilistic graphical models to provide a method that discovers the hidden structure of data (Koller and Friedman, 2009). Traditional topic models such as PLSA (Hofmann, 2001) and LDA (Blei et al., 2003) belong to the Latent Semantic Indexing method. Through indexing, the document-term occurrence matrix can be reduced into low dimensions, which are denoted as latent features. According to these two classical topic models, several topic model-based methods have been proposed and applied in various areas including document classification, recommendation, and transfer learning (Li et al., 2015b, Rubin et al., 2012, Zhuang et al., 2010, Nguyen et al., 2015, Yang et al., 2015, Yao et al., 2018).

Although these models have been widely used in different research domains, unsupervised methods still face challenges concerning dynamic data, which are collected over time (Wang and Mccallum, 2006). LDA model is focused on the co-occurrence of words and their interdependencies but unable to capture the dynamic patterns of the texts (Wang and Mccallum, 2006). Therefore, the time-stamped document cannot be well analyzed by LDA to detect meaningful topics. To overcome the shortcomings of LDA, TOT is developed for exploring the dynamics of the text.

TOT model is established through a continuous distribution over time associated with topics considering word co-occurrence and document timestamps (Wang and Mccallum, 2006). Therefore, the time distribution of one topic is determined by the period when a strong word co-occurrence pattern bursts. TOT model has employed beta distribution over time, covering all data and used a Dirichlet distribution to sample each document and word co-occurrence similar to the LDA model (Wang and Mccallum, 2006). Thus, the proposed model has been considered as an effective topic model to explore the dynamic pattern of text documents. To measure the validity of the topic model, an automatic coherence measure proposed by Mimno et al. (2011) is used. This measure provides a semantic coherence score based on word co-occurrence among the featured words associated with the latent topic. The measure is used as an alternative method replacing the traditional human judge method to validate the results of the topic model (Chang et al., 2009).

In the research domain of megaprojects, the topic model has been used as a mining approach to review the literature and analyze online public opinions (Jiang et al., 2016b, Jiang et al., 2016a). However, a static topic model such as LDA remains as the dominating method used to explore information (Jiang et al., 2016c). Thus, a call for a more dynamic model exists to reflect further how information changes within the development of the project. Moreover, existing studies have focused on the mining and interpretation of results in a general way without specifying the information from stakeholders' perspectives. Therefore, learning through investigating past experiences from existing project documents is essential for project stakeholders. Furthermore, although the data-mining approaches have been extended to extract information from project documents (Le et al., 2018, Liu et al., 2018b), it is still a lack of a robust tool on analysis of text data among unstructured documents relevant to the project. Hence, it calls for further study of the topic model to make dynamic stakeholder analysis on a large number of unstructured text documents relevant to the project.

3.4 Network modeling approach

The concept of network analysis was first proposed by Moreno in 1934. Through the development of graphical and sociological theories, the concept was finalized to be an effective approach to analyze the interdependencies among various elements, systematically presented in a book published by Wasserman and Faust (1994). After that, the approach was introduced into a stakeholder-related study by Rowley (1997) to understand the influence mechanism among stakeholders. In the construction sector, Yang et al. (2009c) pointed out the significance of network analysis, which is to provide a comprehensive view of the entire relationship for improving stakeholder management in construction projects.

Network analysis is regarded as a useful tool to reflect the complexity in the systems in the megaprojects, thus highlighted by Mok et al. (2015) as a major direction for further stakeholder studies. Currently, there are two kinds of network analysis applied in the research of megaprojects. One is to analyze the inter-organizational ties in the projects (Mok et al., 2017a, Dogan et al., 2013), which considers the organizations as nodal elements. Another is to identify the interconnected issues among various organizations and quantify their interdependencies (Yang et al., 2014, Mok et al., 2017c), which considers the stakeholder-associated issues as nodal elements. However, either method is to describe the stakeholder interactions with a simplified one-mode network, which presents the stakeholders and its related issues separately (Opsahl et al., 2010). The advanced two-mode network analysis is conducted in a way that the integrated information of each stakeholder and its related issues presented in one network would reflect the reality more comprehensively (Latapy et al., 2008). Another limitation on the current research is that most of the networks are established at a point of time, which lacks the longitudinal studies to provide a full picture of stakeholder interactions in the whole lifecycle of megaprojects (Mok et al., 2017c). Because of these research limitations, this study employed the two-mode network analysis to consider the stakeholders and their associated issues as a system rather than two separate parts, and to assess their interactions in each stage of the megaprojects, for seeking better strategies to deal with stakeholder issues in a complex environment.

3.5 NK modelling approach

NK modelling was developed by the concept of fitness landscape, which was proposed by Wright (1932) in 1932. The fitness landscape was presented to show the biological evolution by assigning the adaptive values from the mathematical distribution under the certain set of gene combinations. In 1987, the NK model was proposed by Kauffman and Levin (1987) based on the fitness landscape. The model describes the adaptive walks of a group of gene combinations to explore the optimal evolutionary strategies. The parameter N represents the number of genes in a genotype, while the parameter K stands for the interactions of genes.

The NK modelling was brought into the domain of organization and management science in 1990's (Kauffman, 1993, Levinthal, 1997). The simulation model shows how complexity of organizations affects the performance of the system (Ganco, 2017), the strength of which is to provide a method to address the problems of organizational complexity that are difficult to answer empirically (Ganco and Hoetker, 2009). Later, the NK modelling was proved to be effective to study on the adaptive complex system (Capaldo and Giannoccaro, 2015), which is a system combined with the features of dynamics and complexity. The adaptive complex system is composed of networks of adaptive agents that continuously interact with each other over time (Holland, 1995). The model was used to discuss the strategic works in complex adaptive system with the computational simulations (Pascale et al., 1999). Compared to the model of system dynamics and agent-based modeling, the NK modelling approach is particularly competitive on the simulation of the coevolutionary complex system arising from the number of elements (N) and the dynamic interactions among them (K) (Giannoccaro et al., 2018). The model has been applied to understand the evolution mechanism of organizations under dynamic and complex environment. For instance, the NK simulation model helps the organization find a best position in a dynamic environment (Gavetti et al., 2005), assists the researchers in understanding the fit between dynamic organizational interactions and environment (Barr and Hanaki, 2008), and analyzes the interdependence relationship of overall complex supply chain networks (Capaldo and Giannoccaro, 2015). The simulation model has been tail-made to suit the analysis of real-data cases (Siggelkow, 2002), which is useful to understand the dynamic decision-making process with the adaptive search performed by various organizations.

Considered as a complex system, the megaproject involves a large number of stakeholders with complicated interactions during the long-term project duration. As an efficient method for the adaptive complex system, NK approach is eligible to study on dynamic stakeholder interactions in the complex project environment of megaprojects. In megaprojects, the stakeholders with various interests frequently communicate and coordinate with each other to achieve project goals and maximize their own benefits in the project duration, which is similar to a group of agents that seek the optimal performance peak by adaptive walks in the fitness landscape. Therefore, there is potential for introducing the NK simulation model into stakeholder studies to explore the stakeholder complexity and dynamics in megaprojects.

3.6 Case study

The case study is a critical method to validate the proposed approaches for stakeholder analysis (Mok et al., 2017b). The method was introduced by Eisenhardt (1989) as a way suitable for the exploration in the new research area, which has inadequate existing theories. The exploratory case study was popular in the stakeholder management domain to study the problems and challenges of stakeholder analysis (Mok et al., 2017a). Based on another classical study by Yin (2003), the case study could be divided into two approaches: a single-case research and multiple-cases study. Generally, most case studies in the stakeholder management domain are the single-case studies (Mok et al., 2017b, Ogunlana, 2010) or the two-comparative-cases studies (Olander and Landin, 2005, Olander and Landin, 2008, Yang et al., 2014). The limitation of the small number of cases is the generalizations of the research findings, which is a bottleneck of stakeholder studies development (Mok et al., 2017c). To overcome the shortcomings, the information-oriented case sampling strategy was applied to minimize the restrictions of the small sample size (Flyvbjerg, 2006).

The case study method is adopted to validate the proposed models for stakeholder analysis in dynamic and complex environment. The primary aim of the case study is to examine whether the function of each proposed model is effective under the stakeholder analysis scenario of megaprojects, not for the generalization of detailed stakeholder managerial implications in the case. Therefore, the single instrumental case study is conducted since the validation process would set a valuable example for the application of proposed analytical approaches in other megaprojects. The case selection is based on information-oriented sampling (Flyvbjerg, 2006). There are two major criteria. On the one hand, the selected case involves various stakeholders and has records of interactions between stakeholders and relevant issues. On the other hand, the selected case prefers the famous megaproject which has substantial impacts on society, economy, and environment, which was also echoed by similar studies in the megaprojects (Mok et al., 2017c). To follow the criteria, the Hong Kong-Zhuhai-Macao Bridge (HZMB) was selected.

HZMB is a 55-km cross-boundary mega transport project, connecting Hong Kong, Macau, and Zhuhai—the three major cities located at the Pearl River Delta in China. HZMB was built to enhance the economic and sustainable development of the Greater Bay Region. The project was planned in 2008, and the construction work began on 15 December 2009 on the Guangdong side. Nine years later, the construction work was completed on 6 February 2018 and was opened to the public on 24 October 2018. The cases of stakeholder-associated public concerns, conflicts, and relationship management performance in HZMB are chosen as three scenarios to validate the effectiveness of the proposed models in dynamic and complex environment.

3.7 Summary of the Chapter

In summary, the promising methods of stakeholder analysis consist of three approaches in the domain of computer science, mathematics, and complex adaptive system. The Topic modeling approach has the potential to make dynamic stakeholder analysis with exploring knowledge from the longitudinal project documents. The network modeling approach is useful to systematically analyze stakeholder complexity by presenting the complex structure among stakeholders. The NK modeling approach is able to reflect the dynamic stakeholder interactions with the adaptive walks of agents on the stakeholder performance landscape. Besides, the case study is used to validate the proposed analytical methods. In the study, three stakeholder scenarios in Hong Kong – Zhuhai – Macao Bridge project are provided to validate the effectiveness of the proposed stakeholder analytical models in dynamic and complex environment, including stakeholder-associated public concerns, stakeholder conflicts, and stakeholder performance in relationship management.

Chapter 4 A stakeholder-associated topic model for analysis of stakeholder dynamics[2]

4.1 Introduction

Although stakeholder dynamics have been considered as a significant feature of megaprojects (Mok et al., 2015, Yang et al., 2009b), few studies provide the solid evidence of chronological patterns of stakeholders in various project phases. Existing studies have performed a static analysis of stakeholder issues through questionnaires, surveys, and interviews; however, they have failed to show the dynamic features involved during the whole project duration (Lin et al., 2018a). Although data from surveys and interviews have revealed patterns of stakeholder issues to some extent, results are still highly dependent on the involved respondents (Vandeweerdt et al., 2016). A study on the dynamics of stakeholders and their relevant issues in different stages of megaprojects is still missing due to the lack of objective longitudinal empirical evidence to reflect the dynamic patterns in the view of various stakeholders. The topic modeling approach has potential to overcome the limitation (Xue et al., 2020b).

Given the development of text-mining technology, topic modeling has been utilized as a robust tool to detect core concepts from a considerable amount of texts (Yao et al.,

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[2] This chapter is relevant to the publication:
Xue, J., Shen, G. Q., Li, Y., Wang, J. & Zafar, I. 2020. Dynamic Stakeholder-Associated Topic Modeling on Public Concerns in Megainfrastructure Projects: Case of Hong Kong–Zhuhai–Macao Bridge. Journal of Management in Engineering, 36, 04020078.

2016). Topic models are established according to various probabilistic theories, including Probability Latent Semantic Analysis (PLSA), Latent Dirichlet Allocation (LDA), and Topic Over Time (TOT) (Li et al., 2015b). TOT model is a dynamic topic model, which does not only explores the contents of core concepts but also reflects the dynamic patterns of concepts (Wang and Mccallum, 2006). Therefore, analyzing project documents through the mining of critical stakeholder issues and presenting the dynamics of various stakeholder issues in project duration is considered a potential solution. However, given that the current TOT model has few considerations of stakeholders' identifications, it should be further developed to integrate the evaluation function of stakeholders' participation.

In this study, the objective is to propose a dynamic analytical method for stakeholder analysis in megaprojects. The dynamic stakeholder-associated topic modeling approach is designed to identify, evaluate, and manage the stakeholders and their relevant issues by learning the experience from large quantities of unstructured documents relevant to the project. The approach is composed of three parts, including the TOT text-mining model, stakeholder relevance scoring system, and managerial map.

4.2 Model Design

4.2.1 Research framework

The framework of the dynamic stakeholder-associated topic modeling approach (DSTM) is presented in Figure 4.1. First, data were collected from the official documents relevant to the project. Second, the TOT model was employed to detect the stakeholder issues in the project, through which it was obtained the critical stakeholder issues and the annual trend of each stakeholder issue. Third, according to the identified stakeholder issues, we developed a scoring system to measure the link of each stakeholder issue and the corresponding stakeholders. Fourth, we generated the stakeholder relevance score for each stakeholder issue. Fifth, we designed a managerial map for stakeholder issues in megaprojects considering the annual popularity and stakeholder relevance of stakeholder issues, providing relevant guides for decision-makers and project stakeholders in managing stakeholder issues in different stages of megaprojects.

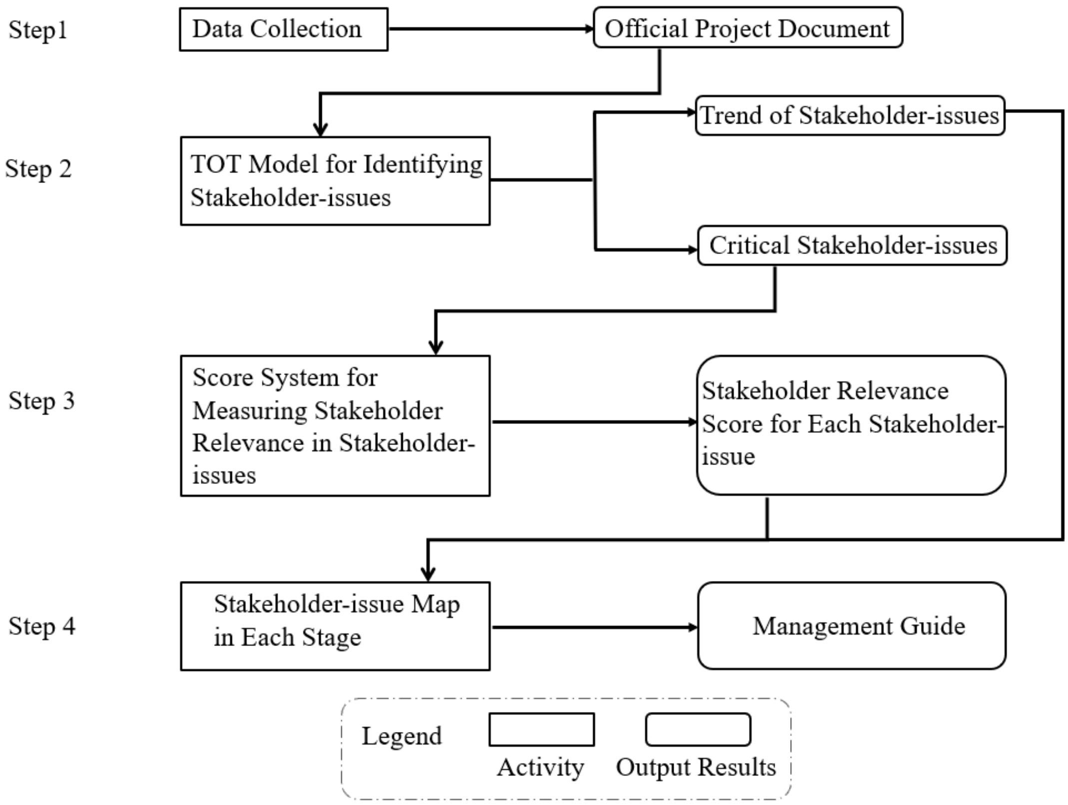

Figure 4.1 The framework of DSTM

4.2.2 Data collection

Official documents relevant to the project are used as the primary data sources in conducting dynamic analysis, given that they provide time-stamped information of stakeholder issues in the changeable environment of mega infrastructure projects (Lee et al., 2017b). These documents are required to meet two criteria. First, the content of these documents should be highly relevant to stakeholder issues. Second, these documents should follow the text format given that the text-mining approach will be applied to implement data analysis.

In this study, the official documents in the library of the Legislative Council of Hong Kong are chosen as the pool of datasets. Given that the Legislative Council of Hong

Kong is an institution wherein the council members who represent the general public participate in the social governance (Vandeweerdt et al., 2016), council documents provide a unique opportunity to reflect the major stakeholder issues in an official way. Moreover, most of the documents of the legislative council are open for the public in a democratic society. Thus, researchers can access legislative councils' documents, which contain reliable longitudinal information of stakeholder issues related to mega infrastructure projects. For instance, the timestamped archives of local mega infrastructure projects can be explored in a variety of congress libraries:

United Kingdom (https://archives.parliament.uk/), Singapore (https://sprs.parl.gov.sg/search/home), United States (https://www.congress.gov/congressional-record), Hong Kong (https://www.legco.gov.hk/general/english/library/index.html), Canada (https://lop.parl.ca/sites/PublicWebsite/default/en_CA/), etc.

4.2.3 TOT model

TOT model was developed based on the traditional LDA. TOT model detects the topic of the target text, considering not only the word co-occurrences but also temporal information. Therefore, the TOT model is used to explore the topic distributions in the documents with the timestamp, reflecting the dynamic features of the detected topic (Wang and Mccallum, 2006). The graphical representation of TOT, as proposed by Wang and McCallum (2006), is shown in Figure 4.2, whereas the summary of the notations used in this section is shown in Table 4.1. The generative process used in Gibbs sampling for parameter estimation is stated as follows:

1. For each topic z, draw a multinomial distribution $\emptyset_z$ from a Dirichlet prior β.
2. For each document d, draw a multinomial distribution θ_d from a Dirichlet prior α.
3. For each word in document *d*:
   (a) Draw a topic z_{di} from multinomial θ_d,
   (b) Draw a word w_{di} from multinomial $\emptyset_{z_{di}}$,
   (c) Draw a timestamp t_{di} from Beta $\varphi_{z_{di}}$.

In this study, the setting of hyper-parameter α and β is the same as in TOT suggested by Wang and Mccallum (2006), wherein α = 50/T and β = 0.1. Moreover, data preprocessing is conducted with term frequency-inverse document frequency (TF-IDF) filtering before running the TOT model to improve the quality of the text, which has removed some frequent but meaningless words (Ramos, 2003).

Table 4.1 Notations of the symbols in TOT

Symbol	Description
T	Number of topics
D	Number of documents
N_d	Number of word tokens in document d
θ_d	The multinomial distributions of topics specific to the document d
$\emptyset_z$	The multinomial distributions of words specific to topic z
φ_z	The beta distributions of time specific to topic z
z_{di}	The topic associated with the ith token in document d
w_{di}	The ith token in document d
t_{di}	The timestamp associated with the ith token in document d

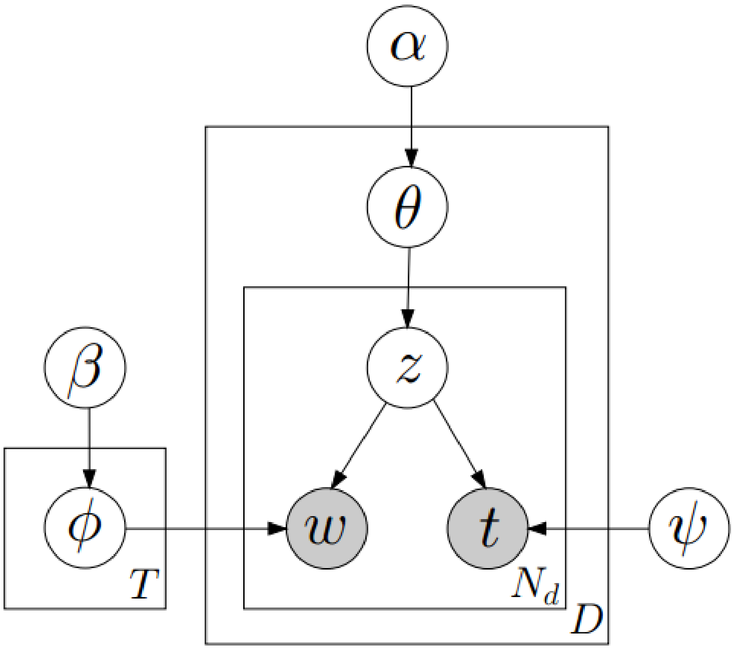

Figure 4.2 Graphic representation of the TOT model for Gibbs sampling

After the Gibbs sampling procedure, it is obtained three probability matrixes: document-topic probability matrix, topic-word probability matrix, and topic-time probability matrix. The first one is the probability distribution over the topics for each document. The second one is the probability distribution over the words for each topic. The last one is the probability distribution over time for each topic.

To describe each topic, 15 most probable feature terms from the topic-word probability matrix are extracted and listed in descending order of their probabilities related to the topic, which are generated by the TOT model. The threshold setting of the top 15 feature terms to interpret the topic is based on two considerations. On the one hand, the number of selected feature terms varies in the previous studies with the scale of top 5, top 10, top 15, and top 20, which proves the range of selected feature terms is not sensitive to the research results (Jiang et al., 2016b, Wang and Mccallum, 2006, Mimno et al., 2011, Jiang et al., 2016c). On the other hand, the coherence validity test of TOT modeling is suggested to be undertaken with the top 15 feature terms (Mimno et al., 2011). Therefore, the top 15 featured words were selected, in consideration of the concept interpretation and the modeling validity test requirement.

To measure the validity of the coherence and typicality of the topics generated by the TOT model, a score called topic coherence is used to assess the results (Mimno et al., 2011). Given the feature word list $V^{(z)}$, topic coherence is calculated for each topic z through the following Formula 1:

$$C\left(Z;V^{(z)}\right)=\sum_{m=2}^{15}\sum_{l=1}^{m-1} log\,\frac{D\left(v_m^{(z)},v_l^{(z)}\right)+1}{D(v_l^{(z)})},\ (1)$$

where $\mathrm{D(v)}$ represents the number of documents the feature word v appears, and $\mathrm{D}(v_m, v_n)$ is the number of documents that contain feature terms v_m and v_n. An absolute value of coherence that is closer to 0 indicates a more representative topic.

4.2.4 Scoring system for stakeholder relevance

When displaying the relative importance of each stakeholder and identified topic Z, a relevance score is utilized. Given the topic Z and the timestamp Y and the stakeholder word v_h, we calculate the probability of how much v_h contributes to each feature word v_w of topic Z in the documents from timestamp Y. The probability is calculated by counting the frequency of paragraphs where stakeholder v_h occurs given the paragraphs containing feature word v_w for all documents from timestamp Y has the feature word v_w occurs. We multiply this probability and the probability of v_w under topic Z, which has already been analyzed by the TOT model. Finally, the relevance score is formulated as the sum of the product of these multiplications. Let $\mathrm{S}(v_w, d)$ be the number of paragraphs that v_w appears in the document d, $\mathrm{S}(v_m, v_n, \mathrm{d})$ be the number of paragraphs that v_m and v_n appear together in the document d, $D(v, Y)$ be the number of documents containing word v with the timestamp Y, and $p(v_w, Z)$ be the probability of feature word v_w of topic Z, which is derived from the topic-word probability matrix. The score is defined in the Formula 2 as follows:

$$S(v_h, Y, Z) = \sum_{w=1}^{W} \frac{\sum_{d=1}^{D(Y)} \frac{S(v_w, v_h, d)}{S(v_w, d)}}{D(v_w, Y)} * p(v_w, Z), \quad (2)$$

where $\mathrm{D(Y)}$ is the number of documents with timestamp Y. In our case study, it is calculated the relevance score of 29 kinds of stakeholders, which is generated by fast browsing the content of project documents. The stakeholders include the Hong Kong SAR government, the Central government, the Macao government, the Guangdong provincial government, the Zhuhai government, the Coordination group, the HZMB Authority, the legislative council, the district council, the ruling party, the opposition party, the court, aviation, tenders, contractors, consultants, subcontractors, suppliers workers, environmental groups, the local community, fishermen, the logistics industry, the tourism industry, the immigration and customs department, shuttle operators, insurance companies, the media, and Hong Kong citizens.

4.2.5 Proposed managerial map for stakeholder-associated issues

A managerial map for stakeholder issues called MSI-Map is designed to show the importance degree of stakeholder issues with a specific timestamp according to the relationship with the popularity of the stakeholder issues and the scores of stakeholder relevance. The vertical axis represents the popularity of each topic using the average annual document correlated probability of the corresponding topic, whereas the horizontal axis represents the relevance of the stakeholders using the sum of stakeholder relevance scores related to each topic. The graph is divided into four blocks by the average of horizontal and vertical values of all points. In Figures 4.3 and 4.4, the managerial map is divided into four zones, which classifies the criticalness of stakeholder issues according to four levels. Zone One is composed of stakeholder issues with high popularity and stakeholder relevance. Zone Two includes stakeholder issues with high popularity and limited stakeholder relevance. Zone Three represents the stakeholder issues with low popularity and wide stakeholder relevance. Zone Four has stakeholder issues with little popularity and limited stakeholder relevance.

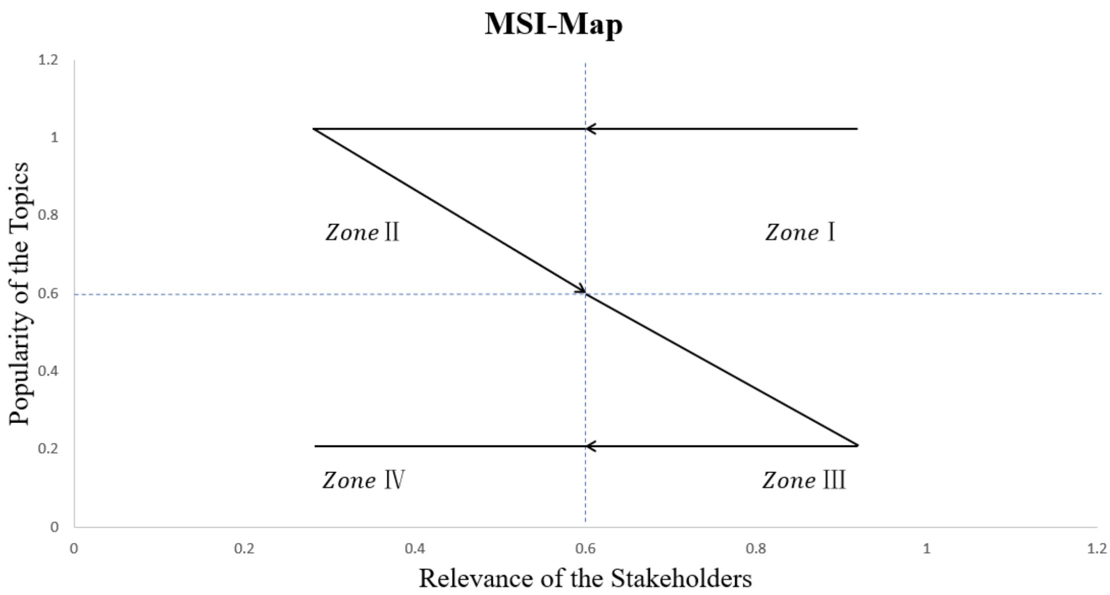

Figure 4.3 "Mirror Z" approach for the management of stakeholder-issues

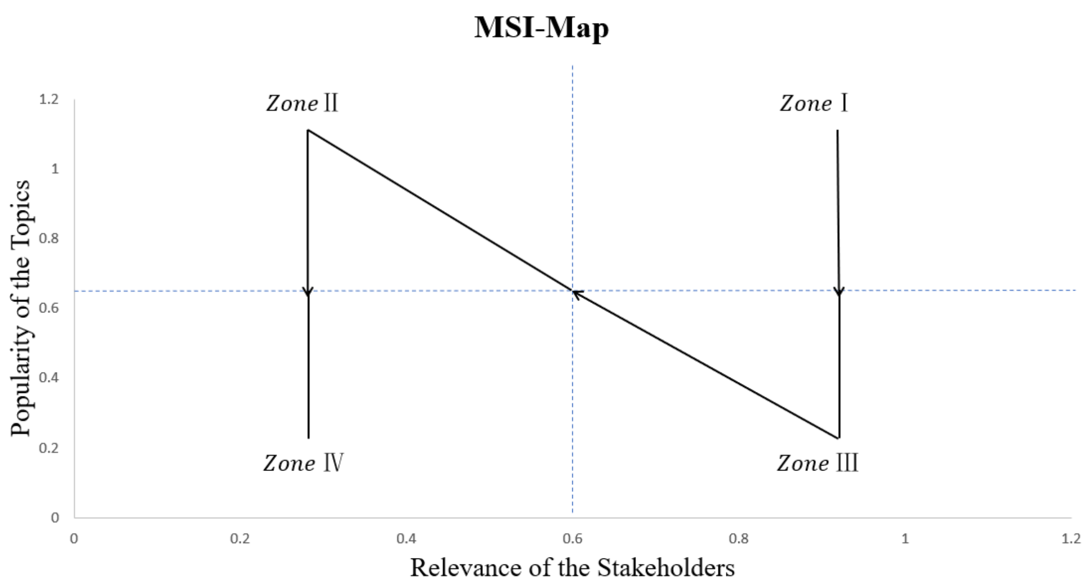

Figure 4.4 "Letter N" approach for the management of stakeholder-issues

Two strategies have been proposed based on the managerial map. The first one is for decision-makers, whereas the other one is for each kind of stakeholders. The decision-makers focus more on the trend popularity of stakeholder issues rather than the stakeholder relevance. Thus, addressing the issues receiving high public attention is essential to decision-makers. Each project stakeholder always considers its interest first, therefore paying more attention to the stakeholder relevance. The divergence on the focus between decision-makers and project stakeholders leads to different priority paths on the managerial map when ranking the criticalness of stakeholder issues. For decision-makers, the management priority on stakeholder issues is to address the high popularity issues first from Zone One to Zone Four, which is similar to the mirror image of the letter "Z" shown in Figure 4. For project stakeholders, the management priority on stakeholder issues is to address first the high stakeholder-relevant issues from Zone One to Zone Three to Zone Two to Zone Four, which is similar to the letter "N" as shown in Figure 4. Therefore, the "Mirror Z" and "Letter N" strategies are proposed to determine the management priority of stakeholder issues in mega infrastructure projects for decision-makers and project stakeholders, respectively.

4.3 Case Study – Stakeholder-associated public concerns in HZMB

The proposed stakeholder-associated topic modeling method could be used to explore stakeholder dynamics of any topics of stakeholder issues. The analytical content of stakeholder issues is determined by the content of original unstructured documents relevant to the project that input to the model. In the case study, the project documents related to the stakeholder-associated public concerns in Hong Kong –Zhuhai – Macao Bridge (HZMB) were fed into the model. Through the proposed DSTM approach, we detected the stakeholder-associated public concerns and their trends in the timeline and drew the managerial map for project stakeholders to achieve dynamic stakeholder management of public concern in three different project phases: planning (2003–2009), construction (2010–2017), and handover (2018). The case study validated the effectiveness of proposed DSTM approach on analysis of stakeholder dynamics by using a real megaproject case.

4.3.1 Results of the data collection

As the Figure 4.5 shows, we downloaded the project documents related to HZMB from the open-source library of Hong Kong Legislative Council by searching the terms: "Hong Kong–Zhuhai–Macao Bridge" and "HZMB." Consequently, it was obtained the raw documents listed in the Figure 4.6, which would be used for further data cleaning.

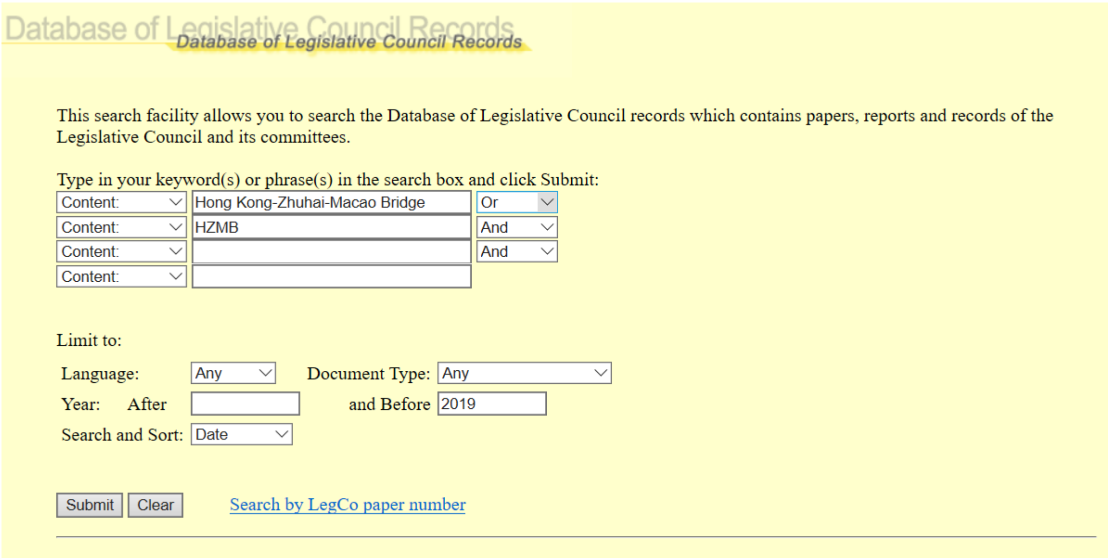

Figure 4.5 The example of a database of legislative council records

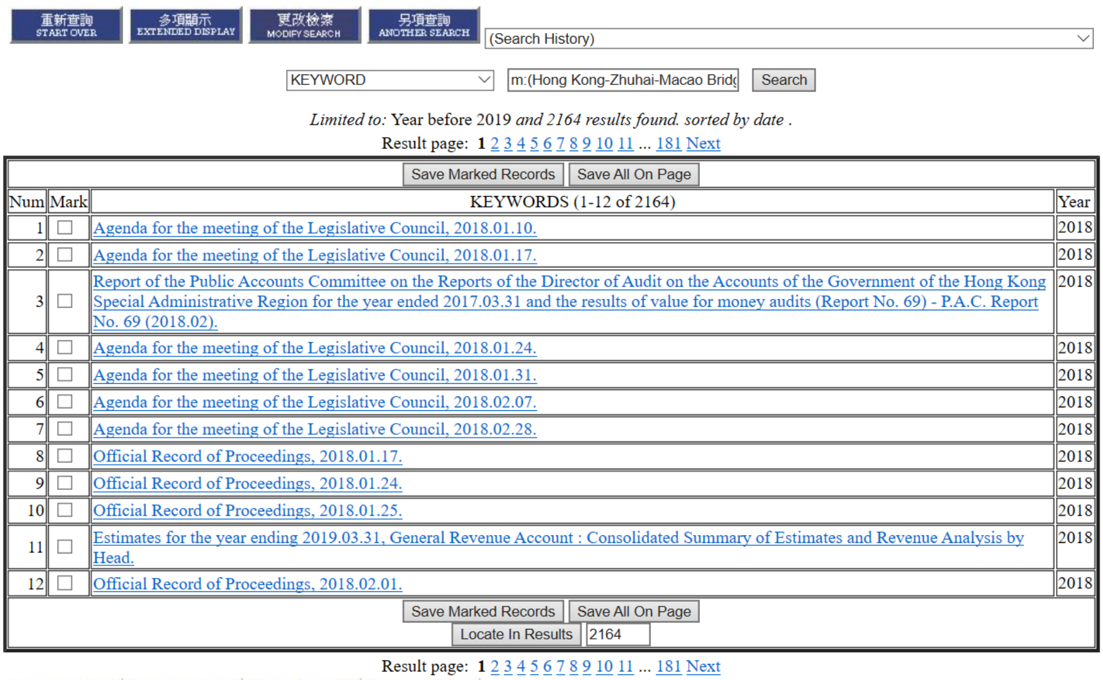

Figure 4.6 The example of raw documents related to HZMB

Given that unrelated contents to the project were found in the collected raw documents, we did a data cleaning by extracting the paragraphs from the raw files with the keywords related to HZMB, ensuring the high relevance between data and the project. As a result, we collected a total of 1748 official documents on HZMB from 2003 to

2018, including the planning, construction, and handover stages. The number distribution of collected documents is shown in the Figure 4.7, which presents the number of documents in each year. According to the classical literature of TOT modeling, the model is proved to be valid from the mega dataset of State-of-Union Addresses to the medium dataset of email collections, and the small dataset of conference proceedings, indicating the size of the dataset is not the constraint of the validity of TOT model (Wang and Mccallum, 2006). Therefore, the number of documents in the case (1748) is adequate for the modeling research, which is also in line with the topic model research by the similar size of the dataset (Jiang et al., 2016c).

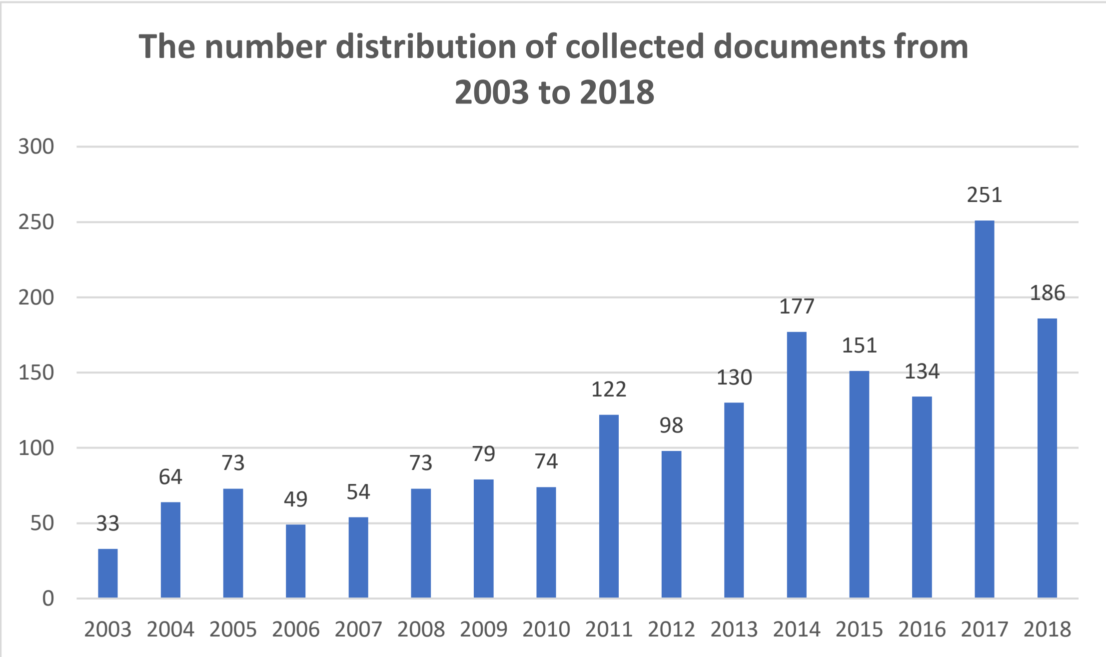

Figure 4.7 The distribution of collected documents from 2003 to 2018

4.3.2 Critical public concerns

Through TOT modeling, the 16-topic model was considered as the most valid model to interpret the documents by the sensitivity analysis according to the topic coherence score shown in Table 4.2. Therefore, 16 topics on public concerns were explored, as presented in Table 4.3. Each topic has corresponding top 15 featured words that exhibited the highest relevance with the clustered topic, indicating the concept of the topic. For instance, clustered topic 0 had the highest relevant feature terms "align" and "lantau," which represent the landing location of HZMB. Moreover, other words such as "tunnel," "environment," and "finance" reflect the considerations in the alignment, thus leading to the concept of topic 0 as "alignment."

In light of the featured words, we interpreted the concept of each topic as follows: alignment, local community, cooperation across governments, environment, immigration and custom service, operation on cross-boundary traffic, local traffic in connective areas, local industry, operation on local traffic, urban development, finance, construction, design, regional economy, and commercial development. The identified topics represent the major public concerns in the project duration on HZMB from 2003 to 2018.

Table 4.2. Distribution of coherences for different topic numbers

Topic Number	10	12	14	16	18	20	22	24
Average Coherence	-48.5053	-48.9602	-51.1143	**-47.1811**	-51.8116	-48.1022	-48.8801	-49.1057

Table 4.3. Top 15 featured terms for each topic in the 16-topic model

Topic	Concept	Feature Terms
#0	alignment	align, lantau, passing, hope, improv, facil, clearance, infrastructure, engine, delay, transport, plan, tunnel, environment, financ
#1	local community	commun, western, infrastructure, control, demand, tuenmun, hksar, preliminary, mainland, macao, arrang, direct, plan, develop, transport
#2	cooperation across governments	volum, invest, expedit, expediti, reach, nwnt, agreement, examin, coordinationgroup, environmentalimpact, competit, contribut, integr, corridor, economicbenefit
#3	environment	environmentalimpact, eastern, cargo, integr, judgment, contribut, economicbenefit, competit, corridor, examin, landfall, mitig, reach, cheklapkok, cooper
#4	immigration and custom service	control, boundary, tuenmun, plan, environ, problem, increase, hksar, develop, transport, territory, environmentalimpactassess, commun, enhance, cost
#5	operation on cross-boundary traffic	road, airport, region, feasibl, traffic, investing, cross, implement, land, future, improv, island, passing, highway, progress
#6	local traffic in connective areas	rail, flow, benefit, tungchung, technic, passing, infrastructur, promot, demand, origin, vehicle, increase, lantau, commenc, region
#7	local industry	service, termin, flow, site, highway, park, investing, time, legal, marin, environment, facil, control, problem, align
#8	operation on local traffic	rail, oper, highway, local, complet, future, increase, connect, hope, facil, toll, commenc, macao, cross, road
#9	local connectivity	north, opportune, viaduct, rout, railway, promot, local, time, toll, guangdong, tmclkl, tmwb, boundary, clearance, region
#10	urban development	lantau, time, mainland, commenc, align, vehicle, assess, environ, preliminary, origin, progress, oper, park, problem, complet
#11	finance	expenditure, cooper, viaduct, boundary, land, crossboundari, vehicle, oper, logist, enhance, rail, plan, site, preliminary, billion
#12	construction	construct, island, guangdong, origin, facility, control, mainbridg, develop, facil, cost, econom, manag, hope, design, preliminari
#13	design	design, assess, zhuhai, public, govern, local, estim, service, macao, hope, lantau, environment, commiss, enhance, commenc
#14	regional economy	public, strategy, connect, crossboundari, govern, cost, technic, infrastructur, site, region, arrang, territory, logist, vehicle, financ
#15	commercial development	shop, bridgeheadeconomi, cheklapkok, busi, advancework, eastern, facility, preliminary, infrastructur, strategy, tuenmuncheklapkok, econom, accid, commerci, hksar

4.3.3 Trend of public concerns

Given the consideration of timestamp information in each document by the TOT model, a trend of public concerns is detected, illustrating the dynamic patterns of each public concern in the project duration. The trend of each public concern is shown in Figure 4.8. The figure reflects the average correlation probability of the documents under each topic in the timeline derived from the document-topic probability matrix of TOT results, reflecting the annual popularity of the topics in the dataset. Generally, public concerns could be divided into three categories due to the various level of popularity for each public concern in HZMB. The detected dynamic features can be explained with the development history of HZMB, which proves the validity of the proposed stakeholder-associated topic modeling approach. The detailed interpretations are as follows.

Figure 4.8. The trend of public concerns in HZMB

First, the most critical public concern is from the cooperation across governments (#2), which attracts high popularity from 2008 to 2014. This period starts from the late planning stage to the early construction stage. Given that the period is at the decision-making phase of HZMB, policies and agreements are reached among three governments: Hong Kong SAR, Macao SAR, and Guangdong Province. Therefore, the performance of governmental cooperation has received substantial public attention and become the only hot topic among public concerns during the given period.

Second, environment (#3), local connectivity (#9), finance (#11), and commercial development (#15) have received medium popularity among critical public concerns. Interestingly, all these four kinds of concerns have received their peaks at the early and late phases of the project duration. First, the environmental issues (#3) have become the focus when the worries of the adequate protection measures on Chinese White Dolphin, one endangered species, have been raised among the public in the early planning stage of HZMB. The issue resurfaces given that the project has been faced with the juridical review of its environmental impact assessment that caused severe project delays in the early construction stage. Besides, the concern of local connectivity (#9) is mainly from the residents in the neighborhood of the project. At the beginning of the planning stage, the voice of simultaneous completion of local connectivity and HZMB has been raised by local residents with the willingness to upgrade the less-developed road system within the areas affected by the projects. However, the local residents' advocating voice turned to worries as the construction of the local connectivity faced project delays when HZMB is close to completion. A similar situation related to commercial development (#15) has occurred, which raises public concern. Given that Hong Kong is an advanced commercial city, one commercial development plan attached with HZMB called "bridgehead economy" has been proposed in the early planning stage, which has gained different opinions from the public. However, the plan has faced fierce debate among the public due to the delay and the technical difficulties at the late construction stage of HZMB. Furthermore, financial arrangement (#11) is another critical public concern. The financial pressure caused by HZMB is widely discussed among public in the initial planning stage, wherein the public worries have escalated due to the severe cost overrun of the project at the end of the construction stage.

Third, besides the five groups of public concerns mentioned above, the other 11 types of public concerns attract the third-level popularity, reflecting the dynamics of abundant concerns from the public.

4.3.4 Managerial map for public concerns

The managerial map of public concerns presents the information on the popularity and stakeholder relevance for each public concern in three different stages: planning (2003–

2009), construction (2010–2017), and handover (2018). As shown in Figure 4.9, the managerial map is provided for decision-makers to learn the management priority of public concerns in the development of HZMB with the "Mirror Z" approach. Besides, Figures 4.10–4.12 indicate the management priority of public concerns for a variety of project stakeholders using the "Letter N" approach, including political groups, construction groups, and pressure groups. The instructions on management priority would benefit decision-makers and project stakeholders to understand the criticalness of public concerns and provide the management guide for public concerns in future mega infrastructure projects.

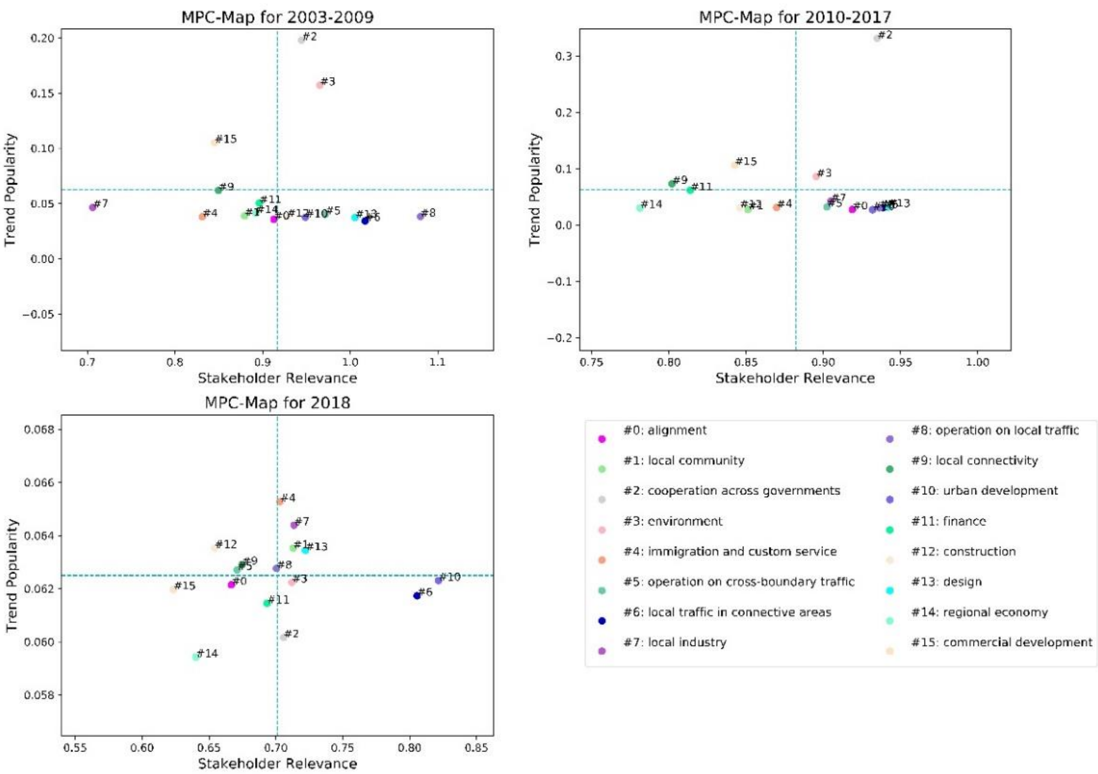

Figure 4.9. Managerial map of public concerns for decision-makers

(1) Decision-makers

Decision-makers overview the general stakeholder relevance for each public concern to understand the stakeholder participation hereby determining the management priority based on the MPC-Map by the "Mirror Z" strategy. In Figure 4.9, the stakeholder relevance in the x-axis represents the involvement level of all project stakeholder groups listed in Table 4.2. According to the results in Figure 4.9, the management guide for decision-makers in each project phase is discussed as follows.

Planning Stage

In the planning stage, one of the most critical public concerns in Zone One is cooperation across regional governments (#2). Given that the political issues are sensitive to the success of mega infrastructure projects (Flyvbjerg, 2014), government cooperation always attracts much attention from the general public, especially in the cross-boundary transport project, which also influences the interest of stakeholders. Hence, government cooperation is quite significant for maintaining a good working relationship among governments across different regions and keeping the collaboration information transparent toward the public. In response to the broad public and stakeholder focus on the governmental cooperation issue, decision-makers need to disclose timely information to dismiss the public worries on "closed decisions" made by authorities (Wu et al., 2019). The instant and transparent information are also recommended to be disseminated by multiple accesses: press, websites, and social media (Li et al., 2012b, Leung et al., 2013), which could benefit a wide range of stakeholders to receive the latest project progress under the political level to make their corresponding preparations accordingly.

Another critical public concern in Zone One is environmental issues (#3). This study supports the findings of the existing research on environmental issues, which are considered as an ongoing concern among various stakeholders in the early site selection phase (Min et al., 2018). The environmental impact of the project is a serious concern among the public, indicating the criticalness of early public participation in the planning stage (Diduck et al., 2013, Herian et al., 2012). Therefore, the decision-makers are suggested to build a widely accepted process for environmental impact assessment through the frequent public consultations among project stakeholders (Liu et al., 2018a). Besides, the proper public petition mechanism is also required to assist the local residents and green groups in conveying their worries and receiving the feedback from the authorities (Xie et al., 2014).

Moreover, commercial development (#15) is a focal public concern in Zone Two with limited stakeholder relevance. The primarily affected stakeholders on this issue are the government and local residents. The precise explanation of positive local economic benefits has been proved to be useful to gain public support (Tummers, 2011, Valentin et al., 2018). In HZMB, one proposal of the development of commercial facilities was initiated by decision-makers in the project planning, which received the warm welcome of local communities.

Construction Stage

In the construction stage, besides the three focal public concerns (government cooperation, environment, and commercial development), another two public concerns have appeared in Zone Two: local connectivity (#9) and finance (#11).

The local connectivity (#9) is introduced by the worries of local residents on the potential heavy traffic pressures caused by the completion of HZMB, which escalated when it was closer to the project due date. Since the expert power of technicians and scientists are capable of enhancing the trust between relevant stakeholders (Leung et al., 2013), the decision-makers are suggested to invite professionals to communicate with the local public to ease their worries.

The financial issue (#11) is caused by the public doubts on financial viability facing the severe cost overrun of HZMB. The number of relevant stakeholders is limited, including the government and contractors. Hence, the focus group meeting is recommended to arrange between relevant stakeholders and public representatives to achieve the collaborations and consensus in the process of applying additional bills to continue the project (Rowe and Frewer, 2005).

Handover stage

In the handover stage, the top critical public concerns in Zone One include the local community (#1), local industry (#7), custom and immigration affairs (#4), and design (#13).

As the project is getting closer to the operation, the realization level for the original planning proposal has started to attract substantial public concerns, which introduces the reviews of the promised economic benefits for the local community (#1) and the performance of project design (#13). The increase in public attention has also exerted the pressure for all internal project stakeholders (contractors, subcontractors, suppliers, and consultants) and the government to prepare for a proper explanation of the divergence between the original planning proposal and the actual project toward the public. Therefore, decision-makers need to establish sufficient public communication access (i.e., public hotline and public email) together with all relevant stakeholders to respond to the complaints from the public instantly (Wang, 2001, Rowe and Frewer, 2005).

Another two public concerns are relevant to the local industry (#7) and custom and immigration affairs (#4). The two issues are referred to the technical arrangements of operational management for HZMB. Therefore, the roundtable negotiation meeting has the potential to address the concerns by inviting all the relevant professionals and public representatives (Xie et al., 2019).

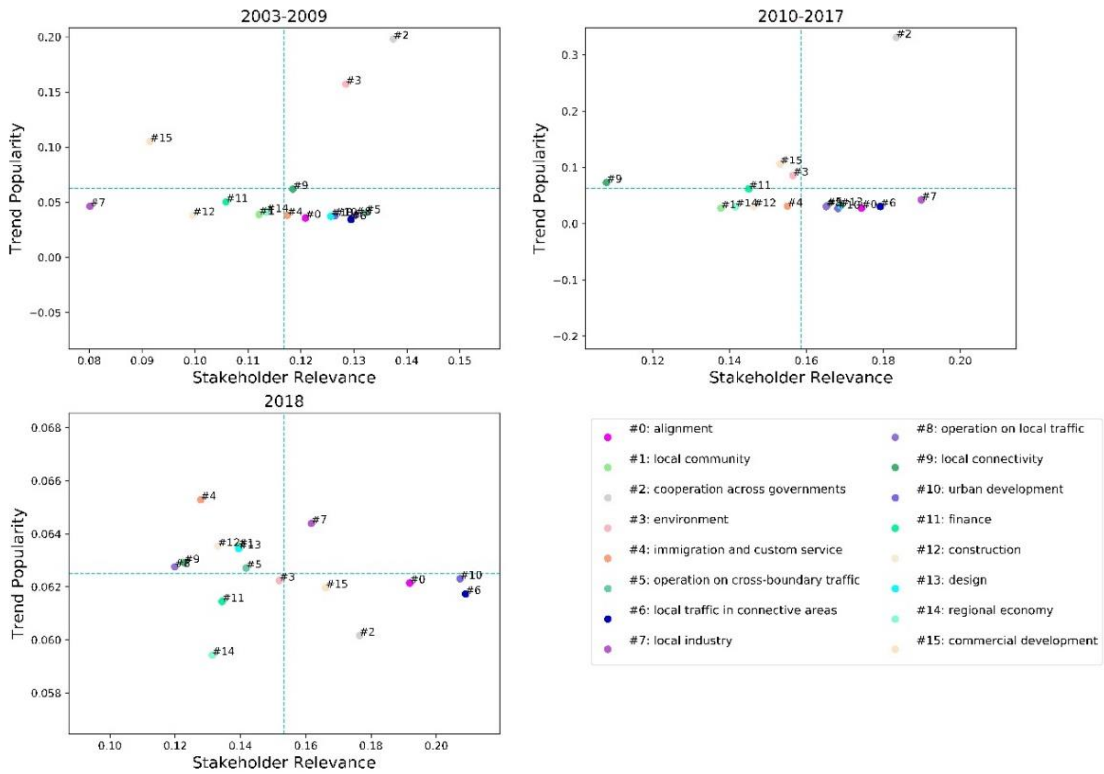

Figure 4.10 Managerial map of public concerns for political groups

(2) Political Groups

Political groups hold various political powers in the council system of Hong Kong, including legislative council, district council, the ruling party, and the opposition party. In Figure 4.10, the stakeholder relevance in the x-axis represents the involvement level of the abovementioned four political groups. According to the results in Figure 4.10, the management guide for political groups in each project phase is discussed using the "Letter N" strategy.

Compared with the general stakeholder relevance shown in Figure 4.9, the concern of local connectivity (#9) moves from Zone Two to Zone One in the planning stage, as shown in Figure 4.10. Thus, the issue of local links has become one of the most critical public concerns for political groups. The development synchronization of local transport systems connecting the HZMB with other urban areas of Hong Kong is one of the significant issues fiercely debated among various political groups. The issue has heavily influenced the final pass of bills related to the project in the planning stage. Therefore, the public-participated advisory committee is recommended to be founded by inviting different political groups and the representatives of local communities to boost the satisfactory development plan of local connectivity with the planning of mega infrastructure projects (Plummer and Taylor, 2013, Webler and Tuler, 2006).

The public concern on the local industry (#7) is located in Zone Three with the highest stakeholder relevance in the construction stage, which makes it the only critical concern located in Zone One in the handover stage. The criticalness of public concerns on the local industry is also validated by the development history of HZMB. The local industry, which mainly refers to the logistics and tourism industry, is a significant issue in the council, given the economic benefits brought by the construction of HZMB in Hong Kong. Therefore, the council has been regularly debating the proposed policies on the development of the local industry. The debate among political groups is initiated at the start of the construction stage and intensified at the handover stage when the project is getting closer to completion and operation. As shown in Figure 4.10, the issue of the local industry attracts less public attention in the construction stage before it becomes a hot topic among the public in the handover stage. Thus, the construction stage would be a suitable period to hold the roundtable negotiation forums between political groups and the representatives of relevant local industry (i.e., logistics, tourism) (Xie et al., 2014), for reaching the acceptable agreement among relevant stakeholders concerning the development strategy of local industry.

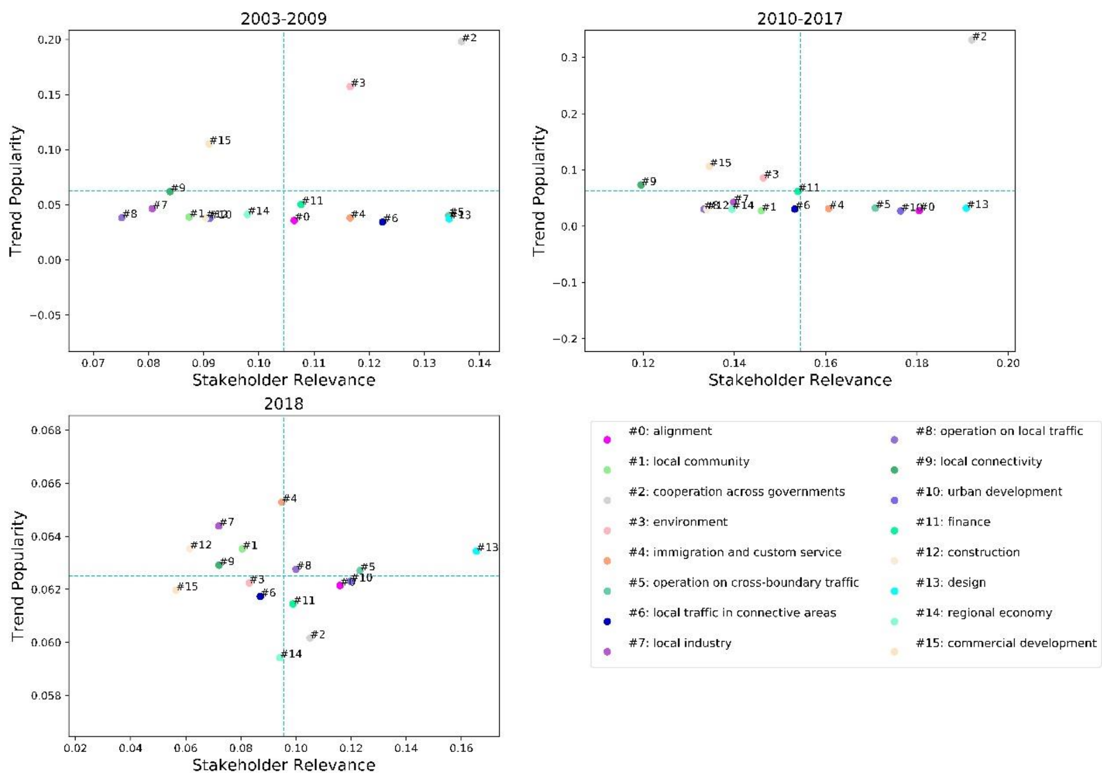

Figure 4.11 Managerial map of public concerns for construction groups

(3) Construction Groups

Construction groups are composed of different participants who are directly involved in the construction work of HZMB, including contractors, consultants, subcontractors, suppliers, and workers. In Figure 4.11, the stakeholder relevance in the x-axis represents the involvement level of the abovementioned five construction groups. According to the results in Figure 4.11, the management guide for construction groups in each project phase is discussed by the “Letter N” strategy.

The public concern of design (#13) has great relevance to construction groups, which is located in Zone Three, with the highest stakeholder relevance during the planning and construction stages. The public popularity of the project design dramatically increases in the handover stage, causing the issue to move to Zone One. The mapping result reflects the close correlation between construction groups and design issues, given that the project design is highly relevant to the behavior of construction groups in the project (Zhao et al., 2016). Less public attention to design issues in the planning and construction stages would not disturb the activities of construction groups. However, the result indicates that the construction groups should still pay special attention to public doubts on design issues in the handover stage. When the mega infrastructure project is close to the operation, the performance of design becomes a focal issue in the media, attracting mass attention among the general public. In the handover stage of HZMB, the media report of some design errors, such as the unexpected movement of the seawall and falsification of the cement report, has raised severe public concern toward the construction groups. Thus, the active feedback of negative news and reports to the public is essential for construction groups to ease public worries (Wu et al., 2019). Besides, the public exhibition of project achievements, such as the awards and new records gained by project design, is recommended to be held to improve the civic pride on the project (Xie et al., 2019).

Another interesting finding is from the construction issue (#12), which is located in Zone Four and considered the least critical issue for construction groups in the planning and construction stages. The technical professions of construction issues cause less public attention (y-axis). The general public would not focus too much on construction activities due to their lack of engineering knowledge. Moreover, the public tends to blame the decision-makers rather than the construction groups concerning poor construction performance (i.e., cost overrun, time delay), which leads to the low relevance between construction issues and construction groups in the x-axis of the map. In the view of public concerns, the result indicates that the general public does not heavily influence detailed construction activities. However, the construction issue is still a critical concern for construction groups, given that the technical difficulties are the significant features of mega infrastructure projects (Flyvbjerg, 2014).

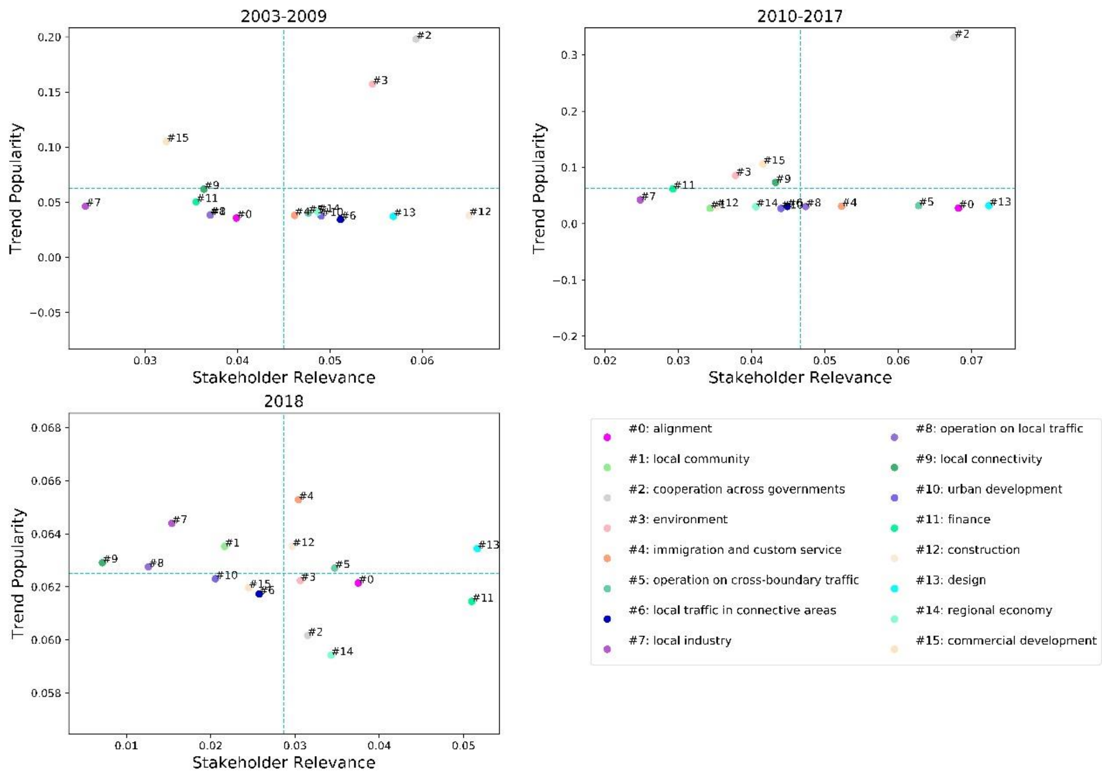

Figure 4.12 Managerial map of public concerns for pressure groups

(4) Pressure Groups

Pressure groups are composed of external stakeholders who pose political oppositions on the project, including environmental groups, fisherman associations, local communities, and media (Li et al., 2015a). In Figure 4.12, the stakeholder relevance in the x-axis represents the involvement level of the abovementioned four pressure groups. According to the results in Figure 4.12, the management guide for pressure groups in each project phase is discussed by the "Letter N" strategy.

In the planning stage, the construction (#12) and design (#13) issues (Zone Three) are the two concerns with the highest stakeholder relevance of pressure groups in the managerial map. The pressure groups are afraid of the disturbance brought by the construction of mega infrastructure projects (Li et al., 2012a). Hence, they emphasize the significance of protection measures into the project design and construction to diminish various adverse effects. In HZMB, the pressure groups have negotiated with decision-makers in a variety of social disturbance issues caused by the construction and design, including the noise led by the coming construction works and the inadequate technical measures to protect the involved marine life in the project design. Hence, pressure groups are encouraged to arrange several rounds of public consultation and polling with decision-makers to convey their worries and demands to improve the quality of design and construction (Norton and Hughes, 2017, Xie et al., 2019). Furtherly, the construction (#12) and design (#13) issues are placed in Zone One in the handover stage because of the review of project performance led by pressure groups. The public-participated evaluation team is advised to build for the joint work between decision-makers and pressure groups to analyze the performance of project execution and urge the authorities to make up for the shortcomings timely (Wang, 2001, Xie et al., 2014).

Another finding is the issue of cross-boundary traffic arrangement (#5), which is located in Zone Three in the construction stage and upgraded to Zone One in the handover stage. The result indicates that the issue of the operational arrangement of mega infrastructure projects has already received full attention among pressure groups in the construction stage, although not acquiring much public focus. In HZMB, the arguments on whether the cross-boundary traffic should be right-driving followed by mainland regulation or left-driving maintained with the Hong Kong regulation have already been discussed by media in the construction stage. In the same period, the worries of gas-emission caused by heavy cross-boundary traffic after the completion of HZMB have been presented by local communities and environmental groups. Before these arguments escalate as major public concerns in the handover stage, public hearings and consultations are recommended to organize in the construction stage to address the conflict of operational arrangement between decision-makers and pressure groups (Boudet et al., 2011, Webler and Tuler, 2006).

4.3.5 Managerial contributions and Implications

Contributions for stakeholder management on public concerns

This study provides a method for decision-makers to undertake stakeholder management on public concerns in mega infrastructure projects with exploring knowledge from unstructured official documents relevant to the project. Around the public concerns, the proposed dynamic stakeholder-associated topic model (DSTM) benefits the decision-makers to identify stakeholder issues, assess the stakeholder relevance, and obtain the stakeholder management strategies (shown in Figure 4.13). With the database of unstructured official text documents in the mega infrastructure projects, the decision-makers first use the method of TOT modeling to identify the critical public concerns and their dynamic patterns automatically. Then, a scoring system is provided for decision-makers to assess the relevance between project stakeholders and each public concern in the timeline. Finally, the managerial map for public concerns is presented for decision-makers to conduct the stakeholder management in each project phase with the "Mirror Z" and "Letter N" approaches. The "Mirror Z" approach is useful for decision-makers to determine the managerial priority of public concerns, while the "Letter N" approach is to guide the managerial priority for each specific project stakeholder.

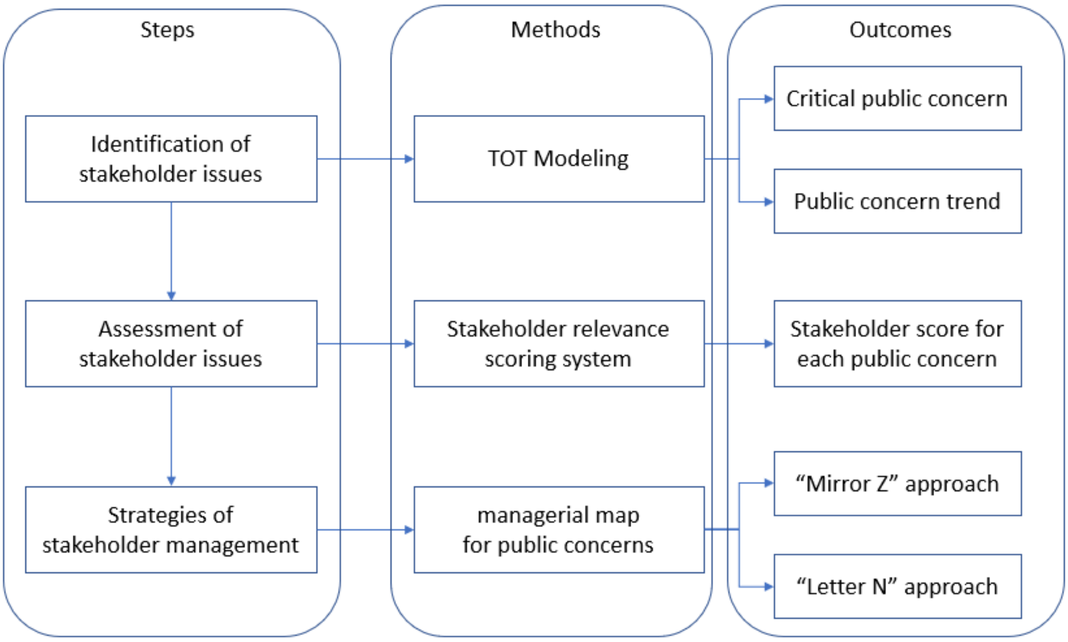

Figure 4.13 The framework of Stakeholder management on public concerns

Implications for project stakeholders on managing public concerns

The managerial implications (shown in Figure 4.14) are summarized based on the interpretations of research results, which provides the reference for project stakeholders on managing public concerns in the future mega infrastructure projects. The implications (shown in Figure 4.14) benefit project stakeholders from three aspects. First, it indicates the critical public concerns for stakeholders in each project phase, as all the included concerns are allocated in the first and second criticalness zones based on "Mirror Z" and "Letter N" approaches. Second, the management strategies are proposed for stakeholders to address the challenges brought by public concerns with effective public involvement methods. Third, the precautionary measures are highlighted for stakeholders based on the dynamic analysis of the managerial map, as the corresponding concerns may attract much more public attention and critics in the later project phase. For instance, the roundtable negotiation forums on the development of the local industry are suggested for political groups to arrange in the construction stage, before the concern would upgrade to Zone One in the handover stage stated in 4.4.2. A similar precaution is also provided for pressure groups on the public concern of cross-boundary traffic arrangements. With the precautionary intervention, the implication is helpful for stakeholders to manage public concerns in advance.

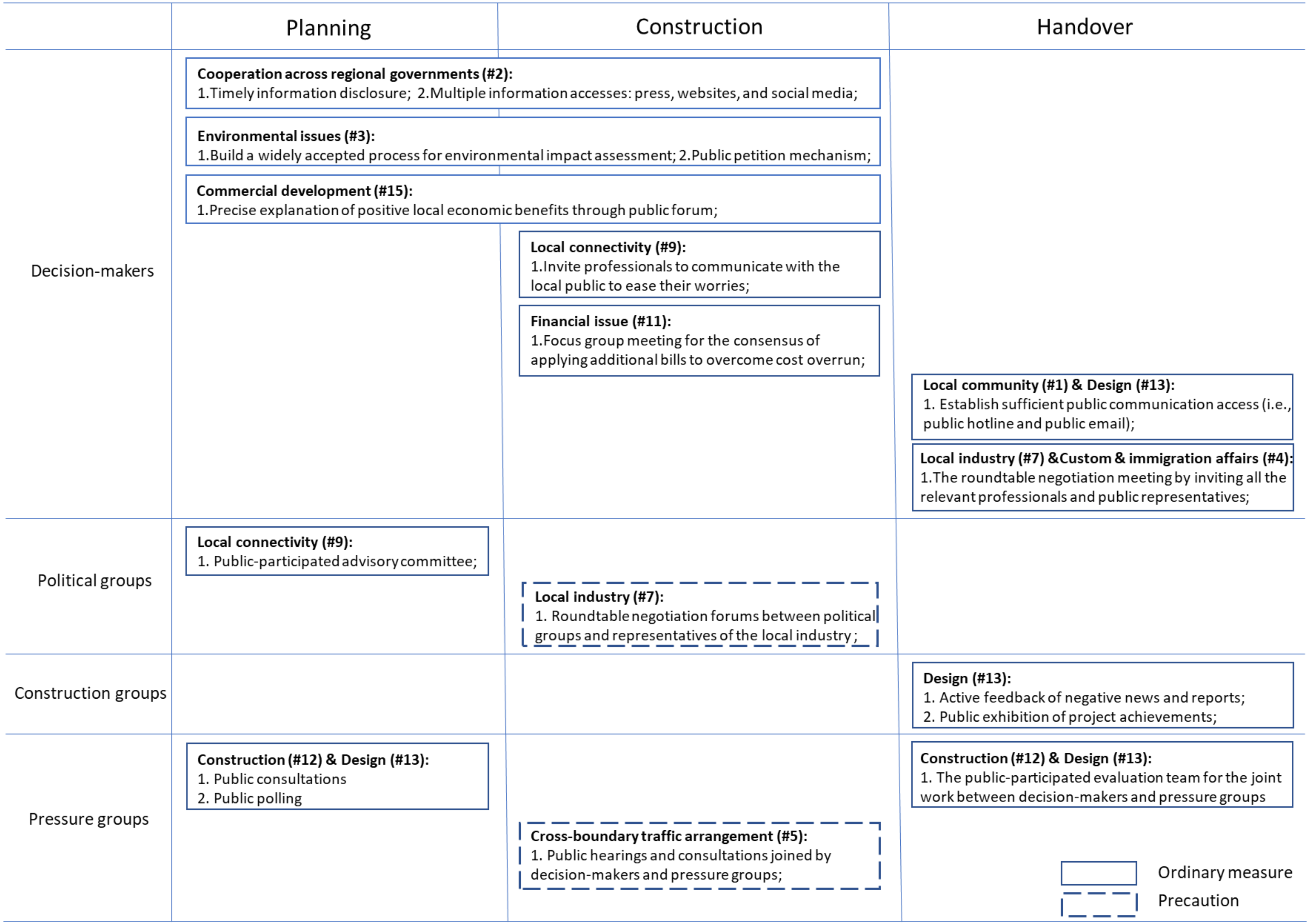

Figure 4.14 Managerial implications for project stakeholders

4.4 Summary of the Chapter

In this chapter, a stakeholder-associated topic model is developed to analyze the stakeholder dynamics in megaprojects with exploring the knowledge from the unstructured documents relevant to the project. The text-mining based approach consists of three modular. First, the TOT model is employed to identify stakeholder issues in the dynamic project environment. Second, the stakeholder score system is established to assess the stakeholder relevance between stakeholders and their relevant issues. Third, a managerial map is proposed for decision-makers and project stakeholders to manage the stakeholder issues in various stages of megaprojects.

With the case of stakeholder studies on public concerns in Hong Kong – Zhuhai – Macao Bridge, the proposed analytical approach is validated to achieve the dynamic stakeholder management by analyzing 1748 unstructured documents relevant to the project. As a result, 16 stakeholder-associated public concerns are identified and tracked in the development of megaprojects. Besides, the managerial map is drawn to determine the managerial priority for decision-makers and stakeholders in each project phase. Finally, a group of management strategies for public concerns are proposed for each stakeholder group. The case proves the validity of the proposed model on analyzing stakeholder dynamics by automated exploration of stakeholder information from longitudinal unstructured documents relevant to the project.

Chapter 5 A longitudinal stakeholder-associated network model for analysis of stakeholder complexity[3]

5.1 Introduction

The megaproject has a complex environment, including the wide range of non-linear, iterative, and interactive stakeholder activities (Weaver, 2007). The complex project environment is caused by a large number of interactions between stakeholders and their relevant issues, which generated complicated interdependent stakeholder relationships (Yang et al., 2009c, Mok et al., 2017b, Xue et al., 2020d). Thus, the effective analysis of stakeholder complexity is useful to understand the stakeholder interdependencies and achieve the stakeholder collaborations in the complex environment of megaprojects. Generally, the stakeholder complexity is composed of three elements: stakeholders, stakeholder issues, and stakeholder relationships, which forms underlying network structure (Yang et al., 2009c).

Social Network Analysis (SNA) has been used in many pieces of research to analyze the stakeholder and its associated issues by providing a comprehensive tool to reflect stakeholder patterns (Mok et al., 2015). Although SNA is widely applied in the project management for stakeholder analysis (Li et al., 2016, Yu et al., 2017), few longitudinal

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[3] This chapter is relevant to the publication:
Xue, J., Shen, G. Q., Yang, R. J., Zafar, I. & Ekanayake, E. 2020. Dynamic Network Analysis of Stakeholder Conflicts in Megaprojects: Sixteen-Year Case of Hong Kong-Zhuhai-Macao Bridge. Journal of Construction Engineering and Management, 146, 04020103.

SNA studies are conducted in the construction projects due to the data applicability, as most data is collected via questionnaire surveys within a given time frame which besets presenting its dynamics (Mok et al., 2017c). Therefore, it is still waiting for the upgraded SNA framework to explore the longitudinal complexity of stakeholders and their relevant issues with the reliable dataset.

Under these circumstances, the purpose of this study is to provide a method to measure the complexity of stakeholders and associated issues and to present the management guide towards the stakeholder issues in the longitudinal complex project environment. In details, it intends to explore answers to three research questions. First, what the critical stakeholder issues are in the complex project environment. Second, how the stakeholder relationships are affected by the changeable stakeholder issues. Third, how to manage the stakeholder issues in the longitudinal complex project environment. To answer the questions, the study proposes the longitudinal network-based framework to reveal the critical stakeholder issues and their affected stakeholder relationships and to map the stakeholder issues for presenting management strategies in different project phases. A case of Hong Kong-Zhuhai-Macao Bridge (HZMB) was presented to validate the effectiveness of the proposed method with 1748 official documents from 2003 to 2018, including the planning, construction, and the handover stage. The findings were discussed to show the longitudinal stakeholder complexity between stakeholders and relevant issues in the development of the megaprojects.

5.2 Model Design

5.2.1 Identification of stakeholder-associated network

The identification of stakeholder groups and their relevant issues is the primary part of stakeholder theory introduced by (Freeman, 1984). Since there are two sets of components in the stakeholder analysis; one is the group of stakeholders; another is the diverse stakeholder issues (Ramirez, 1999). Thus, the nodes in the network are defined as two modes: stakeholders and their associated issues. The link between these two nodes shows the relevance between the stakeholder issues and the corresponding stakeholders, which means the stakeholder issue affects the stakeholder's interests or actions. In the study, we identified the stakeholder issues and their related stakeholders by the document analysis of the longitudinal official meeting minutes relevant to the project in various phases of project duration which reflecting the stakeholder dynamics from a formal and objective perspective. Based on the previous network study, the number of times in which a pair of concepts were co-occurred in the text was counted to measure the closeness between the two concepts in the network (Boutilier and Zdziarski, 2017). The built-up network is useful to assess how closely the two concepts are based on the word co-occurrence in the record (Boutilier, 2011). Following the previous work, since the frequency of project meetings are organized based on the urgency and criticalness of the focal issues, the more critical issues would appear more times in various meeting minutes. Hence, the link was determined by the co-occurrence between each stakeholder issue and its related stakeholders in one meeting. For instance, there is one link connected when both stakeholder issue C_i and stakeholder S_k are mentioned in the record of one official meeting. The co-occurrence frequency assessed the weight of the link between each stakeholder issue and its related stakeholders in the meetings for each year. For example, if stakeholder issue C_i and stakeholder S_k are co-occurred in the records of three different meetings in the year Y_j, the weight of the link C_i - S_k is valued as three in the network of Y_j. Besides, to ensure the relationship strength between the stakeholder issue and its relevant stakeholders, the value of the link weight was finally cross validated by the experts to judge whether the link and weight reflect the closeness in reality. Under the regulations of nodes, links, and link weights mentioned above, the stakeholder-associated networks were built annually in the timeline for the longitudinal study on how stakeholder interactions affect the stakeholder issues in the long-term project duration in megaprojects.

5.2.2 Visualization of stakeholder-associated network

Taken in place of the traditional dyadic representations in the stakeholder theory proposed by (Freeman, 1984), network visualization is considered as a more systematic tool to show the complex relationships among stakeholders and their relevant issues (Mok et al., 2015). The proposed stakeholder-associated network is a two-mode network. One mode of nodes represents the stakeholder issues in each stage of the megaprojects. Another mode of nodes reflects the issue-related stakeholders. The link of the network shows the relevance of stakeholders and their related issues in one year. Hence, a series of annual networks in the project duration established presents the dynamic patterns of stakeholders and their relevant issues.

Compared to the classical one-mode network, it increases the difficulties for the direct analysis of the two-mode network due to the complexity (Liang et al., 2015). Generally, the most common way to analyze the two-mode network is to make the projection (Borgatti and Everett, 1997), after which the two-mode network could be converted into two traditional one-mode networks in convenience of the network analysis. As Figure 5.1 shows, through the projection, the stakeholder network would be generated based on the co-connection relationship between the stakeholder-nodes and the stakeholder issue-nodes. Similarly, the stakeholder-issue network could be established. With the transformation, the traditional one-mode network analysis could be made for the converted stakeholder and stakeholder-issue networks respectively. Unlikely to the previous studies which initially established the stakeholder or stakeholder-issue networks independently, the converted stakeholder network is built based on the link with issues in the two-mode network that contains more interaction information, as well as the converted stakeholder-issue network which is established with the synthesis of the stakeholder information. Therefore, the converted networks are mixed with the interaction information, which is beneficial for the further analysis of stakeholders and their relevant issues.

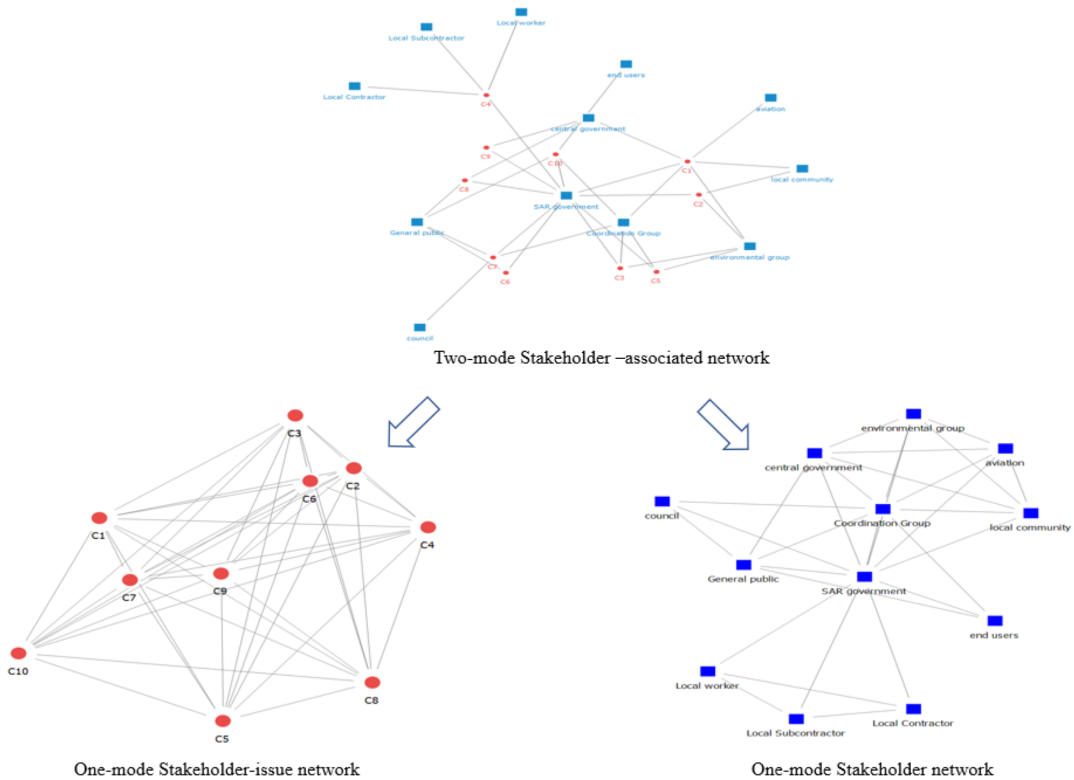


Figure 5.1 The projection of the two-mode stakeholder-associated network

5.2.3 Analysis of stakeholder-associated network

Stakeholder analysis is an essential part of the classical stakeholder theory (Freeman, 1984), which benefits the stakeholders to understand the critical relevant issues and their affected relationships in the project. Compared to the traditional statistical methods for detecting the critical issues (Yang et al., 2010), the network analysis considers all the involved stakeholders as one system to make analysis rather than regarding each stakeholder as an independent variable (Yang et al., 2009c), which is beneficial to have a systematic assessment for identifying the critical stakeholders and their relevant issues (Liang et al., 2015).

(1) Stakeholder-issue network analysis

The prioritization of stakeholder issues in a stakeholder-issue network is beneficial to understand the major stakeholder issues that happened at a given time point (Lienert et al., 2013, Yang and Zou, 2014). Since the centrality was proposed by Freeman as a critical indicator to show the node importance in the network analysis (Freeman, 1978), this study selected the degree centrality of each stakeholder issue-node for assessing the node importance. Further, node degree centrality represents the structural importance in the network as the node with higher degree centrality shares more direct links with neighbor nodes (Rowley, 1997). In the study, the calculation of nodal degree centrality in a projected conflict network is as follows.

$$N(C_i) = \frac{\sum w_{ij}}{\sum w} \ (i \neq j),$$

Where C_i represents the ith stakeholder-issue in the network, $\sum w_{ij}$ is the sum of link weights which are connected with the ith stakeholder-issue, $\sum w$ is the sum of link weights in the whole network.

(2) Stakeholder network analysis

Stakeholder issues have a deep influence on the relationship between related stakeholders. In the stakeholder network, the link reflects the stakeholder relationship, which is built by the common stakeholder issues in the original two-mode network with the projection, showing the stakeholder-associated consequences caused by the stakeholder-issues. Therefore, the link assessment in the stakeholder network assists in testing the impacts of stakeholder-issues towards stakeholder relationships. In the network analysis, the link betweenness centrality represents the extent of a specific link located as a bridge for all the other links in the whole network (Rowley, 1997). It is regarded as a typical indicator to evaluate the critical ties (Mok et al., 2017c). In the study, the calculation of link betweenness centrality in a projected stakeholder network is as follows.

$$B(S_{ij}) = \sum_{a,b \in S} \frac{\sigma(a,b|S_{ij})}{\sigma(a,b)} \quad ,$$

Where S_{ij} represents the link connected between the stakeholder node "i" and "j", $\sigma(a,b)$ is the number of heaviest-weight paths connecting the node a and b, $\sigma(a,b|S_{ij})$ is the number of heaviest-weight paths passing through the link S_{ij}, node a and b belong to the set of stakeholder nodes S in the network.

(3) Stakeholder-issue map analysis

As the stakeholder issue is composed by two core concepts: stakeholder and stakeholder-issue, the management strategy should consider both the importance of stakeholder-issue and its stakeholder proliferation. For better exploring the features of each stakeholder-issue, this study proposed a stakeholder-issue map including three steps as depicted in Figure 2. First, the node centrality degree was used to reflect the importance of the stakeholder-issues (Freeman, 1978). Second, the subgraph of the corresponding stakeholder-issue nodes in the two-mode network was extracted and then calculated the number of its related stakeholders, which was regarded as the indicator to assess the extent of stakeholder participation. Third, each stakeholder issue was located on the map with the X-axis of stakeholder participation and Y-axis of stakeholder-issue importance. Take stakeholder-issue node C1 in Figure 5.2 as an example, C1 has a node degree centrality (NDC) valued as 0.8 over the average level (0.6) in that particular year, while connecting 6 stakeholder groups which is also higher than the average issue-node associated stakeholder number (5). Thus, C1 is located in Zone One in the yearly stakeholder-issue map. Followed by the example, characteristics of each stakeholder issue were presented using the stakeholder-issue map.

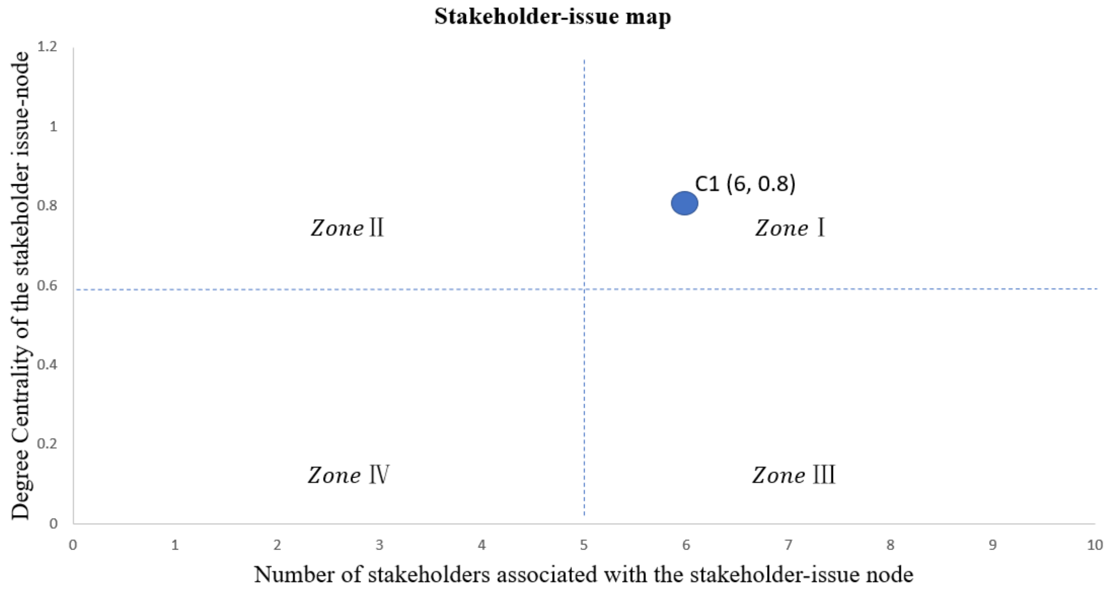


Figure 5.2 The stakeholder-issue map analysis

5.2.4 Assessment of stakeholder-associated network

(1) Critical stakeholder issues

Based on the results of stakeholder-issue network analysis, the assessment of critical stakeholder issues in the dynamic project environment could proceed. According to the value of nodal degree centrality of each stakeholder issue, the stakeholder issues are ranked in the descending order. Based on the previous study by Liang et al. (2015), the critical factors are defined as the node with high centrality value. In the study, the stakeholder issues above average centrality value are selected as the critical stakeholder issues, since the higher value represents the more critical role in the projected stakeholder-issue network. However, the threshold (above average centrality value) of critical stakeholder issues could be varied depending on the demand of stakeholder-issue analysis in the megaprojects.

(2) Affected stakeholder relationships

Based on the results of stakeholder network analysis, the criticalness of affected stakeholder relationships in the dynamic project environment could be assessed. According to the previous stakeholder studies by Mok et al. (2017c), the critical stakeholder groups are firstly identified by the rank of node centrality degree in the projected stakeholder network. Then the link betweenness centrality (LBC) is employed to evaluate the affected stakeholder relationships for each critical stakeholder group. In the study, the stakeholder groups above average nodal centrality value are firstly selected as the critical stakeholder groups. Then a number of top-ranked LBC links are considered as the most affected stakeholder relationships for each critical stakeholder group. The threshold setting of the top-ranked links is set as the minimum number of stakeholder links in the network, which means each identified stakeholder node can explore at least the setting number of close connections. The threshold of affected stakeholder relationships could be varied depending on the demand of stakeholder-issue analysis in the megaprojects.

5.2.5 Proposed "Mirror Z" strategies for stakeholder management

The stakeholder theory suggests the managerial strategies should be concise and easy for the managers among stakeholder groups to employ (Freeman, 1984). Hence, based on the results of stakeholder-issue map analysis, quick managerial guidance is proposed for senior project managers according to the network-based evaluation.

As shown in Figure 5.3, the stakeholder-issue map is divided into four zones, which classifies the seriousness of stakeholder issues with four levels. Zone One consists of the stakeholder issues with high criticalness and stakeholder relevance, considered as the top serious stakeholder issue. Zone Two includes the stakeholder issues with high criticalness and limited stakeholder relevance, recognized as the second serious stakeholder issue. Zone Three has stakeholder issues with low criticalness and wide stakeholder relevance, regarded as the third seriousness level. While Zone Four has stakeholder issues with low criticalness and limited stakeholder relevance as the least seriousness. Based on the seriousness level, the management priority on stakeholder issues follows the order from the most to the least serious, namely from Zone One to Zone Four in the map similar as the mirror image of letter 'Z'. It is now proposed as the "Mirror Z" approach to determine the management priority of stakeholder issues in megaprojects.

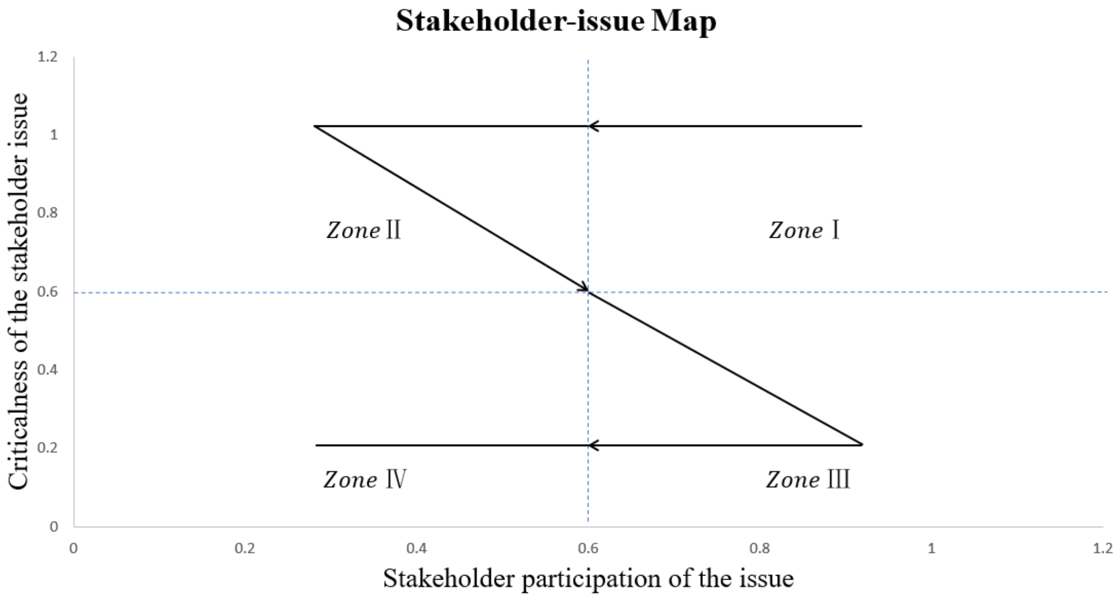


Figure 5.3 "Mirror Z" approach for stakeholder issues in the megaprojects

5.2.6 Framework of longitudinal network analysis on stakeholder complexity

Based on the approaches presented in 5.2.1-5.2.5, a framework is established to explore the longitudinal complexity of stakeholders and relevant issues in megaprojects. The framework (Shown in Figure 5.4) is composed of four parts, including stakeholder-issue identification and visualization, stakeholder-issue analysis, stakeholder-issue assessment, and stakeholder-issue management. Combined with the longitudinal data, the network-based framework provides a systematic method to analyze the stakeholder complexities from identification to evaluation and management in different project stages.

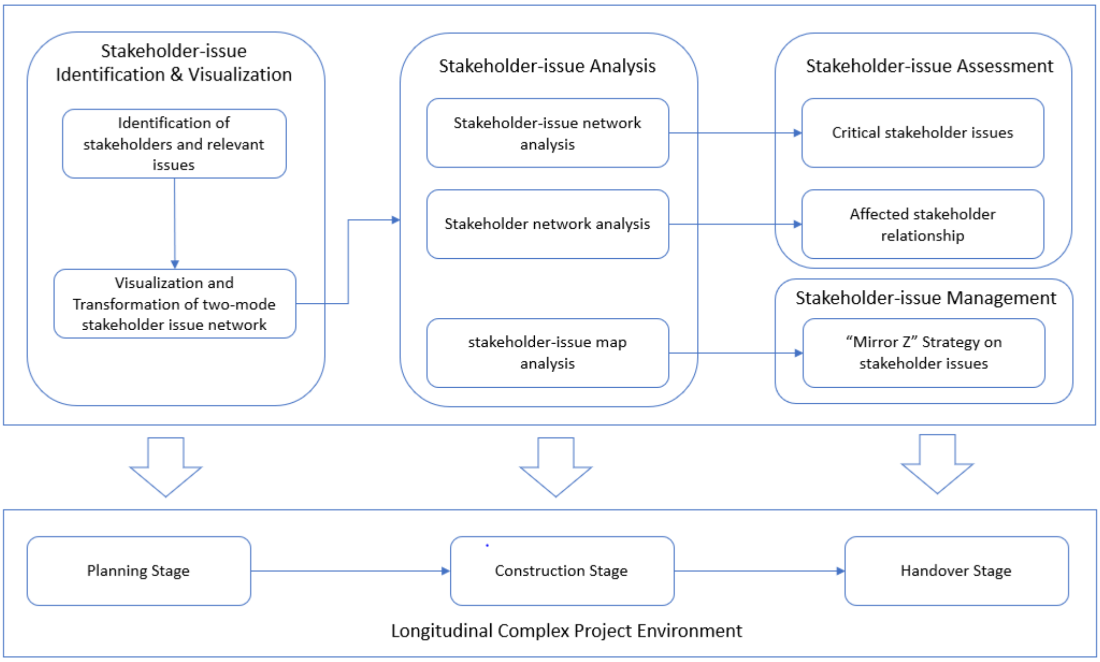


Figure 5.4 Framework of longitudinal network analysis on stakeholder issues

5.3 Case Study – Stakeholder conflicts in HZMB

As the case study was introduced as a method suitable for the exploration in the new research area which has inadequate existing theories by Eisenhardt (1989), it is employed to validate the framework of dynamic network analysis on stakeholder issues in megaprojects with stakeholder conflicts. The single instrumental case study is conducted since the validation results of the proposed framework have the potential to be transferred to other megaprojects and a more comprehensive understanding of the phenomenon could be gained with the investigation under a project setting (Mok et al., 2017c). The case selection is based on information-oriented sampling (Flyvbjerg, 2006). There are two major criteria. On the one hand, the selected case involves various stakeholders and has records of conflicts among stakeholders. On the other hand, the selected case prefers the famous megaproject which has substantial impacts on society, economy, and environment, which was also echoed by similar studies in the megaprojects (Mok et al., 2017c). To follow the criteria, the Hong Kong-Zhuhai-Macao Bridge (HZMB) was selected. The HZMB is a 55-kilometer cross-boundary mega transportation project, connecting Hong Kong, Macau, and Zhuhai—three major cities on the Pearl River Delta in China to enhance the economic and sustainable development of the Greater Bay Region. It is the longest sea-crossing infrastructure on earth designed for 120 years and cost is around 127 billion RMB in total. While the HZMB involves various stakeholders and many conflicts occurred due to various incidents, including delays and budget overruns, worker deaths and injuries, faked safety testing, seawall integrity and falling number of dolphins. The case study protocol is followed by the proposed framework from stakeholder-conflict identification and visualization to the management strategies step by step. The unit of analysis is at the project level from the planning to construction and handover stage, and the observation unit is each stakeholder group which is the main actor in the research.

5.3.1 Research results

(1) Results of data collection

The data collection was undertaken by five researchers in the field of stakeholder and conflict management in megaprojects from February to April in 2019. The official documents were searched in the legislative council library in Hong Kong where preserved the life-cycle documents of local megaprojects. The searching term was "Hong Kong-Zhuhai-Macao Bridge" and "HZMB". Finally, 1748 official documents on Hong Kong-Zhuhai-Macao Bridge from 2003 to 2018 were collected. The stakeholder conflicts were extracted from the documents by desktop analysis, then three experts each from government, contractor, and local community (Profiles are shown in Appendix B.3) who involved in the project from the beginning to the end were invited to cross-validate the results of data collection. Consequently, 334 conflicts and 32 kinds of stakeholders were identified from the project stage of planning, construction to handover. Based on the rules stated in the section of 5.2.1 and 5.2.2, the yearly two-mode stakeholder-conflict networks were built, then transformed to the conflict and stakeholder networks respectively. The results were visualized by Netminer 4.0 as shown in Figure 5.5.

To furtherly analyze the stakeholder-conflict network, the large number of identified stakeholder conflicts (334) were categorized by their causes. In general, the category of stakeholder conflicts was set according to the characteristics of megaproject development by Flyvbjerg (2014), including technology, politics, economics, and aesthetics. In the technological aspect, the causes of stakeholder conflicts are concentrated on the cost, schedule, quality, and safety issues(Nassar and Abourizk, 2016). In terms of the political aspect, the stakeholder conflicts are around the issues of labor, transparency, legal, and politics (Doloi, 2013, Aliza et al., 2011, Pinto, 2000, Boudet et al., 2011). The cause of stakeholder conflicts related to the economics consists of regional economy, local connectivity, urban development, finance, and the toll policy (Lützkendorf et al., 2011, Liyanage and Villalba-Romero, 2015, Lee et al., 2017b). Moreover, the aesthetical conflict is caused by design issues among project stakeholders (Lu et al., 2000). Besides these four aspects, the conflicts also occur when stakeholders face the challenges of the issues on environmental protection, project alignment, and operational management (Zafar et al., 2019, Irimia Diéguez et al., 2014, Zhou et al., 2019). Overall, there are 17 categories in the research based on the previous studies: cost, schedule, quality, safety, labor, environment, transparency, finance, economy, connectivity, operation, urban development, alignment, legal, design, toll, and politics.

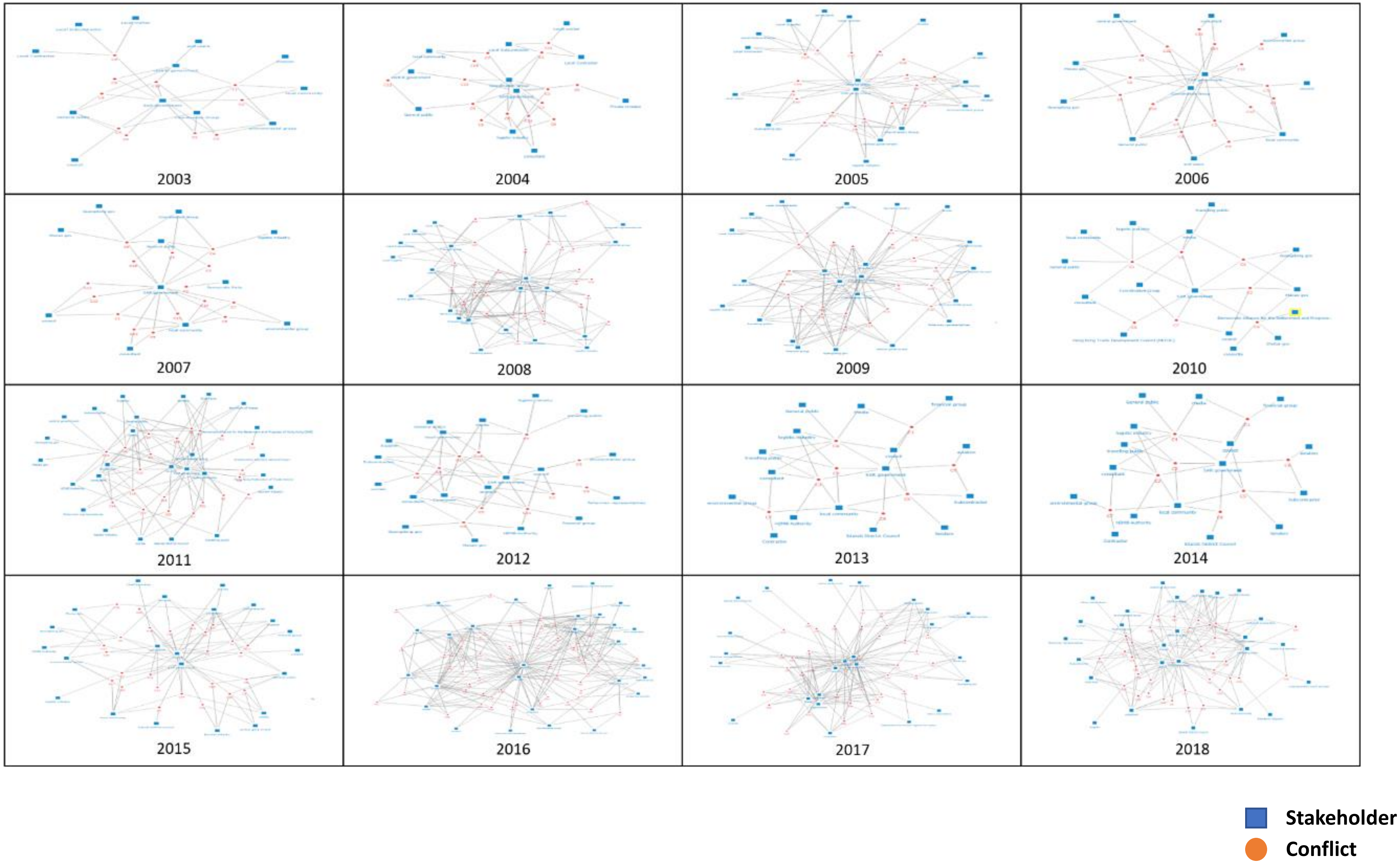


Figure 5.5 The two-mode stakeholder conflict networks on HZMB from 2003 to 2018

(2) Results of critical stakeholder conflicts

In the study, the top 30 percent of the conflicts is selected as the critical conflicts, since the higher value represents the more critical role in the projected conflict network. The threshold setting of the top 30 percent in the study is because the mean nodal degree centrality value of all the identified conflicts is around the level of 30 percent from the top (shown in Appendix B.1), which means the centrality values of top 30 conflicts are above average. Therefore, top 30 percent of the conflicts were selected as the critical conflicts in the year based on the rank of the node degree centrality (NDC) in the projected conflict network (Appendix B.4). The annual identified conflicts (Appendix B.6) were furtherly interpreted by three groups: environmental conflicts, neighboring conflicts, and traditional conflicts. Among them, neighboring conflicts contain the categories of connectivity and urban development, while traditional conflicts include the categories of cost, schedule, quality, and safety. The reason for the selection of the three perspectives was from two aspects. First, these three kinds of conflicts presented the clear chronological patterns in the timeline, providing the evidence to supplement the dynamic patterns of relevant stakeholder conflicts in the previous studies (Nassar and Abourizk, 2016, Zhou et al., 2019, Lee et al., 2017b). Second, the percentage of each kind conflict was 27 percent (Traditional), 16 percent (environmental), 13 percent (neighboring), which ranked the top 3 largest groups of identified critical stakeholder conflicts. In comparison, the remaining ten categories shared the other 44 percent. It is worthwhile to explore the dynamics of the top 3 groups since they provide adequate evidence to trace the chronological patterns. Therefore, based on the annually identified conflicts (Appendix B.6), it is shown (Figure 5.6) the dynamics of critical conflicts by three groups: environmental conflicts, neighboring conflicts, and traditional conflicts, which will be discussed in 5.2.1.

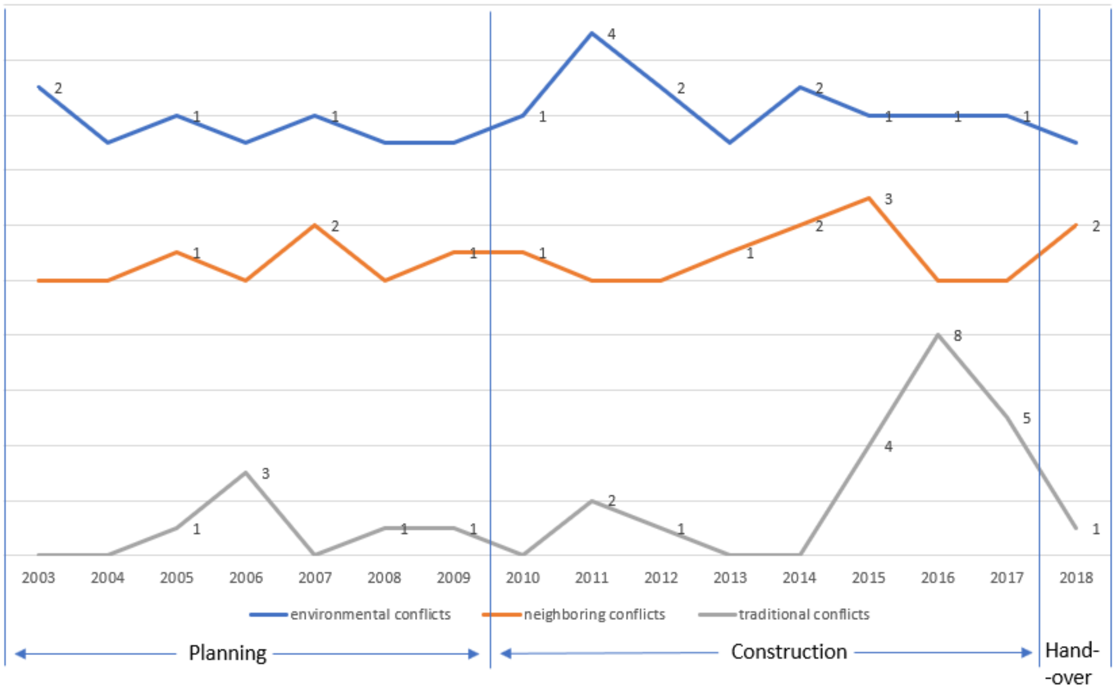


Figure 5.6 The number of annual critical conflicts from 2003 to 2018

(3) Results of affected stakeholder relationships

In the study, the top 30 percent of the stakeholder groups are selected as the critical ones, and the top 3 LBC links are considered as the most affected stakeholder relationships for each critical stakeholder group. The threshold setting of the top 30 percent in the study is because the mean nodal degree centrality value of all the identified stakeholders is around the level of 30 percent from the top (shown in Appendix B.2), which means the centrality values of top 30 stakeholders are above average. The threshold setting of the top 3 links is set as the minimum number of stakeholder links in the network is three, which means each stakeholder node can explore at least three close connections. Therefore, the critical links were identified based on the rank of the link betweenness centrality degree (LBC) in the projected stakeholder network (Appendix B.5). In Table 5.1, it is presented the dynamics of affected stakeholder relationships by five groups: local industry, green groups, construction groups, supervision groups, and governmental organizations, which will be explicated in 5.2.2.

Table 5.1 Critical stakeholder relationships in HZMB from 2003 to2018

Stakeholder	Stage	Year	Critical link with link betweenness centrality
Local industry	P	2003	S9-S11(1.0); S9-S13(1.0)
		2004	S9-S1(10.0); S9-S13(5.0); S9-S12(5.0); S11-S1(10.0); S11-S13(5.0); S11-S12(5.0)
		2005	S9-S1(13.0); S9-S10(1.3); S9-S13(1.3); S11-S1(13.0); S11-S10(1.3); S11-S13(1.3); S12-S1(13.0); S12-S10(1.3); S12-S13(1.3)
		2009	S18-S1(9.3)
	C	2010	S17-S1(6.0); S17-S5(2.5); S17-S10(2.2)
		2013	S17-S15(3.6); S17-S1(3.5); S17-S7(2.2)
	H	2018	S17-S15(3.9); S17-S1(3.4); S17-S7(3.2)
Green groups	P	2008	S16-S1(8.1); S14-S1(6.4)
		2009	S15-S19(4.1); S16-S5 (2.7); S16-S7(2.2); S14-S5(2.7); S14-S7(2.2)
	C	2011	S14-S1(4.6); S14-S24(4.6); S14-S7(3.4); S15-S1(4.7); S15-S24(3.9); S15-S7(3.5)
		2014	S14-S1(3.9); S14-S20(3.1); S14-S8(2.4); S15-S23(3.5); S15-S20(3.3); S15-S9(2.8)
	H	-	-
Construction groups	P	-	-
	C	2011	S9-S1(5.0); S9-S7(3.0); S9-S13(2.9); S10-S17(4.5); S10-S24(4.4); S10-S1(3.8)
		2012	S9-S1(3.8); S9-S13(3.7); S9-S6(3.2); S11-S1(4.6); S11-S13(2.7); S11-S7(2.6); S12-S1(4.9); S12-S10(2.3); S12-S7(2.2)
		2013	S10-S14(6.4); S10-S9(6.4); S10-S1(5.6)
		2015	S9-S1(4.3); S9-S3(3.5); S9-S7(3.3); S11-S1(5.4); S11-S7(4.4); S11-S20(2.5); S12-S1(5.2); S12-S7(4.2); S12-S21(2.5); S10-S30(4.3); S10-S15(4.3); S10-S17(3.6)
		2016	S9-S1(6.5); S9-S16(5.8); S9-S21(5.3)
		2017	S9-S12(3.6); S9-S21(3.6); S9-S13(1.7); S11-S13(1.5); S11-S12(3.4); S11-S21(3.4)
	H	-	-
Supervision groups	P	2008	S19-S8(4.2); S19-S24(3.1); S19-S9(2.7)
		2009	S19-S15(4.1); S19-S8(3.1); S19-S9(2.9)
		2011	S19-S1(4.6); S19-S3(3.2); S19-S4(3.2)
		2014	S19-S6(5.3); S19-S29(4.7); S19-S24(4.3)
		2016	S19-S1(4.7); S19-S24(4.0); S19-S13(3.5)

		2017	S19-S31(3.7); S19-S22(3.5); S19-S10(3.5)
	H	2018	S19-S22(4.8); S19-S15(4.3); S19-S10(4.3)
Governmental organizations	P	2003	S1-S9(9.0); S1-S11(9.0); S1-S13(9.0)
		2005	S1-S10(13.3); S1-S9(13.0); S1-S11(13.0)
		2006	S1-S14(10.0); S1-S10(5.5); S1-S2(4.7); S3-S1(3.7); S3-S5(2.7); S3-S20(2.0)
		2007	S1-S10(8.0); S1-S15(7.0); S1-S29(7.0)
		2008	S1-S16(8.1); S1-S14(6.4); S1-S8(4.4); S3-S1(3.2); S3-S5(2.4); S3-S19(2.3); S4-S1(3.2); S4-S5(2.4); S4-S19(2.3)
		2009	S1-S18(9.3); S1-S21(5.3); S1-S9(4.4); S3-S10(3.5); S3-S1(3.5); S3-S7(2.6)
	C	2010	S1-S13(11.0); S1-S28(9.5); S1-S27(9.5); S3-S19(5.6); S3-S1(4.8); S3-S7(3.1)
		2011	S1-S28(25.0); S1-S18(25.0); S1-S13(14.5)
		2012	S1-S16(18.0); S1-S14(13.0); S1-S3(10.2)
		2013	S1-S23(11.8); S1-S8(8.5); S1-S27(7.6)
		2014	S1-S3(8.6); S1-S4(8.6); S1-S17(8.6)
		2015	S1-S8(17.5); S1-S30(8.8); S1-S6(8.4)
		2016	S1-S21(19.3); S1-S16(17.8); S1-S23(10.9); S3-S1(6.9); S3-S24(3.4); S3-S20(2.9); S6-S1(6.4); S6-S24(3.4); S6-S20(2.8)
		2017	S1-S8(18.0); S1-S13(7.7); S1-S12(7.6)
	H	2018	S1-S8(16.2); S1-S26(13.5); S1-S12(10.5); S4-S1(4.3); S4-S7(3.2); S4-S22(3.0); S3-S1(4.3); S3-S7(3.2); S3-S22(3.0); S6-S24(4.1); S6-S13(3.9); S6-S1(3.6)

Note:

P: Planning stage (2003-2009), C: Construction stage (2010-2017), H: Handover stage (2018)

Sn-Sm (value): Link Stakeholder n to Stakeholder m (value of link betweenness centrality)

Stakeholder group: S1.Hong Kong SAR; S2.Central Government; S3.Macao SAR; S4.Guangdong Province; S5.Coordination group; S6.HZMB Authority; S7.Legislative Council; S8.District council; S9.Contractor; S10.Consultant; S11.Subcontractor; S12.Supplier; S13.Worker; S14.Environmental group; S15.Local community; S16.Fishermen; S17.Logistic industry; S18.Tourism industry; S19.Media; S20. General public; S21.Tender; S22.Shuttle operator; S23.Aviation; S24. Travelling public; S25.Immigration; S26. Insurance; S27.Financial group; S28. Ruling party; S29. Opposition party; S30. Chief Executive; S31. Independent Commission Against Corruption; S32. Ferry Company

Table 5.2 The results of Stakeholder-conflict map in HZMB from 2003 to 2018

Stage	Zone	Cost	Schedule	Quality	Safety	Labor	Environment	Transparency	Finance	Economy	Connectivity	Operation	Urban	Alignment	Legal	Design	Toll	Politics
	I	2	1	0	0	0	0	0	7	1	1	1	0	2	1	0	2	1
Planning	II	1	10	0	0	0	7	1	3	4	8	6	3	1	1	6	3	1
(2003-2009)	III	1	1	0	0	5	3	0	0	5	0	2	0	1	0	0	0	1
	IV	0	4	1	0	4	7	1	2	4	2	2	0	0	0	0	3	0
	I	12	3	6	7	2	8	2	0	0	1	6	4	0	0	1	1	0
Construction	II	4	3	1	1	2	0	1	0	2	3	10	9	0	1	0	0	1
(2010-2017)	III	0	0	2	0	1	3	2	1	1	2	11	1	0	0	2	1	1
	IV	4	8	3	4	4	9	1	0	4	5	13	2	0	0	0	0	0
	I	0	0	0	1	0	0	0	0	1	2	2	0	0	2	0	1	2
Handover	II	2	0	0	0	0	0	0	0	1	2	2	1	0	1	0	0	0
(2018)	III	0	1	0	1	0	0	0	1	0	0	3	0	0	0	0	0	1
	IV	1	1	0	0	0	0	0	0	0	1	3	1	0	1	0	0	0

Note: The value in the table represents the number of stakeholder-conflicts under each category

Strategy for the conflicts in Zone I: Collaboration

Strategy for the conflicts in Zone II: Compromising

Strategy for the conflicts in Zone III: Avoiding

Strategy for the conflicts in Zone IV: Accommodating

(4) Results of stakeholder-conflict map

The stakeholder-conflict maps were drawn according to the three stages in the timeline of the project duration: planning (2003-2009), construction (2010-2017), and handover (2018). A stakeholder-conflict map was developed to reflect the relationship between conflict importance and stakeholder participation. Based on the 17 categories stated in the first part of the section 5.3.1, the results of the stakeholder-conflict map are shown in Table 5.2, beginning from the stage of planning to construction and handover.

5.3.2 Interpretation of results

The dynamic patterns of stakeholder conflicts in HZMB are interpreted based on the results derived from the proposed framework. Moreover, the results are cross-validated by follow-up interviews with senior experts (more than ten-year working experience) who directly involved in the project. The interviewees come from the stakeholder groups listed in Table 5.1. Each interview lasted for more than 1 hour. There are two key questions in the interview: one is whether the results derived from the framework are valid; another is what the reasons behind the result of data analysis are.

(1) The longitudinal critical stakeholder conflicts

Pioneering conflicts from the environmental issues

The conflicts caused by environmental issues are considered as environmental conflicts, which have been highlighted in the previous megaproject studies (Lienert et al., 2013, Zhou et al., 2019). Most environmental conflicts are led by the worries of potential environmental pollution in the development of the megaprojects. The evidence of this study shows the chronological priority of environmental conflicts would be at the beginning of the planning and construction stages as the pioneering conflicts (shown in Figure 5.6). The evidence is validated by interviewees, who also emphasized the criticalness of the environmental conflicts at the start of two stages respectively. In the early planning stage, the worries on the protection of marine life had caused the conflicts between the green groups and Hong Kong SAR government in 2003, which is in line with the previous opinions that environmental and ecological concerns are active among stakeholders in the early site selection phase (Min et al., 2018). While environmental issues also became the first major conflict group among the stakeholders in the construction stage. The interviewees highlighted one breaking event that an old lady who lived in the local community filed a case against the government department to the court on the potential misconduct of the environmental impact assessment (EIA) report related to HZMB in 2010, which suspended the commencement of the construction work for 15 months. As the pioneering conflict, the interviewees revealed that the event triggered a series of following conflicts on cost overrun, time delay, and the late start of the local connectivity, indicating the amplified effects of environmental conflicts in the ongoing construction stage (Lee et al., 2017b).

Neighboring conflicts from the connected areas

The neighboring conflicts refer to the stakeholder confrontations due to the dissatisfaction of the local economic development nearby the megaprojects (Lee et al., 2017b). For instance, the local connectivity and urban development are clearly identified as two focal sources of the neighboring conflicts in the research results. The evidence furtherly shows the breakout point of neighboring conflicts in the mid-term of the planning and construction stages respectively, while becoming fiercer in the handover stage (shown in Figure 5.6). The interviewees explained that the neighboring conflicts were introduced by the worries and desires of the local community. In the planning stage, the conflict lays behind the worries of the inadequate local transport system to cope with the expected heavy traffic volume of HZMB. The conflict leads to reduced community support for the project among residents and district council representatives. With the construction of HZMB, the desires of urban development in neighboring areas triggered the "bridgehead economy" proposal designed by the Hong Kong SAR government, referring to the commercial development of the project facility and the local town. However, conflicts occurred around the change of land use, the structure safety, and the disturbance to the local community caused by the potential flourished tourism industry. When it came to the handover stage, the conflicts escalated since both worries and desires of the local communities were not carefully addressed.

The time delays and the technical difficulties of local connectivity and local commercial facilities received a wide public attention leading to the doubts on the smooth integration of the bridge system and the local urban system. Hence , the interviewees pointed out that the synchronization of the local auxiliary infrastructure and urban facilities could be the critical conflict sources of a mega infrastructure project, though which is seldom identified in the earlier research.

Traditional conflicts erupted in the planned due date

The conflicts, related to the aspects of cost, time, quality, and safety, are defined as traditional conflicts in the study, which exert direct influences on project performance (Chen et al., 2014, Chen et al., 2017, Nassar and Abourizk, 2016, Maemura et al., 2018). As Figure 5.6 shows, the project suffered a dramatic increase in traditional conflicts since the year 2016, when the bridge was intended to be completed. The finding supplements the previous study by detecting the exact time for these traditional conflicts to erupt (Wu et al., 2018). The delay of the project completion stimulated the burst of traditional conflicts. Of them, the occupational safety issues account for the most critical conflicts, causing the tensions among the workers, media, council, contractors, and government in the last two years of the construction stage, though the first fatal safety accidents occurred in 2012. The suspension phenomenon implicates that the traditional conflicts would be activated by the time overrun of the megaprojects. A similar viewpoint is also indicated by interviewees that as the schedule is the common goal for most stakeholders, compromising would be inclined to reach towards the traditional conflicts in the ongoing construction stage. However, the incompletion of the planned schedule disrupts the shared goal among stakeholders, causing the burst of traditional conflicts that have been hidden since the project commences.

(2) The longitudinal critical stakeholder relationships

Local industry

The local industry mainly consists of construction-related companies (S9, S10, S11, S12), logistic companies (S17), and tourism companies (S18). The relevant conflicts are concentrated in the early planning stage (from 2003 to 2005 shown in Table 5.1). The interviewees mentioned that the local industry made both positive and negative roles in the conflicts based on their economic benefits. On the positive side, the local industry stood with the Hong Kong government to expedite the project for exploring more job and economic opportunities from the mainland market, regarded as a supportive muscle among stakeholders in the initial stage. However, the priority level of local participation in the project caused the conflicts between government and local construction-related companies in the same period.

Green groups

The green groups include environmental groups (S14), fishermen (S16), and the local community (S15). According to the results in Table 5.1, the green groups have the critical ties with the Hong Kong SAR government, Coordination Group, council representatives, and media in 2008 and 2009, then becoming the critical stakeholders in 2011 and 2014, respectively. The period covers the end of the planning stage and the first half of the construction stage when the project was at the important decision-making phase. The dynamic pattern is verified by interviewees, who considered the conflicts on environmental issues are frequently intensified around the project bill-voting period driven by green groups. The tensions not only severely affected the relationship between government, council members, and green groups (S14-S1,S15-S1,S16-S1,S14-S7,S15-S7,S16-S7), but also negatively impacted on the project supportiveness from the media and general public (S15-S19,S14-S20,S15-S20).

Construction groups

As the key project stakeholders, the construction groups, including the contractor(S9), subcontractor (S11), supplier (S12) and workers (S13), played an important role in the conflicts from the beginning to the completion of the construction. Of them, according to Table 5.1, the contractor is the major party listed as the critical stakeholder for 5 out of 8 times (2011,2012,2015,2016,2017) during the construction period. For the contractor, the top relationship was with the Hong Kong government, which was the top link for almost each year (except 2017), indicating the critical tie between contractor and the government in the mega infrastructure project (Deng et al., 2014). Moreover, the construction groups faced the major challenge in the relationship with the construction workers and council representatives (S9-S7,S11-S7,S12-S7,S9-S13,S11-S13). The interviewees pointed out the challenge was primarily caused by conflicts on safety issues. The industrial injury and death in the HZMB project caused the severe conflicts between construction groups and the labor union, meanwhile interfered by council representatives. The conflicts exerted the heavy pressure on the construction groups in the construction stage of the project.

Supervision groups

As a critical stakeholder group, according to Table 5.1, media was positioned at the centre of stakeholder networks especially when big conflicts happened. For instance, the media had critical links with Hong Kong, Macao, and Guangdong government in 2011(S19-S1, S19-S3, S19-S4) when the severe environmental judicial review occurred causing the suspension of the project construction. While in 2017, the media was critically connected by the independent inspection department and consultants (S19-S31, S19-S10) as the fabrication of the cement experimental report from the consultant causing the big conflict on HZMB. According to the feedback of interviewees, in most cases, the media stood closely with the environmental groups, traveling public and workers, whereas with different voices against the governmental organizations, contractors and consultants.

Governmental organizations

The collaboration of governmental organizations is the determinant for the success of the cross-boundary megaprojects (Andrić et al., 2019), which is also echoed by interviewees. The prominent criticalness is evident by the links among three governments related to HZMB identified by stakeholder network analysis. For instance, according to Table 5.1, the critical links among the governments of Hong Kong SAR (S1), Macao SAR (S3), and Guangdong Province (S4) were always connected as critical links from the planning to construction and handover stage of the project (S1-S3,S1-S4,S3-S1,S4-S1). The critical links indicated the importance of relationship among the three governments: Hong Kong SAR, Macao SAR, and Guangdong Province, as addressing the conflicts together with the coordination and collaboration. The three governments also cooperated to tackle the challenges from the operational conflicts in the handover stage, when they occupied the top three positions in the center of the stakeholder network (shown in Table 1). With the major links connected by shuttle bus operator (S3-S22, S4-S22), insurance company(S1-S26) and district councils(S1-S8), the three governments formed the coordination coalition to address the conflicts related to cross-boundary transport arrangements.

(3) The longitudinal stakeholder-conflict management strategies

Proposed "Mirror Z" strategies for stakeholder-conflict management

Based on the results of stakeholder-conflict map analysis, quick managerial guidance is proposed for senior project managers in the combination of the network-based evaluation and conflict management theory (shown in Figure 5.7).

With the integration of the conflict management strategies in the previous study, the managerial implication of the "Mirror Z" approach could be presented on tackling the conflicts in each zone of the map with the following strategy: collaborating, compromising, avoiding, and accommodating (Jia et al., 2011). In Zone One, the collaborating strategy is recommended as all parties faced the most serious conflicts, which requires the openness, exchange of information, and careful examination of the differences between the parties (Rahim, 2017). In Zone Two, the compromising should be optimal among stakeholders. The focal group consultation could be frequently organized as limited stakeholder participation for achieving the practical solutions with the mutually acceptable agreement (Tsai and Chi, 2009). In Zone Three, the avoiding strategy is suggested as a large number of stakeholders are involved in low criticalness conflicts. As reaching the agreement is not easy due to the wide stakeholder participation, the withdrawing from the threatening position for all parties to postpone the conflicts would be more efficient since the issues are less critical (Sunindijo and

Hadikusumo, 2013). In Zone Four, accommodating would be the best solution to solve the least seriousness conflicts under a harmony environment. As conflicts in the Zone Four is least critical with limited stakeholders, it would be better for all parties to reach the consensus as soon as possible with a high degree of cooperativeness rather than wasting time and resource(Rahim, 2017).

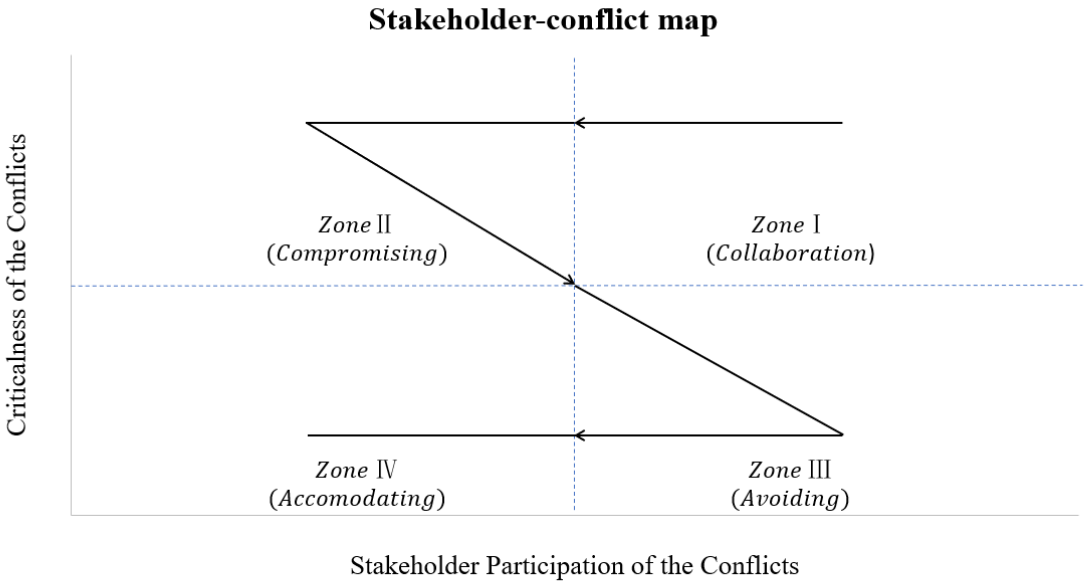


Figure 5.7 "Mirror Z" strategies for stakeholder-conflict management

Planning Stage

In the planning stage, most conflicts on financial arrangements are located in the Zone One (Table 5.2), with the high conflict criticalness and stakeholder participation, which indicates that the financial issue was the top serious stakeholder-conflict in the early stage of HZMB. Since the conflict caused by the divergent views on the selection of financial modes, fiscal distribution among three governments, financial viability of the bridge, the interviewees agreed with the significance of the wide collaboration among governmental organizations, the legislative council, the media and general public to reach the consensus. Otherwise, it would be difficult to start the project.

The conflicts on schedule, environment and local connectivity were the top three issues located in Zone Two (Table 5.2), with the high conflict criticalness and fewer stakeholder participation. As the number of involved stakeholders is limited, reaching a compromise with the frequent contacts is the best solution towards the conflicts. For instance, the interviewees revealed that public consultations were organized to effectively relief the tensions between Hong Kong SAR and green groups on environmental issues.

Most conflicts on labor issues placed in Zone Three and Zone Four (Table 5.2), implicating the less criticalness in the planning stage. The interviewees considered the corresponding avoiding and accommodating strategies are helpful to shelve disputes on the labor conflicts. As the tendering policy would not be among the prior issues in the early stage of the project, the conflicts on the protection of local laborers would be better to put aside and cool down with the cooperative environment among stakeholders instead of escalating the tensions.

Construction Stage

In the construction stage, the conflicts caused by cost overrun were the top one conflict in the Zone one (Table 5.2), where most conflicts on safety and quality issues appeared in the same zone. The results revealed that these three kinds of conflicts should be managed at the priority, being the most serious ones. Since the issues on cost, safety and quality have a direct influence on the project performance (Flyvbjerg et al., 2003), the relevant conflicts require the collaboration among wide-range stakeholders to seek for the immediate remedy, which was also echoed by interviewees.

Conflicts on operational management were the largest group in Zone Two, Three, and Four respectively (Table 5.2), reflecting the significant role in the map. The conflicts on operational issues are barely distributed equally in each zone of the stakeholder-conflict map in the construction stage, indicating the requirement of the diversity on corresponding management strategies. For instance, most conflicts in Zone Two were caused by the transport arrangements of Hong Kong Crossing Boundary Facilities (HKCBF), which were highly critical, as HKCBF would undertake the role as a hub in the traffic system of HZMB. However, the conflicts were much focused on the technical details which referred to the limited stakeholders with professions, such as the Hong Kong Government, consultant, and council members. For ensuring the progress of the project, the interviewees agreed that the compromising strategy would be optimal for stakeholders to reach the agreement. While conflicts in Zone three referred to the arrangement of the local transport system, which was not so urgent in the construction stage but attracting the attention from many stakeholders, especially among local communities, the general public, and media. For these conflicts, the interviewees pointed out that avoiding strategy may prove effective in postponing the conflict and keep discussions in a peaceful way rather than confrontations.

Another interesting phenomenon is from environmental issues, on which the relevant conflicts show the polarization in the map, i.e. 8 cases in Zone One whereas 9 cases in Zone Four (Table 5.2). According to the interview findings, the polarization is caused by the time divergency of the conflict occurrence since the environmental conflict was the major conflict in the initial stage of the construction period, then turning into the less-criticalness zone. As discussed in the first part of the section 5.3.2, the environmental issues always take the leading position among stakeholder conflicts, causing project delay and the cost overrun of the project. The eruption of environmental conflicts in the early period of the construction stage (Located in Zone One) heavily influences the wide range of project stakeholders, thus calling for the collaboration strategy among stakeholders to reach the agreement efficiently for stopping the further negative chain effects towards the project. However, as the project goes on, various conflicts erupt besides the environmental issues, which diversifies the focus among stakeholders. As a consequence, the importance of environmental conflicts downgrades from the dominating issue which determines the project's success to the ordinary issue which only affects the direct relevant stakeholders. The suggested accommodating strategy is approved by interviewees, which benefits relevant stakeholders to solve the conflict smoothly and harmoniously to keep the project forward in the middle and late phase of the construction stage.

Handover Stage

In the handover stage, the conflicts on operational arrangements, local connectivity, and legal issues were the top three largest groups in HZMB (Table 5.2). Of them, most conflicts on local connectivity and legal issues were located in Zone One and Two, which shows the high criticalness of the two kinds of conflicts in the handover stage. In contrast, the operational arrangements received the conflicts equally distributed in each zone respectively (Table 5.2), implicating the diverse features towards conflict criticalness and stakeholder relevance. The general cross-boundary arrangements caused the severest conflicts among stakeholders located in Zone One, including the adoption of right-driving policies and 24-hour traffic arrangement. As the general arrangements refer to the contradiction of official traffic regulations between the Mainland and Hong Kong, the interviewees reminded the effectiveness of collaboration strategies among involved government departments to find feasible solutions to eliminate the contradicts in the history of HZMB. In Zone Two, the operational conflicts turn to the local traffic pressure on Hong Kong Port and Link Road. Based on the interview findings, the relevant stakeholders are mainly in Hong Kong region relieving the stress on cross-boundary negotiation, thus easier to reach a compromise among stakeholders.

Moreover, the conflicts on political issues such as the fears on the too-close integration between the regions connected by the project should be paid attention since 2 out of 3 political conflicts are in the Zone One (Table 5.2). The interviewees supported the corresponding collaboration strategy for project stakeholders to remove the political worries particularly from the media and the general public.

5.4 Summary of the Chapter

In this chapter a longitudinal stakeholder-associated network model is proposed to analyze the stakeholder complexity in different phases of megaprojects. The network-based model presents and evaluates the complex structure between stakeholders and their relevant stakeholder issues in megaprojects. It is composed of four parts, including stakeholder-issue identification and visualization, stakeholder-issue analysis, stakeholder-issue assessment, and stakeholder-issue management. Combined with the longitudinal data, the network-based framework provides a systematic method to analyze the changes of stakeholder complexities in the project environment from identification to evaluation and management in different project stages.

The proposed model provides managerial implications of generalized management process on stakeholder complexity in megaprojects. The management process is composed of three phases. First, it is essential for stakeholders to understand stakeholder issues' criticalness, with prioritizing the critical stakeholder-issues from a large number of interacted project issues. Second, each stakeholder is suggested to recognize the most affected stakeholder relationships in a project by prioritizing the interdependent stakeholder connections. Third, the stakeholders are recommended to determine the stakeholder-issues' managerial priority by the proposed "Mirror Z" approach, considering the level of stakeholder-issue criticalness and stakeholder participation in the complex environment of megaprojects.

With the case of stakeholder studies on stakeholder conflicts in Hong Kong – Zhuhai – Macao Bridge, the proposed analytical approach is validated by analyzing stakeholder complexity between stakeholders and associated conflicts in various project phases, including planning, construction, and handover. The annual stakeholder-conflict networks are established from 2003 to 2018 with the development of HZMB. There are 334 stakeholder-conflicts and 32 kinds of stakeholders identified in total. Through the modeling analysis, the three kinds of critical stakeholder-conflicts and most affected stakeholder relationships for five major stakeholder groups are revealed. Besides, with the assist of stakeholder-conflict map, it benefits the decision-maker to determine the management priority of stakeholder conflicts and manage them by corresponding strategies, including collaborating, compromising, avoiding, and accommodating. The case successfully validates the proposed model on analyzing the stakeholder complexity by integration of the stakeholder-issue network and longitudinal stakeholder information.

Chapter 6 A Network-NK simulative model for stakeholder performance in dynamic and complex environment

6.1 Introduction

As there is a lack of simulation models that evaluate the stakeholder performance in megaprojects stated in the section 2.7, the bottleneck comes from the difficulties to quantitively reflect the stakeholder interactions in the project duration which are faced with the challenges of complexities and dynamics (Yang et al., 2009c, Ganco and Hoetker, 2009). The organizational management of megaprojects are switched from the traditional control paradigm to latest adaptive paradigm, which aims at increasing the adaptability of organizations to tackle with the inherent dynamics and complexity of the megaprojects (Xue et al., 2020c, Weaver, 2007). Under these circumstances, it is essential to develop the stakeholder simulation model considering how stakeholders respond to the complex and dynamic environment.

The network model provides an effective tool to present the complexities of interrelated elements involved in projects (Lee et al., 2017a), since the linearity relationship is not the reality between stakeholders and their relevant issues in megaprojects. The stakeholder complexities have been successfully analyzed in the cultural building projects, infrastructure projects, urban-redevelopment projects (Yu et al., 2017), and prefabricated housing projects (Luo et al., 2019). The previous network studies focus on either the complex interactions of stakeholders or the complicated interdependencies of stakeholder issues, lacking the integration of information from both aspects (Xue et al., 2020d). To overcome the limitations, the two-mode network model is proposed to comprehensively depict the interactions between stakeholders and stakeholder-associated issues, which is beneficial to present the complex environment of megaprojects.

The NK model is an organizational simulation tool to reflect the evolution of strategies in the decision-making process under the dynamic environment of the adaptive complex system (Ganco, 2017). The model was developed from the concept of fitness landscape, which was used to describe the evolution path of genotypes in the biological domain (Kauffman and Levin, 1987). It was introduced into organization and management sciences by providing a simulation method to model the organization evolution process which is difficult to reveal empirically (Kauffman, 1993, Levinthal, 1997). The parameter N represents the number of involved stakeholders, while K stands for the interaction level among them (Giannoccaro et al., 2018). The NK model simulates the searching process of various interacted stakeholders to explore optimal performance values in the unpredictable dynamic project environment by self-adaptiveness (Ganco, 2017). Therefore, the model has the potential to simulate the stakeholder performance in the dynamic environment of megaprojects, which are also regarded as the complex system.

In this study, the integrated Network-NK simulation model is proposed to simulate the stakeholder performance under the complex and dynamic environment in megaprojects. The research is composed of two parts. First, the design of Network-NK simulation model is introduced step by step to evaluate the stakeholder performance in megaprojects. Second, the proposed Network-NK model is validated by case of stakeholder performance on relationship management in Hong Kong-Zhuhai-Macao Bridge.

6.2 Model design

6.2.1 Framework of the simulation model

As Figure 6.1 shows, the simulation model is composed of three parts: input, processing, and output. The input modular is consists of two components. Input one is the two-mode stakeholder-issue networks, which explicitly present the complexity of relationships between stakeholders and their associated issues in various stages of megaprojects. Input two is the influence distribution of stakeholder strategies towards each kind of stakeholder issues, which reflects the general trend of random stakeholder performance under each strategy in the dynamic environment of megaprojects. The processing modular is the Network-NK model, which simulates the stakeholder interactions in the complex and uncertain environment of megaprojects. Output one is the result of stakeholder evolution analysis, which shows the simulation result of general stakeholder performance after stakeholder interactions in each timepoint of the megaproject. Output two is the result of stakeholder resilience analysis, which indicates the resilience level of each stakeholder struck by the associated issues.

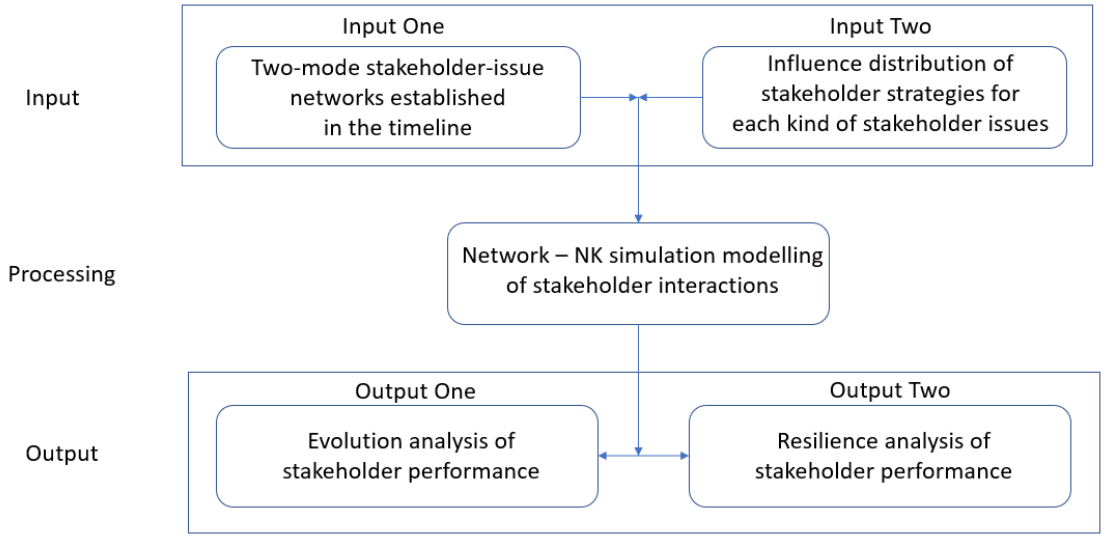


Figure 6.1 Framework of the simulation model

6.2.2 Input One: Network of stakeholder issues

The two-mode network of stakeholder issues is established to reflect the complex environment of megaprojects. There are two components of two-mode stakeholder-issue network. One mode is the stakeholders, another mode is the stakeholder-associated issues, which shows two elements of stakeholder interactions. The link represents the stakeholder involves the corresponding issue in the project duration. The two-mode network model comprehensively reflects the complicated relationship between stakeholders and their relevant issues, which set the basis on the further simulation analysis of stakeholder interactions.

6.2.3 Input Two: Influence of stakeholder strategies

The influence of stakeholder strategies is required to be assessed, which is useful to establish the distribution of stakeholder performance values under each stakeholder strategy. The distribution of stakeholder performance values presents the general scope of pay-off values corresponding to each strategy. There are two sources obtaining the assessment information. One is from the previous empirical studies which have already done the similar evaluation. Another one is based on the wide-range surveys among experts and professionals. The mean and standard deviation of evaluation scores from the survey lead to generate the normal distribution of stakeholder performance values. After the assessment of influence of stakeholder strategies, the pay-off value distribution P_i is obtained for each stakeholder strategy D_i.

6.2.4 Process: Network-NK modeling of stakeholder interactions

(1) NK parameter

As two critical parameters in the NK model, N represents the number of project stakeholders in the coming megaprojects, while K refers to the complexity of project stakeholders. Towards a specific stakeholder issue derived from Input One, N stands for the number of stakeholders related to the issue, while K is equivalent to N-1 as each involved stakeholder behavior would be influenced by other stakeholders associated with the same issue.

(2) Performance Landscape

The performance landscape is generated according to the stakeholder performance on each kind of issues. For a specific issue, each relevant stakeholder would determine its strategy d_i to improve the performance. Therefore, it generates a decision vector for a specific issue C,$D = (d_1, d_2, \ldots, d_N), d_i \in \{0,1, \ldots, n\}$, where n represents the number of strategies. For each specific d_i, the enhancement decision leads to a pay-off value to measure the stakeholder performance under this decision. Correspondingly, a pay-off vector is generated as $P = (P_1, P_2, \ldots, P_N)$. The value of P is derived from the Input Two, which draws the influence distribution of each stakeholder strategy. Therefore, the final integrated stakeholder performance value $P(D)$ under a specific decision vector D is $P(D) = (\sum_{i=1}^{N} P_i)/N$.

To generate the performance landscape of a specific issue C, it is randomly generated all the combinations of the decision vector D and their corresponding pay-off vectors P and integrated stakeholder performance values $P(D)$. The performance landscape of the specific issue C is composed of all the combinations of D, P, and $P(D)$.

(3) Searching method

The searching method reflects how stakeholders switch their strategies for improving their performance (Rivkin and Siggelkow, 2002). For a specific stakeholder issue, relevant stakeholders automatically search the optimal performance score on the performance landscape, reflecting the dynamic nature of stakeholder behaviors in megaprojects. Besides, each stakeholder's decision is influenced by other stakeholders associated with the same issue. When one stakeholder changes the strategy, other stakeholders alter their solutions simultaneously, which represents the dynamics of stakeholder interactions. Therefore, the searching method is crucial to reflect how stakeholder interactions to seek the optimal performance for a stakeholder-associated issue in the dynamic environment of megaprojects.

The searching method is based on the local search modular, which was popular to explore the local peak of the performance landscape (Ganco, 2017, Sommer and Loch, 2004). The principle of the local search is to switch the elements in the decision vector D for the exploration of the better integrated stakeholder performance value P(D), then making the iterations until the value cannot be improved, which means the decision combination among stakeholders reaches to an optimal point (Ganco, 2017).

Based on the local search, there are two basic searching methods reflecting the stakeholder collaborations faced with the common stakeholder issue: planning and learning (Weaver, 2007). It is furtherly explained as follows.

The first method is called the "planning" strategy, which assumes each stakeholder in the NK model would seek collaborations and accept the compromising arrangement with the aim to achieve the optimal performance tackling the common stakeholder issue. Thus, when the searching initiates:

If $P(D_{n+1})$> $P(D_n)$:

$$D_n = D_{n+1}$$

$$P(D_n) = P(D_{n+1})$$

The second method is called the "learning" strategy, which assumes each stakeholder in the NK model would only seek the solution to improve its own performance tackling the issue. The "learning" strategy reflects the situation when each project organization would learn how to address the issue with the primary aim of improving its own performance. Thus, when the searching initiates:

As the decision vector D under n iterations $D_n = (d_n^1, d_n^2, \dots, d_n^N)$, the corresponding pay-off vector is $P_n = (P_n^1, P_n^2, \dots, P_n^N)$,

If each P_{n+1}^i>P_n^i, $i \in [1, \mathrm{N}]$:

$$D_n = D_{n+1}$$

$$P(D_n) = P(D_{n+1})$$

In fact, both "planning" and "learning" strategies occur in reality. For instance, As shared with the common aim to complete a successful project, some internal stakeholder groups (contractor, consultant, subcontractor) would follow the "planning strategy," as they can make the compromise to achieve the best performance of the system (Ujene and Edike, 2015). While as the mainstream opposition forces, some stakeholder groups (local community, green group, opposition political party) would follow the "learning strategy," as they only focus on the improvement of their own interests (Olander and Landin, 2008, Xue et al., 2020a). Therefore, it is proposed the third searching method in combination with the "planning" and "learning" strategies as follows.

For a specific issue, on the one hand, the stakeholder group who follows the "learning" strategy focuses on the improvement of its own performance (P_{n+1}^{i}>P_{n}^{i}); On the other hand, the stakeholder group who follows the "planning" strategy expects the overall performance towards the issue could be improved ($P(D_{n+1})$> $P(D_n)$).Thus, when the searching initiates:

Assume that j represents the group of stakeholders who follow a "learning" strategy,

If $P(D_{n+1})$> $P(D_n)$ and each P_{n+1}^{i}>P_{n}^{i}, $i \in j$:

$$D_n = D_{n+1}$$

$$P(D_n) = P(D_{n+1})$$

In the study, we employ the third searching method that is proposed in combination of the "planning" and "learning" strategies. When the searching finishes, it is obtained the optimal integrated stakeholder performance value of the system $P(D)_{optimal}$ and optimal pay-off value vector $P = (P^{S_1}, P^{S_2}, \dots, P^{S_k})_{optimal}$. With the optimal pay-off value vector, the performance score of each stakeholder group S_k in the involved issue could be obtained as $(P^{S_k})_{optimal}$. Both $P(D)_{optimal}$ and $(P^{S_k})_{optimal}$ are beneficial for decision-makers to make further analysis on stakeholder performance in the stakeholder issue.

(4) Integration of NK-models in the network

As one specific stakeholder-issue is considered as one NK model, there are several NK models in the two-mode stakeholder-issue network shown in Figure 6.2.

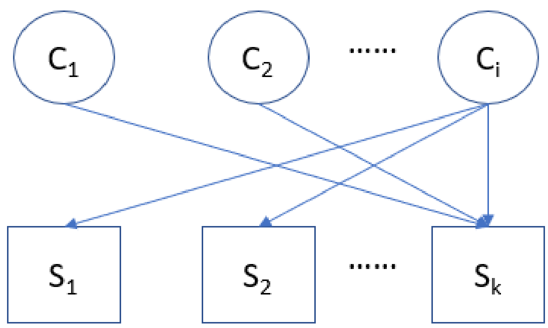


Figure 6.2 The two-mode stakeholder-issue network

As Figure shows, each issue C_i and its relevant stakeholder S_k are formed as one NK model. The performance score of each issue C_i is the optimal integrated stakeholder performance score $P(D)_{optimal}$ of its own NK model, which represents the vulnerability of the stakeholder issue in views of the project stakeholders. The higher value of $P(D)_{optimal}$ means the less vulnerability of the stakeholder issue. The calculation is as follows.

$$P(C_i) = P(D)_{optimal} \ ,$$

Since each stakeholder group S_k may join various issues in the network, the performance of S_k should be comprehensively evaluated by pay-off value in the NK model of each involved issue. Therefore, the performance score of each stakeholder group S_k is determined by the mean of optimal pay-off values in each of relevant NK models. The calculation is as follows.

$$P(S_k) = \frac{\sum (P_{C_i}^{S_k})_{optimal}}{The\ number\ of\ invovled\ issue\ C_i}$$

Where $(P_{C_i}^{S_k})_{optimal}$ means the optimal pay-off value of stakeholder group S_k under its involved issue C_i.

(5) Simulation Example

The simple case is presented in the section to show the simulation process step by step. Assume that the two-mode stakeholder-issue network (Figure 6.3) comprises two issue-nodes (C1, C2) and four stakeholder-nodes (S1, S2, S3, S4). The Subgraph C1, including issue C1 and relevant stakeholders (S1, S2, S3), is selected to present the NK-based simulation process. While, the simulation of the Subgraph C2, which consists of issue C2 and relevant stakeholders (S2, S3, S4), is followed by the same procedure as the subgraph C1.

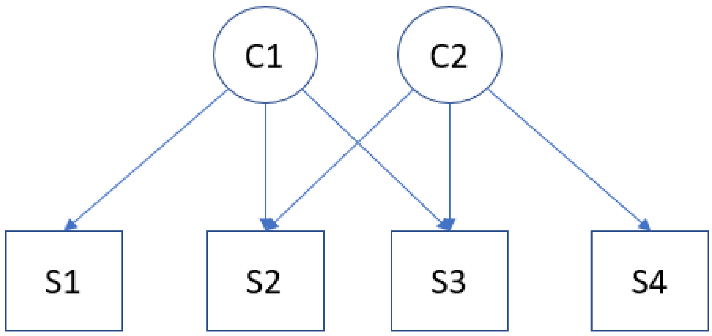


Figure 6.3 The example of the two-mode stakeholder-issue network

Step One: NK parameter for Subgraph C1

As stated in the first part of Section 6.2.4, the Subgraph C1 is considered as an NK-based model. As the issue C1 is related to three relevant stakeholders (S1, S2, S3), the parameter of the number of relevant stakeholders, N is equal to 3. Since each stakeholder's decision is influenced by another two stakeholders' decisions, the parameter of K is equal to 2.

Step Two: Performance landscape for Subgraph C1

As stated in the second part of Section 6.2.4, each of the stakeholders (S1, S2, S3) in Subgraph C1 would determine its own enhancement strategy to improve the performance towards the issue C1. Assume the stakeholders have two strategies in total and the influence distribution of the strategies are based on the normal distribution with the key parameters shown in Table 6.1.

Table 6.1 The example of the normal distribution of pay-off values

Parameter	Enhancement Strategy	
	Strategy One (1)	Strategy Two (0)
μ	0.5	0.4
σ	0.05	0.1

The number of decision configuration of the system is $2^3 = 8$ in total. The possible decision vectors are as follows.

$$D_1(0,0,0), D_2(0,0,1), D_3(0,1,1), D_4(0,1,0), D_5(1,0,0), D_6(1,0,1), D_7(1,1,0), D_8(1,1,1)$$

Correspondingly, the possible pay-off vectors are automatically generated based on the normal distribution of pay-off values with the parameters in Table. The results are as follows.

$$P_1(0.375,0.416,0.269), P_2(0.484,0.225,0.499), P_3(0.533,0.495,0.425),$$

$$P_4(0.504,0.503,0.180), P_5(0.497,0.351,0.320), P_6(0.504,0.340,0.437),$$

$$P_7(0.437,0.526,0.239), P_8(0.466,0.539,0.486)$$

Furtherly, each possible stakeholder performance value is the mean of the corresponding pay-off vector shown as follows.

$$P(D_1) = 0.353, P(D_2) = 0.403, P(D_3) = 0.484, P(D_4) = 0.396,$$

$$P(D_5) = 0.389, P(D_6) = 0.427, P(D_7) = 0.401, P(D_8) = 0.497,$$

Overall, all the possible decision vectors, the corresponding pay-off vectors, and the stakeholder performance values are made up of the performance landscape for Subgraph C1.

Step Three: Searching method for Subgraph C1

As stated in the third part of Section 6.2.4, each of the stakeholders (S1, S2, S3) has embedded its searching strategy, which determines the way that it continually improves the performance towards the issue. Assume the distribution of searching strategies among stakeholders is shown in Table 6.2.

Table 6.2 The example of the searching strategies among stakeholders

Stakeholder	Searching Strategy	
	Planning	Learning
S1	✓	×
S2	✓	×
S3	×	✓

According to the searching strategies listed in Table 6.2, S1 and S2 follow the "planning strategy," which they concern whether the performance of the system would be improved when the iteration starts, while S3 follows the "learning strategy" which it only matters whether its own performance would be upgraded.

Following the third searching method stated in section 3.0, each point is generated randomly, and the searching path on the performance landscape is as follows.

When the searching initiates:

Point 1: $D_1(0,0,0)$, $P_1(0.375,0.416,0.269)$, $P(D_1) = 0.353$

Point 2: $D_4(0,1,0)$, $P_4(0.504,0.503,0.180)$, $P(D_4) = 0.396$

Though $P(D_4) > P(D_1)$, the 3rd value of P_4 (0.180) is less than the 3rd value of P_1 (0.269), which means the performance of S3 is not improved. Hence, the optimal point remains at Point 1.

Point 3: $D_6(1,0,1)$, $P_6(0.504,0.340,0.437)$, $P(D_6) = 0.427$

As $P(D_6) > P(D_1)$, and the 3rd value of P_6 (0.437) is higher than the 3rd value of P_1 (0.269), the optimal point switches from Point 1 to Point 3.

Point 4: $D_7(1,1,0)$, $P_7(0.437,0.526,0.239)$, $P(D_7) = 0.401$

As $P(D_7) < P(D_6)$, it means the performance of the system is not improved. Hence, the optimal point remains at Point 3.

Point 5: $D_8(1,1,1)$, $P_8(0.466,0.539,0.486)$, $P(D_8) = 0.497$

As $P(D_8) > P(D_6)$, and the 3rd value of P_8 (0.486) is higher than the 3rd value of P_6 (0.437), the optimal point switches from Point 3 to Point 5.

Point 6: $D_2(0,0,1)$, $P_2(0.484,0.225,0.499)$, $P(D_2) = 0.403$

As $P(D_2) < P(D_8)$, it means the performance of the system is not improved. Hence, the optimal point remains at Point 5.

Point 7: $D_3(0,1,1)$, $P_3(0.533,0.495,0.425)$, $P(D_3) = 0.484$

As $P(D_3) < P(D_8)$, it means the performance of the system is not improved. Hence, the optimal point remains at Point 5.

Point 8: $D_5(1,0,0)$, $P_5(0.497,0.351,0.320)$, $P(D_5) =, 0.389$

As $P(D_5) < P(D_8)$, it means the performance of the system is not improved. Hence, the optimal point remains at Point 5 — searching Finishes.

Finally, the optimal point is Point 5. The performance score of the system is 0.497. The performance score of each stakeholder is 0.466 (S1), 0.539 (S2), 0.486 (S3), respectively.

As the point is generated randomly, there is not only one searching path that existed. Besides, some decision vectors may not appear only once, while some decision vectors may not appear in the searching route, which reflects the uncertainty of stakeholder dynamics in reality. To improve the robustness of the simulation results, we repeat the searching process for 1000 times to obtain the average optimal performance score of the system and each stakeholder shown in Table 6.3.

Table 6.3 The simulation result of the stakeholder performance in Subgraph C1

	System	S1	S2	S3
optimal performance score based on 1000 times simulation	0.478	0.470	0.475	0.489

Step Four: Results integration of the network

Following the simulation process of the Subgraph C1, the simulation results of the Subgraph C2 could be obtained as Table 6.4 shows.

Table 6.4 The simulation result of the stakeholder performance in Subgraph C2

	System	S2	S3	S4
optimal performance score based on 100 times simulation	0.472	0.471	0.456	0.489

According to the Figure 6.3, the network consists of two issues and four stakeholder groups. Based on the simulation results of Subgraph C1 (Table) and C2 (Table), the general performance score of each issue is 0.478 (C1) and 0.472 (C2), respectively. The performance score of each stakeholder group is 0.470 (S1), 0.473 (S2), 0.473(S3), and 0.489(S4). As both S2 and S3 are connected with two issue-nodes, their stakeholder performances are assessed by the mean of the performance values derived in the network. Thus, the performance score of S2 is the mean of the score values in the Subgraph C1 (0.475) and Subgraph C2 (0.471), which is equal to 0.473. The performance score of S3 is the mean of its corresponding values in the Subgraph C1 (0.489) and Subgraph C2 (0.456) equal to 0.473. Overall, the simulated performance score of issues and relevant stakeholders in the network system is shown in Table 6.5.

Table 6.5 The simulation result of the performance score in the network system

Issue	C1	C2		
Performance score for the issues	0.478	0.472		
Stakeholder	S1	S2	S3	S4
Performance score for the stakeholders	0.470	0.473	0.473	0.489

6.2.5 Output One: Stakeholder evolution analysis

Since the two-mode stakeholder-issue networks are established in the timeline from the beginning to the end of the megaprojects (shown in Figure 6.4), it is obtained the simulation results of Network-NK model at each given time point, which assists the decision-makers to understand the variations of stakeholder performance towards the changeable issues in the project duration.

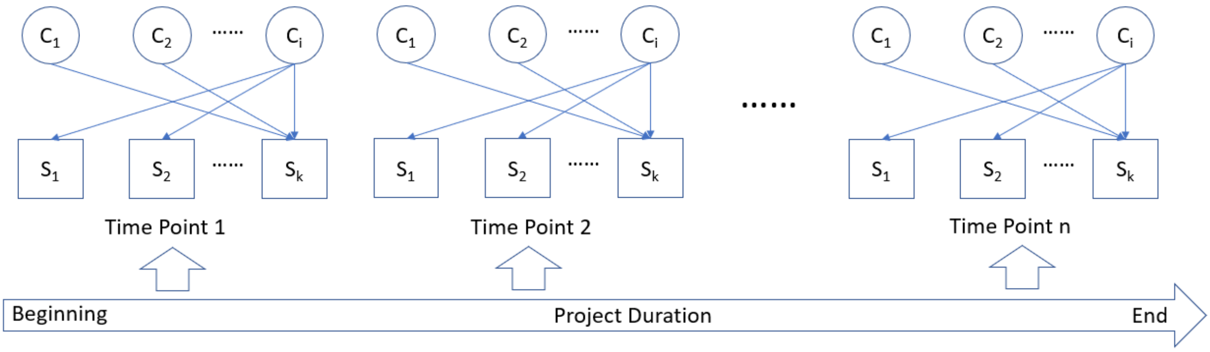


Figure 6.4 The timestamped stakeholder stakeholder-issue networks

Based on the simulation method stated from the first to the fourth part of Section 6.2.4, the stakeholder-issue network could be used to forecast the performance of each issue $P_n(C_i)$ and stakeholder $P_n(S_k)$ at the given time point n. With the timestamped information of each network, it could be depicted the evolution of the performance of each issue and stakeholder, shown in Figure 6.5 and Figure 6.6, respectively. The two figures (Figure 6.5 and 6.6) show the trend of stakeholder issues and stakeholder performance in the timeline, indicating the risky level of stakeholder-issues and the weakness of stakeholder performance in different stages of the megaprojects.

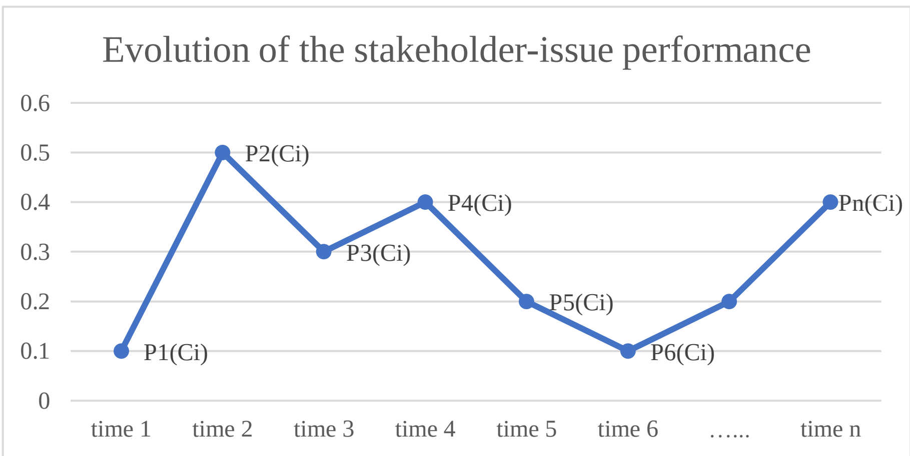


Figure 6.5 Evolution of the stakeholder-issue performance

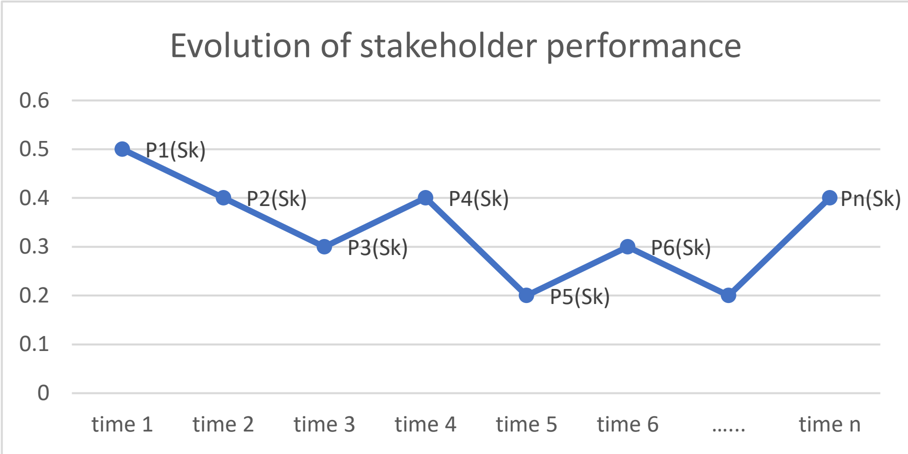


Figure 6.6 Evolution of the stakeholder performance

6.2.6 Output Two: Stakeholder resilience analysis

Resilience is determined by the balance between the vulnerability level due to associated risks and capability level of targets (Pettit et al., 2010, Pettit et al., 2013). As the stakeholder issue may negatively influence the stakeholder performance, the measurement of stakeholder-issue vulnerability and stakeholder capability is important for decision-makers to understand the stakeholder resilience faced with the challenges brought by stakeholder issue.

The measurement is dependent on the indicators derived from the proposed Network-NK model. On the one hand, the stakeholder-issue vulnerability is assessed by the performance score of the stakeholder issue ($P(C_i)$). The lower stakeholder-issue performance score means the issue may lead to the weaker performance of relevant stakeholders if it happens, indicating the higher vulnerability due to the stakeholder-issue. On the other hand, the stakeholder's capability is measured by the performance score of the stakeholder ($P(S_k)$). The higher performance score implicates the better capability of the stakeholder dealing with the corresponding issue. Thus, it is proposed the stakeholder-resilience map according to the assessment value of stakeholder-issue vulnerability and stakeholder capability shown in Figure 6.7.

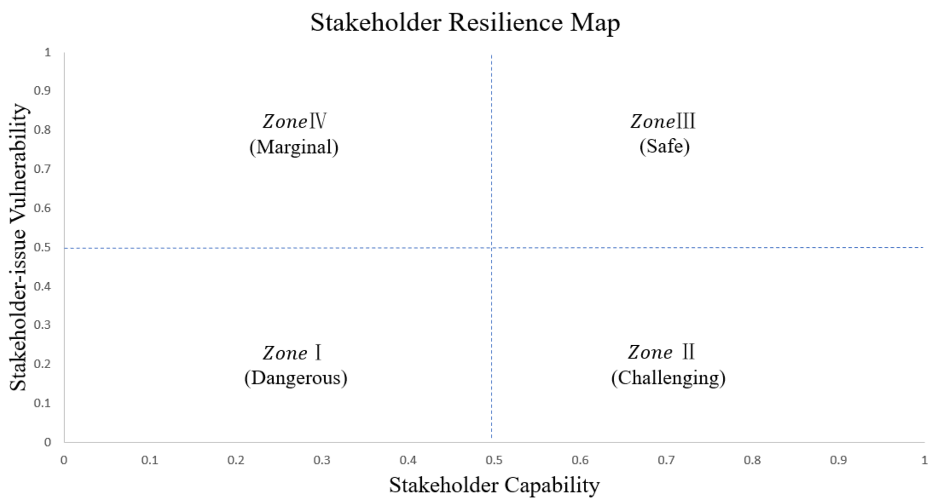


Figure 6.7 The stakeholder-resilience map

As Figure 6.7 shows, the proposed stakeholder-resilience map is composed of a vertical axis and a horizontal axis. The vertical axis represents the value of stakeholder-issue vulnerability. The vertical value which is closer to 0 indicates the issue is more vulnerable. The horizontal axis stands for the value of stakeholder capability. The higher of the horizontal value means the better stakeholder capability faced with the stakeholder issue. Each stakeholder issue could be drawn on the map to show the relevant stakeholder resilience if it occurs. The map is divided into four blocks by the average of vertical and horizontal values of all points, leading to Zone One, Two, Three, and Four.

In Zone One, the stakeholder resilience is weak with the high level of stakeholder-issue vulnerability and the low level of stakeholder capability. Hence, the stakeholder issue located in Zone One is the most dangerous one requiring relevant stakeholders to take precautionary measures to enhance the stakeholder capability. In Zone Two, the stakeholder resilience is medium as the stakeholder-issue vulnerability is serious, but the stakeholder capability is also competent. As the vulnerability level is high, the stakeholder issue in Zone Two is challenging, which deserves to be alerted for relevant stakeholders to manage it seriously. In Zone Three, the stakeholder resilience is perfect with low stakeholder-issue vulnerability and high stakeholder capability. Thus, the stakeholder issue in Zone Three is safe, which would not exert much negative influence on relevant stakeholder performance. In Zone Four, the stakeholder resilience is a trivial concept of the stakeholder issue since both stakeholder-issue vulnerability and stakeholder capability are at the marginal level. As the stakeholder-issue in Zone Four does not pose adverse influence on relevant stakeholders in general, it is still encouraged the associated low-capability stakeholder to improve its management capacity when the resource is available and the workload is acceptable.

6.3 Case Study – Simulation of stakeholder performance on relationship management in HZMB

As stakeholder relationship is faced with various challenges in dynamic and complex project environment, the quality of relationship management for each project stakeholder directly affects the completion of the project (Liu et al., 2015). According to the framework of stakeholder management established by Yang and Shen (2014), stakeholder relationship management is regarded as an important part, which has been proved to have a critical effect on project performance (Meng, 2012). According to the stakeholder management framework, formal and informal relational strategies are two approaches to enhance stakeholder relationship in construction projects (Yang and Shen, 2014). While the stakeholder conflicts caused by complex environment damaged the stakeholder relationship in the development of construction projects (Yang and Shen, 2014, Xue et al., 2020d).

Focusing on megaprojects, they are generally composed of a large number of project stakeholders with the dynamic interactive relationships and the complex project organization structure (Holland, 2000). The complex stakeholder structure between project stakeholders and stakeholder issues (Shi et al., 2016) and stakeholders' adaptability towards dynamic changes in the whole life cycle of megaprojects will have a great impact on stakeholder relationship management (Xue et al., 2012, Tang and

Shen, 2015). At present, there is a lack of effective ways analyzing the stakeholder performance on relationship management in dynamic and complex environment of the megaprojects, which is quite essential for decision-makers to understand the weakness moment and resilience capacity for relationship management in the view of project stakeholders.

In this study, the Network-NK model was employed to analyze the stakeholder performance on relationship management. As Figure 6.8 shows, the simulation research consists of three components. The first part is to conduct an empirical study on the inner influential mechanism between stakeholder relational strategies and megaproject performance, which obtains the stakeholder performance distribution when the stakeholders decide to improve their relationship management faced with conflicts relevant to megaproject performance through formal or informal relational strategies. The second part is to draw the stakeholder-conflict network in various stages of megaprojects, depicting the complex environment of megaprojects. The third part is to make analysis by Network-NK model to evaluate the stakeholder performance on relationship management by simulating dynamic stakeholder interactions in Hong Kong-Zhuhai-Macao Bridge (HZMB). Based on the result of Network-NK simulation model, the evolution and resilience of stakeholder performance were detected by simulation results, which were furtherly interpreted with the development history of

HZMB.

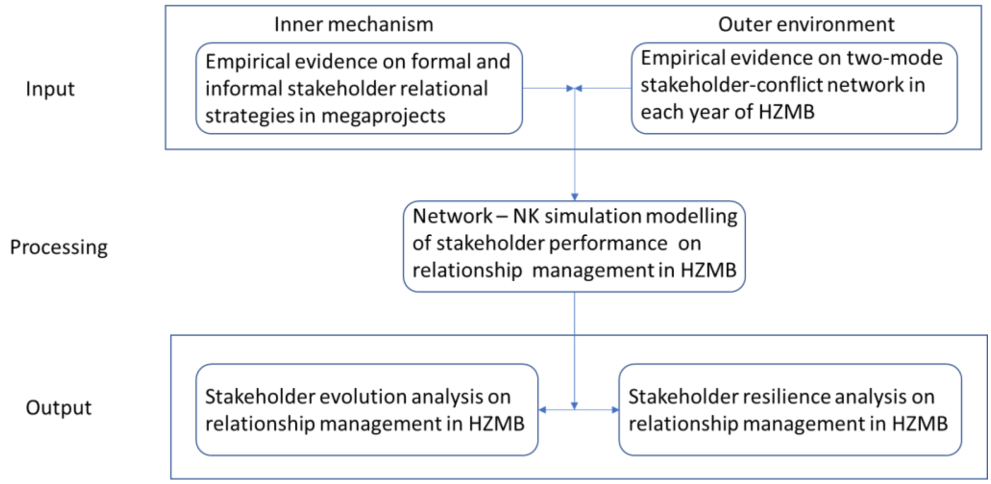


Figure 6.8 Framework of the simulation process in case study

6.3.1 Input One: formal and informal stakeholder relational strategies in megaprojects[4]

(1) Formal relationship

A formal relationship is an official connection among stakeholders in megaprojects. Generally, formal relationships are normative, reflecting the governance structure based on rules, such as laws, contracts, and other codified artifacts (Jensen, 1995, Prell et al., 2010). The position of each stakeholder's formal relationship is clearly defined by a given governance structure (Prell et al., 2010). On the one hand, most stakeholders in megaprojects are linked by complex contractual structures (Holland, 2000). The contract relationship is established and operated by contract endorsement, management,

[4] This section is relevant to the publication:
Xue, J., Shen Geoffrey, Q., Yang Rebecca, J., Zafar, I., Ekanayake, E. M. A. C., Lin, X. & Darko, A. 2020. Influence of Formal and Informal Stakeholder Relationship on Megaproject Performance: A Case of China. Engineering, Construction and Architectural Management, 27, 1505-1531.

and conflict resolution (Zheng et al., 2008, Zhang et al., 2016b). On the other hand, nearly all official activities in megaprojects are under inspection by supervision structure, which consists of the government, legislative council, and local professional associations (Zhai et al., 2017). Based on these two governance structures, there are two major formal stakeholder relationships in megaprojects: contractual and supervision relationship.

(2) Informal relationship

The informal relationship is an intangible connection among the stakeholders in megaprojects (Zou et al., 2010). Unlikely the contractual and supervision relationships, the informal relationship is not protected by law, but playing a critical role in strengthening the quality of stakeholder performance (Yang and Shen, 2014). Transaction costs can be significantly reduced between project organizations with the assist of an informal relationship (Dyer and Singh, 1998). Since it improves the effectiveness of flexibility, solidarity, and information change between organizations, the informal relationship can work as lubricants to make cooperation among stakeholders running smoothly (Poppo and Zenger, 2002). However, due to the complexity of megaprojects, it is difficult for contracts to cover all the risks during the lifecycle of the project (Kumaraswamy et al., 2005). Hence, informal relationship management can effectively improve cooperation when organizations are facing uncertainties (Zheng et al., 2008). Regarding the content on the informal relationship, it could be divided from perspectives of affection and political authority (Krachardt, 1993, Tichy et al., 1979), which are furtherly composed of four kinds of relationships: influence, common goals and interests, trust, and friendship. In details, considering the division of affects, informal relationship represents the intimate relations among stakeholders, which is referred to friendship and trust by Krachardt (1993). In terms of political authority, there are two sub-divisions. On the one hand, the political coalition among stakeholders is established by common individual and group goals (Tichy et al., 1979). On the other hand, the influence network among stakeholders is highlighted as another invisible authority relationship structure in the previous study (Torenvlied and Velner, 1998, Ackermann and Eden, 2011).

(3) Megaproject performance

The concept of the megaproject performance is derived from the project performance, which is defined as the extent of achieving the project objectives (Pmi, 2013). Since the megaprojects are more complex than the traditional construction projects due to the increasing complexity of the project scope and environment (Hu et al., 2013), the theory of project performance is no longer limited to the iron triangle of project management: time, cost, and quality, requiring the extension with the broad views (Weaver, 2007). Taking the megaprojects in China as an example, the reliable organizational performance established by informal relational ties between project stakeholders and the state has been highlighted as a determinant to achieve the success of the megaprojects for Beijing Olympic Games (Chi et al., 2011). Besides, as the development of the megaprojects triggers the social protests and tensions due to the conflicts between local residents and other project stakeholders, the central government has issued the compulsory requirement of the societal performance assessment in the feasibility study of each megaproject in China (Liu et al., 2016b). Based on the existing studies, the megaproject performance could be furtherly interpreted by two aspects in addition to the classical project view. From the micro perspectives, the performance of organizations and their interactions impacts the process of the megaprojects (Hu et al., 2016). From the macro perspectives, as megaprojects have a significant influence on the local society (Flyvbjerg, 2014), societal performance has been considered as a critical assessment to examine the project success of the megaprojects (Liu et al., 2016b). Thus, it explains the megaproject performance from the three perspectives as follows.

In the inter-organizational level, the 3Cs (communication, coordination, collaboration) reflect the interrelations of multiple stakeholders and have been highlighted to facilitate the project value from relational perspectives (Lin et al., 2018b). The existing studies describe the current situation of 3Cs in megaprojects. First, numerous stakeholders make difficulties in exchanging information and building relationships among institutions, causing the communication problem in megaprojects(Hu et al., 2014). Besides, more knowledge is required to explore how to improve the coordination within megaprojects, mainly when dealing with conflicts among stakeholders (Söderlund, 2011). As many professional teams jointly work in one project (Suprapto et al., 2015), the efficiency of collaborations among stakeholders plays a critical role in megaproject success.

In the project level, schedule, cost, and quality were regarded as three determinants in the classical theory of project management by Martin Barnes in 1969. Based on the experience of megaprojects around the globe, cost overruns and project delays are much serious in the industry (Flyvbjerg et al., 2003). Meanwhile, aiming to build large and innovative projects, more advanced technologies have been widely used, which increases the difficulties of quality control in megaprojects due to the complexity of techniques and the lack of existing standards (Flyvbjerg, 2014). Besides the traditional triangle model of project management, safety is another critical issue in megaprojects (Lin et al., 2017). As most megaprojects have a high political impact on the local society (Flyvbjerg, 2014), the on-site safety management receives substantial attention from the government to reduce the incident rate and improve the sustainable safety performance (Ma et al., 2019).

At the societal level, as an effective way to create job opportunities, megaprojects attract close attention to labor protection (Wu et al., 2015). Unfortunately, several labor protests and conflicts have occurred in recent years, leading to catastrophic results in relevant projects (Xu et al., 2019). Besides, environment protection is one of the top concerns for the community around the megaproject, as reducing environmental damage is an important social responsibility for project stakeholders in megaprojects towards society (Wang et al., 2017a, Lin et al., 2016). Since most megaprojects involve a considerable investment by government, project transparency is essential for the public to understand whether the money of taxpayers is spent legally and effectively (Locatelli et al., 2017, Lin et al., 2017).

In summary, ten aspects are evaluating the megaproject performance from the inter-organizational level to the project and societal level, including communication, coordination, collaboration, schedule, cost, quality, safety, labor protection, environmental protection, and project transparency.

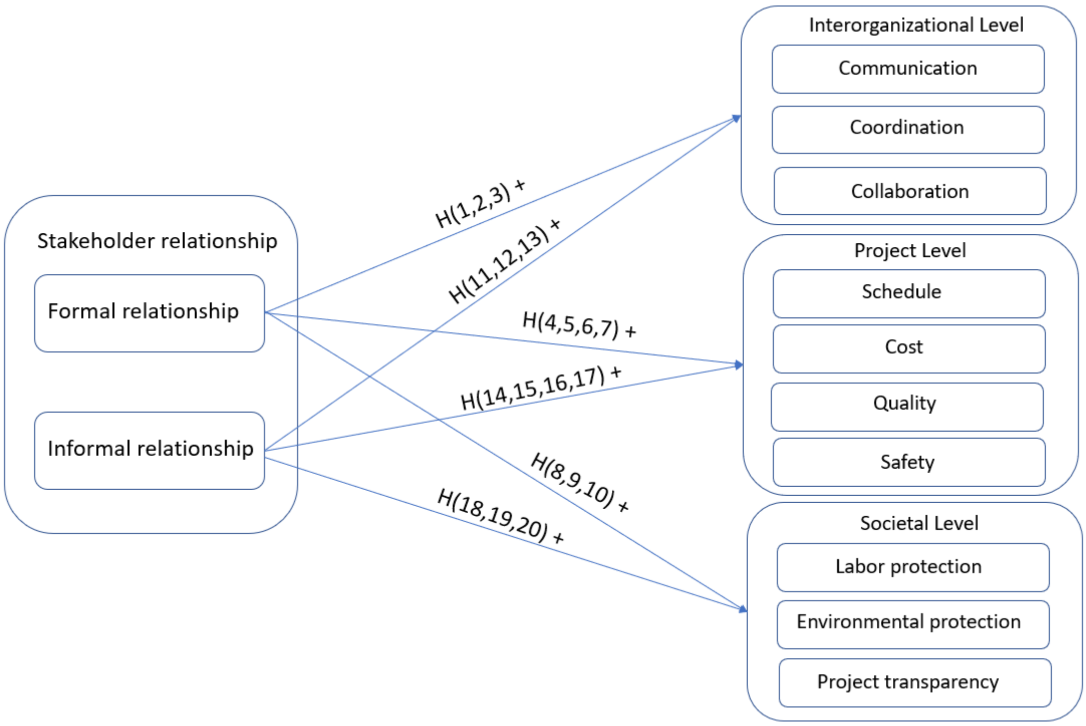


Figure 6.9 The hypotheses of the PLS-SEM research

(4) PLS-SEM test of influence on formal and informal relational strategies

The previous studies have assumed twenty hypotheses regarding the effects between formal and informal relational strategies and issues relevant to the megaproject performance (Xue et al., 2020a). The hypotheses were assumed formal and informal relational strategies exerted positive influence on all the ten aspects of megaproject performance in China (shown in Figure 6.9). Then, a partial least squares structural equation modeling (PLS-SEM) was used to verify the hypotheses by assessing a structural correlation among independent constructs (Xue et al., 2020a). The results of hypothesis testing were shown in Table 6.6.

Table 6.6 Results of Hypothesis Testing

From	FR		INFR		
To	Path coefficient	T value	Path coefficient	T value	Results
COM	0.340 [c]	3.609	0.508 [c]	5.557	H1: Supported H11: Supported
COO	0.482 [c]	4.672	0.371 [c]	3.648	H2: Supported H12: Supported
COL	0.352 [b]	3.049	0.387 [c]	3.362	H3: Supported H13: Supported
SCH	0.330 [b]	2.979	0.347 [b]	3.085	H4: Supported H14: Supported
COST	0.490 [c]	3.845	0.134	1.097	H5: Supported H15: Not supported
QUA	0.509 [c]	5.291	0.205	1.939	H6: Supported H16: Not supported
SAFE	0.441 [c]	4.709	0.310 [b]	3.014	H7: Supported H17: Supported
LABOR	0.561 [c]	5.530	0.177	1.621	H8: Supported H18: Not supported
ENV	0.501 [c]	5.352	0.233 [a]	2.190	H9: Supported H19: Supported
TRANS	0.255 [a]	2.147	0.394 [c]	3.656	H10: Supported H20: Supported

As Table 6.6 presented, there were three hypotheses rejected, including H15, H16, and H18, which indicates only formal relationship exerts a significant impact on the issues of cost, quality, and labor protections. PLS-SEM supported all the remaining hypotheses. Based on the path coefficient values, the different effects between formal and informal relationships on megaproject performance were revealed. Formal relationship shows more significant influence on the issues of coordination (0.482>0.371), safety (0.441>0.310), and environmental protection (0.501>0.233).

While the informal relationship has more effectiveness on the issues of communication (0.508>0.340) and project transparency (0.394>0.255). Besides, formal and informal relationship show a close impact on the issues of collaboration (0.352, 0.387) and schedule (0.330, 0.347).

(5) Validation of PLS-SEM hypothesis testing results

The validation of PLS-SEM hypothesis testing results is essential for the researchers to consider whether the results are reliable to be the inputs of the Network-NK simulative model. Therefore, five key stakeholders were invited who had a rich experience (more than ten years) on megaprojects to attend the individual follow-up interviews. Each interview lasted for more than 1 hour to help us explore the reasons behind the result of data analysis. The interview samples are shown in Table 6.7, providing comprehensive views of different project stakeholders on the current situation in megaprojects. The validation results are as follows.

Table 6.7. Characteristics of interview samples

Code	Experience (years)	Stakeholder Type	Project Type
SO	10	Government	Transport
PM-1	12	Client	Energy
PM-2	11	Contractor	Airport
PM-3	15	Subcontractor	Harbor
PM-4	11	Consultancy	Public Building

In the inter-organizational level, informal relationship (0.508) has a stronger impact on the performance of communication among stakeholders than the formal relationship

(0.340). Although formal relationship provides the duties and regulations in the communication, most communications require flexibilities when facing with the uncertainties in the megaprojects. One project manager (PM-2) from the contractor verifies the situation that sometimes it is still challenging to have efficient communication between organizations with contractual or supervision relationship, but without an excellent informal relationship. The project manager (PM-2) also points out that compared with the formal relationship, the informal relationship is more efficient to make instant communication to answer the emergencies in the megaprojects. On the contrary, formal relationship (0.482) plays a more critical role in the performance of coordination than the informal relationship (0.371). Unlikely with the communication focusing on the information exchange, coordination is for the optimal allocation of organizational tasks among stakeholders to maximize the overall outcomes (Lin et al., 2018b). Therefore, the formal relationship has the advantages of the distribution of responsibilities and duties based on the contract provisions or supervision regulations. The finding also reveals that formal (0.352) and informal relationships (0.387) are equally important in the performance of collaboration. Formal relationship regulates the responsibilities of each stakeholder in the joint working. While informal relationships stimulate the incentives and willingness of collaboration among stakeholders, which is echoed by Dewulf and Kadefors (2012).

In the project level, formal relationship (H5, H6) significantly impacts the performance of quality and cost in megaprojects, while informal relationship (H15, H16) shows insignificant impacts. The results indicate that the quality and the cost performance should be improved by the formal relationship rather than the informal one. For cost performance, as megaprojects are long term projects, the inflation of materials, the complexed technical problems, and the interruption caused by political forces and natural disasters lead to the severe cost-overrun problems (Siemiatycki, 2016). Unfortunately, the informal relationship rarely makes a significant impact when facing those challenges. One project manager (PM-1) from the client explains that, as cost issues are highly related to the interests and benefits of stakeholders, it is difficult for them to make compromises and reach agreements in their teamwork without the basis of contract provisions or the mediation from the supervision forces, even though they have good informal relationship. In contrast, a transparent cost risk allocation in the contract provides a foundation to face the uncertainties and complexities in the megaprojects (Molenaar, 2005). One senior officer (SO) from the government mentioned that when some unforeseen risks happen, an instant and effective interaction with supervision groups can gain policy supports, which is prone to alleviate the cost overrun and receive the extra budget for project recovery. In terms of quality control, project quality should be strictly controlled by rules and specifications stated in the contract and supervised by the independent forces (Yung and Yip, 2010), while the informal relationship may interfere with the strictness of quality control by unofficial connections between organizations, which brings the variations on quality performance. For instance, one project manager (PM-2) from the contractor reveals that trust among stakeholders may cause the potential risks of less strictness in the quality inspections and the punishment of irregulated behaviors may not be firmly conducted due to the friendship between the organizations. In addition, one senior officer (SO) from the government points out that as some quality problems can be hidden for a long time, the coalition among stakeholders may be formed to cooperate with several misconducts on quality for achieving the common goals and interests, which could bring them instant profits. To improve safety performance, formal relationship (0.441) has a relatively higher impact than the informal relationship (0.310). As rules and regulations are considered as a significant role in the safety management, frequent inspections and no compliance with violations of safety standards can lead to better safety implementation (Swuste et al., 2012). Hence, the formal relationship plays a critical role in safety control by establishing functional interactions between stakeholders and supervision groups. Meanwhile, informal relationships supplement the reinforcement of safety performance. As the present study shows that more protection and a safer environment are not always adequate without the improvement of safety culture (Feng, 2013), the informal relationship is useful to cultivate the culture by supporting the smooth communication between project participants and workers (Mohammadi et al., 2018). For schedule performance, formal (0.330) and informal (0.347) relationship show the close positive impact, indicating that the two kinds of relationships complementary with each other on the schedule issues. On the one hand, formal relationship strengthens the contract management among stakeholders, which is regarded as a critical factor to mitigate the time delay by providing a clear objective and obligation in the contract system (Oyegoke and Al Kiyumi, 2017). On the other hand, informal relationship helps stakeholders to obtain timely responses in different kinds of activities with efficient communications, saving the time for the megaprojects, explained by one project manager (PM-4) from the consultancy.

At the societal level, the formal relationship has a positive impact on the performance of labor protection, while the effects of informal relationships are insignificant. The results implicate that contract and supervision are two dominant ways to protect labors' rights, consistent with the study by Lan et al. (2015) and Montgomery and Maggio (2009). Though establishing an informal relationship between workers and other stakeholders enhances the labors' job satisfaction (Li et al., 2018), it makes limited effects on protecting their human rights. One project manager (PM-3) from the subcontractor mentioned that currently, the primary function of the informal relationship between workers and other stakeholders is for increasing labors' productivity. However, the higher productivity with the sacrifice of their rest and health probably makes labors' working situation even worse. In the aspect of environmental protection, formal relationship (0.501) shows a more significant impact on the informal relationship (0.233). As the unforeseen environmental risks may frequently occur due to the complexities of megaprojects, one senior officer (SO) from the government pointed out that long-term cooperation between project participants and supervision groups is beneficial to detect the potential risks and make the instant action if problems arise. At the same time, the positive effect of maintaining an excellent informal relationship between the project team and local communities cannot be ignored as the residents in the neighborhood are major stakeholders heavily involved in environmental issues (Wang et al., 2017a, Lin et al., 2018a). One project manager (PM-2) from the contractor explains that the friendship and trust between project participants and community leaders is an effective way to relieve the worries of environmental issues and make the community cooperated with project teams to protect the environment. For the improvement of project transparency, the Informal relationship (0.394) has a more significant impact than the formal relationship (0.255). Although formal relationship provides a shield to improve the project transparency with rules and regulations, there are still incidents of corruptions happened from time to time (Shan et al., 2015). The results indicate that the performance of informal relationships plays a more critical role in improving project transparency. One project manager (PM-1) from the client explains that good informal relationship is useful for stakeholders to deal with unclear issues in the contract. Otherwise, corruption would often take place to solve those problems. Besides, as most corruptions are for establishing a close relationship between organizations (Zhang et al., 2016a), stakeholders with good informal relationships have fewer incentives to build similar relationships with the price of committing the crime.

In summary, the validation results are shown in Figure.6.10, which proves the validity of PLS-SEM hypothesis testing results. Therefore, the influence distribution of formal and informal relational strategies on the conflicts relevant to the megaproject performance can be drawn according to the empirical evidence of PLS-SEM hypothesis testing results.

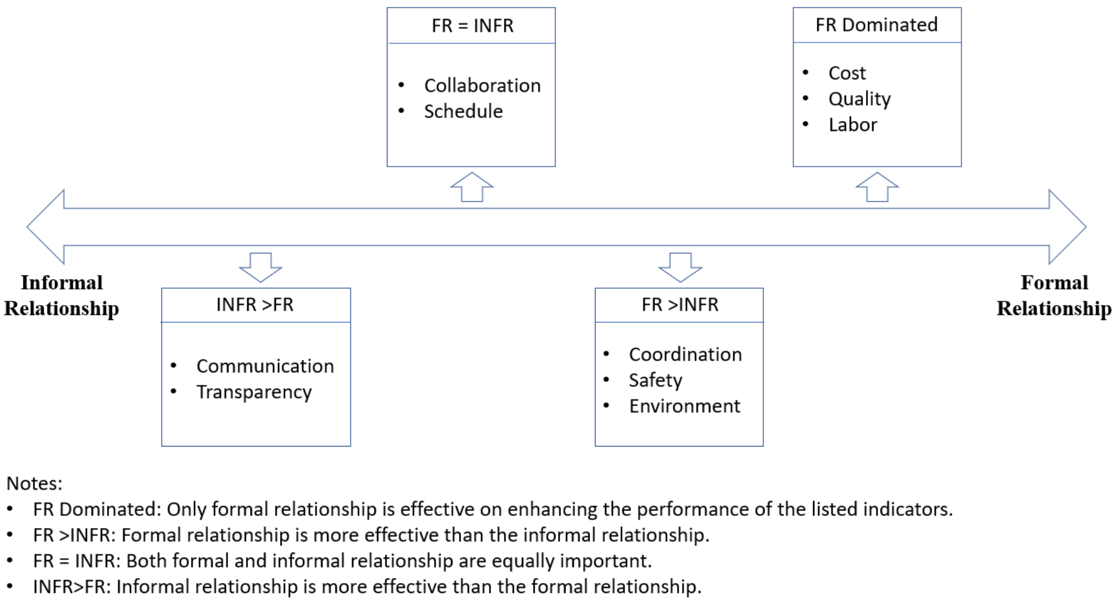


Figure 6.10 Formal & Informal relational strategies on megaproject performance

(6) The influence distribution of formal and informal relational strategies

Based on the empirical evidence derived from the PLS-SEM assessment (Table 6.6), the stakeholder performance distribution is obtained to reflect how formal and informal relational strategies perform facing the challenges of conflicts which influence the corresponding project performance in ten aspects: communication, coordination, collaboration, cost, schedule, quality, safety, labor, environment, transparency (Xue et al., 2020a). As Table 6.8 shows, the "Ave" and "Dev" represent the mean and deviation values, respectively. With the two critical parameters, the normal distributions of stakeholder performance under formal and informal relational strategies are generated towards the issues from organizational level to project and societal level. There is one special note. As informal relational strategy performs insignificantly facing the issues on cost, quality, and labor, the PLS-SEM results indicate the informal relational strategy does not exert the significant effect around these issues, which means there is no general distribution scope of stakeholder performance under the circumstances. Therefore, the standard normal distribution is particularly set to reflect the random stakeholder performance in those conditions. As stated in the section 6.2.3 of the model design, the influence distribution of formal and informal relational strategies is essential to generate the pay-off values for stakeholder performance on relationship management in the Network-NK simulative model.

Table 6.8 The parameters of the influence distribution of formal and informal relational strategies

	FR		INFR	
Type of the conflicts	Ave1	Dev1	Ave0	Dev0
COM	0.340	0.094	0.508	0.091
COO	0.482	0.103	0.371	0.102
COL	0.352	0.115	0.387	0.115
SCH	0.330	0.111	0.347	0.112
COST	0.490	0.127	0.000	1.000
QUA	0.509	0.096	0.000	1.000
SAFE	0.441	0.094	0.310	0.103
LABOR	0.561	0.102	0.000	1.000
ENV	0.501	0.094	0.233	0.106
TRANS	0.255	0.119	0.394	0.108

6.3.2 Input Two: Two-mode stakeholder-conflict network in HZMB[5]

The two-mode stakeholder-conflict network reflects the complex risky environment of stakeholder relationship management. The network is composed of the stakeholder mode and conflict mode, which shows the complicated interdependencies between stakeholders and their relevant conflicts. As the official documents in the Legislative Council of Hong Kong record the debates before each bill vote regarding HZMB, the council documents present a comprehensive view of stakeholder conflicts in every

[5] This section is relevant to the publication:
Xue, J., Shen, G. Q., Yang, R. J., Zafar, I. & Ekanayake, E. 2020. Dynamic Network Analysis of Stakeholder Conflicts in Megaprojects: Sixteen-Year Case of Hong Kong-Zhuhai-Macao Bridge. Journal of Construction Engineering and Management, 146, 04020103.

aspect of HZMB in the timeline.

The procedures of building a two-mode stakeholder-conflict network are as follows. First, the concepts of conflict issues are identified by desktop analysis of council documents. Second, the stakeholders relevant to each conflict issue are also identified when conflicts and relevant stakeholders appear in the same documents. Third, the links are drawn connecting the identified conflict issues and relevant stakeholders. For instance, the conflict on the protection of Chinese White Dolphins refers to the stakeholder groups including the Coordination Group of three regional governments, the Hong Kong government, and the environmental groups. Following the procedures, as Figure shows, the conflict node is 'the protection of Chinese White Dolphins' and there are three stakeholder nodes regarding three relevant stakeholder groups. The links represent the relevance between the conflict issues and involved stakeholders.

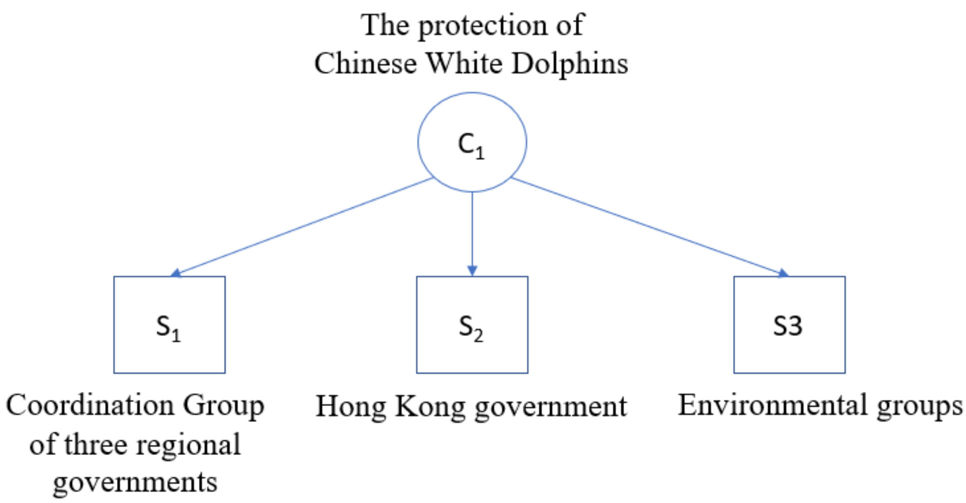


Figure 6.11 The example of the basic two-mode network in HZMB

The two-mode stakeholder-conflict network in Figure 6.11 is the basic unit of the network system in HZMB, which is also regarded as the basic NK model. With the timestamped documents, the annual stakeholder-conflict network is established as Figure 6.12 shows. The number of conflict nodes in the annual network represents the sum of basic NK models in that year. The annual network is used to calculate the stakeholder performance and stakeholder-conflict performance in each timepoint of HZMB.

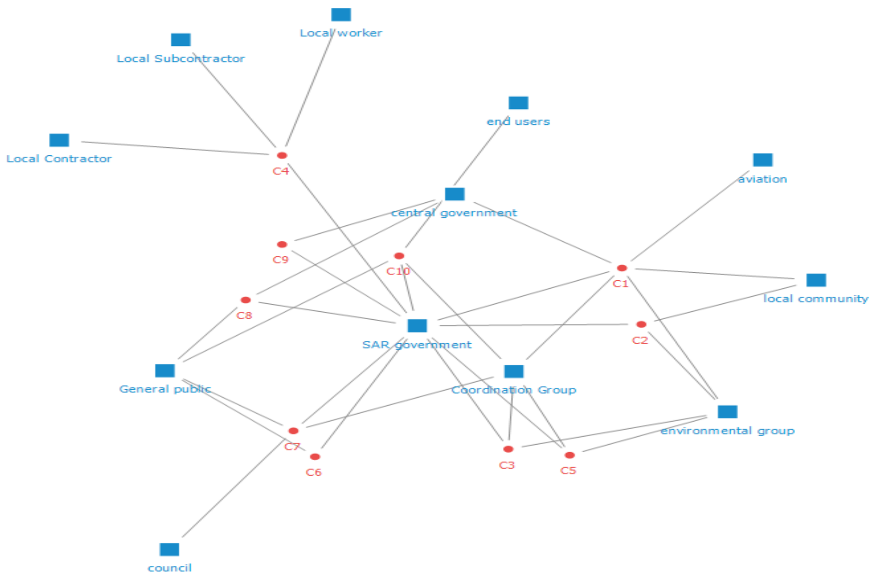


Figure 6.12 The example of the annual stakeholder-conflict network in HZMB

Finally, as Figure 6.13 shows, sixteen two-mode stakeholder-conflict networks are developed from 2003 to 2018, covering the various phases of HZMB from the planning to construction and handover. As stated in the section 6.2.2 of the model design, the two-mode stakeholder-conflict networks clearly depict the complex environment in convenience for establishing NK models to simulate dynamic stakeholder interactions on the relationship management of HZMB.

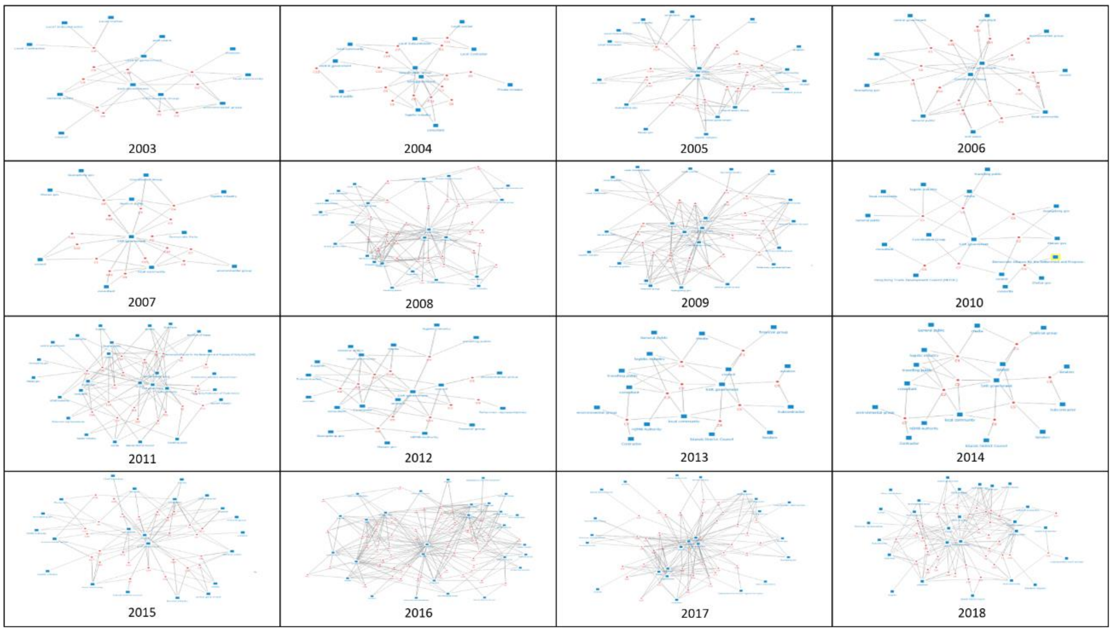


Figure 6.13 The two-mode stakeholder-conflict networks in HZMB

6.3.3 Processing: Network-NK simulative modelling of stakeholder performance

As Figure 6.14 shows, the processing procedure includes five steps as follows.

First, the NK model is established for each subgraph of stakeholder-conflict network based on the result of 6.3.2. Each subgraph forms one NK model, including the stakeholder-conflict and its affected stakeholders. The parameter N represents the number of involved stakeholders in the conflict. The parameter K is equal to N-1, indicating each stakeholder strategy coping with the conflict would influence on the decision-making of other involved stakeholders. As there are 334 subgraphs (conflicts) in the stakeholder-conflict network of HZMB, 334 NK models are preliminarily established.

Second, the influence distribution of relationship management strategies for each kind of conflicts is generated based on the result of 6.3.1. For a specific conflict, each relevant stakeholder would determine the enhancement priority between formal and informal relationships to improve the relationship management performance. Under each strategy, it is obtained the performance value based on the corresponding influence distribution.

Third, the performance landscape is generated for each stakeholder-conflict. It includes all the possible combinations of decision vectors D, pay-off value vectors P, and conflict performance value $P(D)$. There are 334 pieces of performance landscape built in total.

Fourth, the searching method is allocated for each stakeholder group. In the study, the stakeholders following the planning method are consist of government, construction groups, and local industry groups, while environmental groups and pressure groups follow the learning method.

Fifth, the Network-NK model runs to simulate the stakeholder interactions of relationship management in various stages of megaprojects. To avoid the influence of extreme values, the simulative model is set to run for 1000 times and the final simulative results are based on the mean values of 1000 pieces of experimeantal results (Sommer and Loch, 2004, Capaldo and Giannoccaro, 2015).

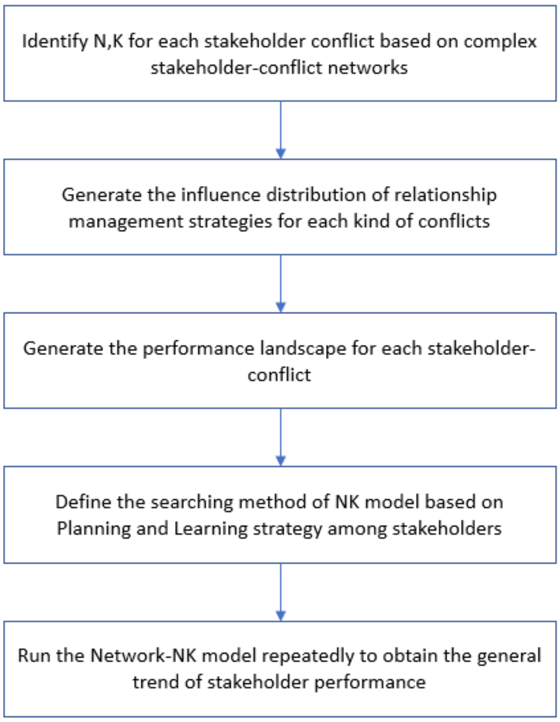


Figure 6.14 The steps of modeling processing

6.3.4 Output One: Stakeholder evolution analysis

The stakeholder evolution analysis is useful to evaluate the trend of stakeholder performance and conflict performance on relationship management in various stages of the megaprojects. As stated in the section 6.2.5 of the model design, the trend of stakeholder performance is helpful to reveal the weakness moments of stakeholders to manage relationships in various stages of megaprojects. While the trend of conflict performance benefits stakeholders to understand the risky level of stakeholder conflicts towards relationship management among stakeholders. In the study, five stakeholder groups are analyzed on the performance trend in the timeline, including the government, construction groups, pressure groups, environmental groups, and local industry groups.

Besides, the conflict performance is elaborated from organizational level to project and societal level, with ten types of conflicts which highly influences megaproject performance stated in the section 6.3.1.

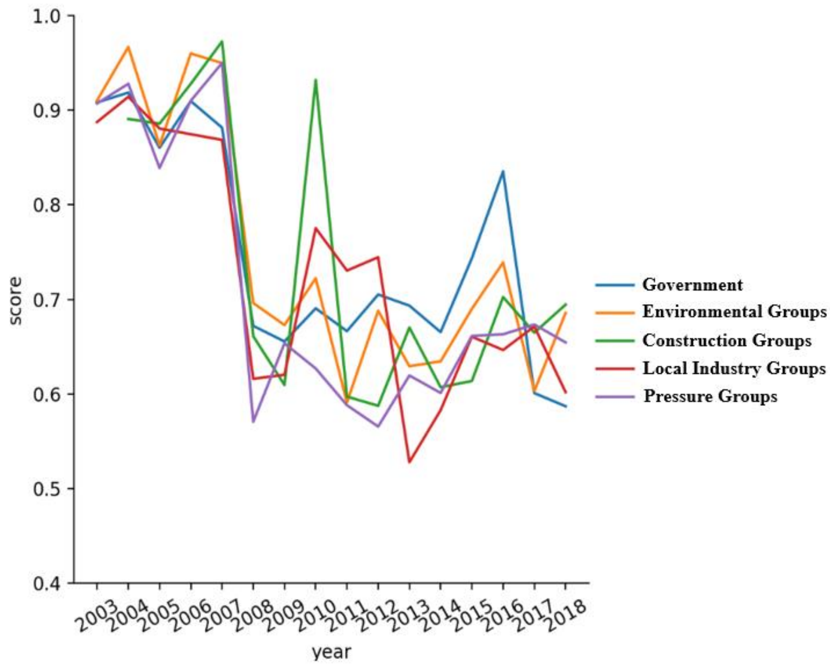


Figure 6.15 The evolution of stakeholder performance on relationship management in HZMB

(1) Evolution analysis of stakeholder performance

As Figure 6.15 shows, there are two general longitudinal trends on stakeholder performance according to the simulation results of the proposed Network-NK model. First, the performance score is at a high level in the initial stage while plunges and maintains at a low level in the mid and late phases of the project. Second, the stakeholder performance has experienced three significant drops in the year of 2008, 2011, and 2017, respectively. The two trends are consistent with the reality in the development history of HZMB, which verifies the validity of the proposed Network-NK model. The detailed explanation is as follows.

The first phenomenon indicates the stakeholder relationship has different performance between the period before and after the project bill is passed by the National Congress. The stakeholder performance scores maintain at a high level in the early stage of HZMB. Based on the previous stakeholder-conflict study, in the first five years (2003-2007), the number of conflicts is contained on a small scale. The fewer conflicts create a relatively peaceful environment for the relationship among stakeholders. In 2008, as the feasible project study is proposed to National congress for the voting, the conflicts around the financial arrangement, alignment arrangement, environmental protection, and operational management involves a wide range of stakeholders, thus introducing the eruption of conflicts when the project came to the decision-making phase. Following the congress bill pass of HZMB in 2008, the project turned to the construction phase when most tasks were under processing on site. The various construction tasks brought stakeholder conflicts in different aspects, which exerted an adverse impact on stakeholder relationships. Therefore, the performance score of all stakeholders experiences a sharp decrease in the decision-making phase and then maintains the low-score performance in the whole construction period.

The second phenomenon highlights three milestones with extreme challenges of relationship management among stakeholders. The simulation result implicates that the stakeholder relationship management would face difficulties, especially in three-time points of the project: the late planning stage, the beginning of the construction stage, and the end of the construction stage. The first milestone was in 2008, when the project bill was passed by the National Congress. As the project planning reached the decision-making point, the upcoming vote stimulated the burst of stakeholder conflicts because most conflict issues were not allowed to be vague in the final feasibility report. As each stakeholder intended to maximize its benefit, the stakeholder relationships suffered the first significant intension. The second milestone was in 2011, when the project was planned to commence construction. The environmental groups appealed the project to the higher court on the worries of ecological protection. The environmental conflicts exerted heavy pressures on stakeholder relationships, which suspended the project for over one year for the negotiations between government, construction groups, environmental groups, and pressure groups. The last milestone is in 2017, when it was one year before the project completion. The burst of stakeholder conflicts was introduced by the schedule delay of the project, which was echoed by the stakeholder-conflict study. The postponement of the project activates a series of conflict issues among stakeholders, including cost-overrun, quality incidents, and safety injuries, which causes the difficulties of stakeholder relationship management.

As stated in the section 2.6, stakeholder performance refers to the achievement level of stakeholder's objectives and interests (Wang and Huang, 2006, Hu et al., 2016). Focused on the relationship management in megaprojects, the performance of each kind of stakeholder groups represents the achievement level of maintaining good relationships with relevant stakeholders when accomplishing project goals (Bourne and Walker, 2008, Meng, 2012, Vaux and Kirk, 2018). In the study, the evolution of stakeholder performance on relationship management in HZMB is discussed from perspectives of each stakeholder group, including the government, construction groups, pressure groups, environmental groups, and local industry groups.

Government

The evolution of government performance on relationship management in HZMB is shown in Figure 6.16, which reflects the achievement level of the government to maintain good relationships with relevant stakeholders when accomplishing project goals in various timepoints of project duration (Zhai et al., 2017, Wang and Huang, 2006). The government performance experienced two sharp decreases of stakeholder performance on relationship management in 2008 and 2017, which is in line with the general longitudinal trend for all stakeholders. Since the government took the role of coordinating the stakeholder relationship in those two conflict-outbreak moments, the performance score suffered from a significant plunge due to the frequent confrontations between government and relevant stakeholders, which was echoed by Xue et al. (2020d).

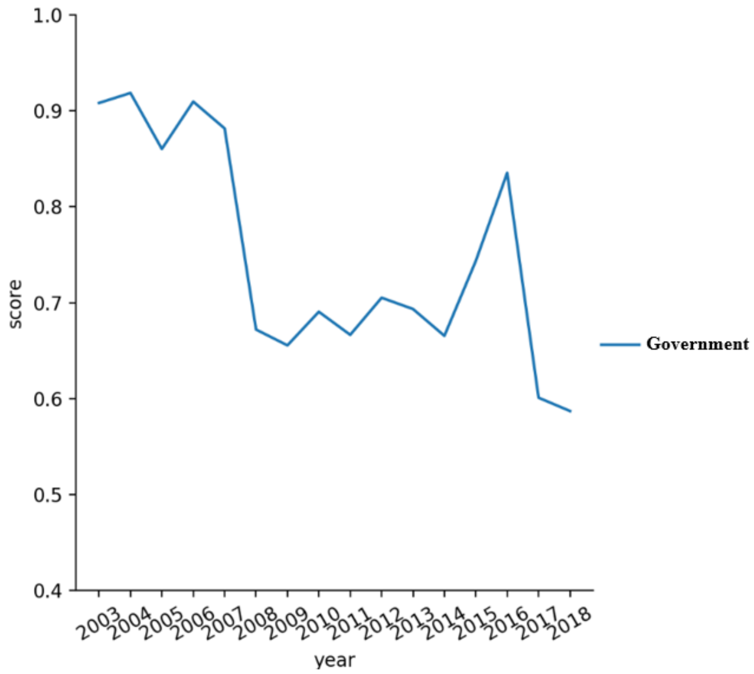


Figure 6.16 The evolution of government performance on relationship management in HZMB

Construction groups

As Figure 6.17 shows, the performance of construction groups has two significant decreases in 2008 and 2011, respectively. The sharp reduction in 2011 was introduced by the environmental conflicts, which led to the severe delay of project commencement. The environmental conflict brought heavy pressure on the relationship management of construction groups. The conflict erupted between the government and environmental groups, but it caused the economic loss of construction groups due to the project delay. It was difficult for construction groups to negotiate with both sides, as the interests between the government and environmental groups were opposite (Xue et al., 2020a).

In the whole period of the construction phase, the relationship management of construction groups faced the chanllenges due to the conflicts between the government and environmental groups, leading to the performance score at the low level.

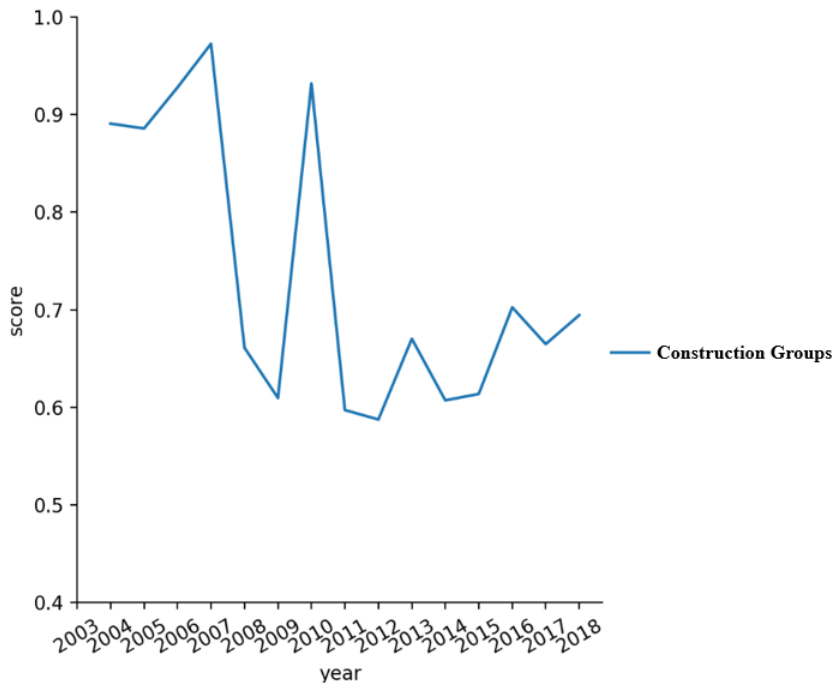


Figure 6.17 The evolution of construction groups' performance on relationship management in HZMB

Pressure groups

As Figure 6.18 shows, the performance of pressure groups has two significant decreases. One was in 2008 when the HZMB was in the decision-making point. Another one was from 2009 to 2012 when the HZMB was in trouble with environmental conflicts. In the two timepoints, pressure groups had tensions with the government, which led to the low stakeholder performance on relationship management. After 2012, the performance score has a steady increase and reaches a platform from 2015 to 2018. The phenomenon indicates that the pressure groups started to handle the communication approaches with the government to convey their worries and anger through constructive and peaceful ways, after two fierce conflicts in 2008 and 2011. The indication is validated by the history of HZMB. Even in 2017, when a variety of conflicts erupted, no fierce conflict occurred between pressure groups and government, thus the performance score of pressure groups remaining at a constant level at the late stage of HZMB.

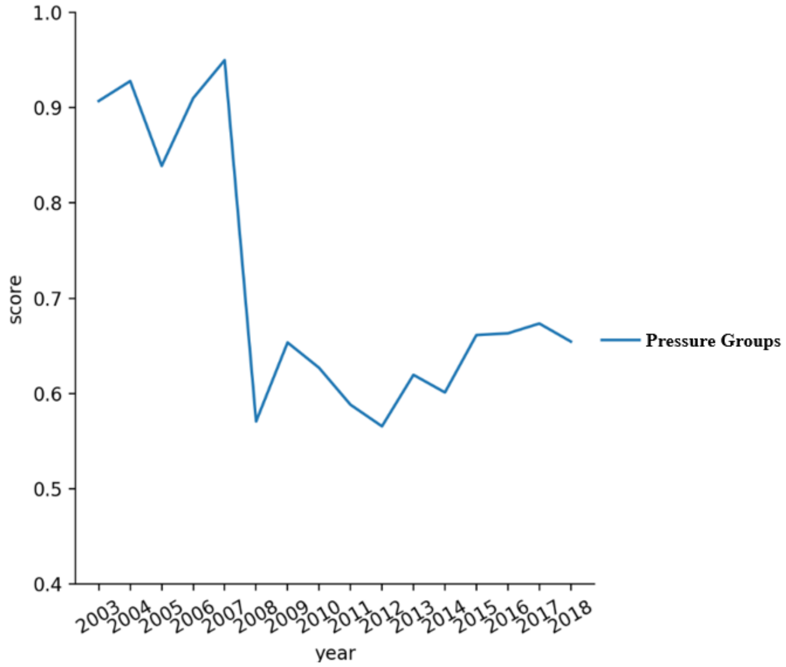


Figure 6.18 The evolution of pressure groups' performance on relationship management in HZMB

Environmental groups

As Figure 6.19 shows, the performance of environmental groups suffered three dramatic drops in 2008, 2011, and 2017, respectively. Compared to the decline in 2008, the other two moments suffered deeper plunges, indicating the performance of environmental groups has more challenges in the construction stage. In the history of HZMB, the low performance was introduced by two significant conflicts at the beginning and late construction phase. The first drop was caused by the legal disputes on the environmental impact assessment report of HZMB, leading to the delay of the project commencement. The dispute triggered the tensions between the environmental groups, construction groups, and the government. The second drop was driven by the worries of air pollution and noise caused by the traffic flow with the completion of HZMB, which damaged the relationship between environmental groups and the government.

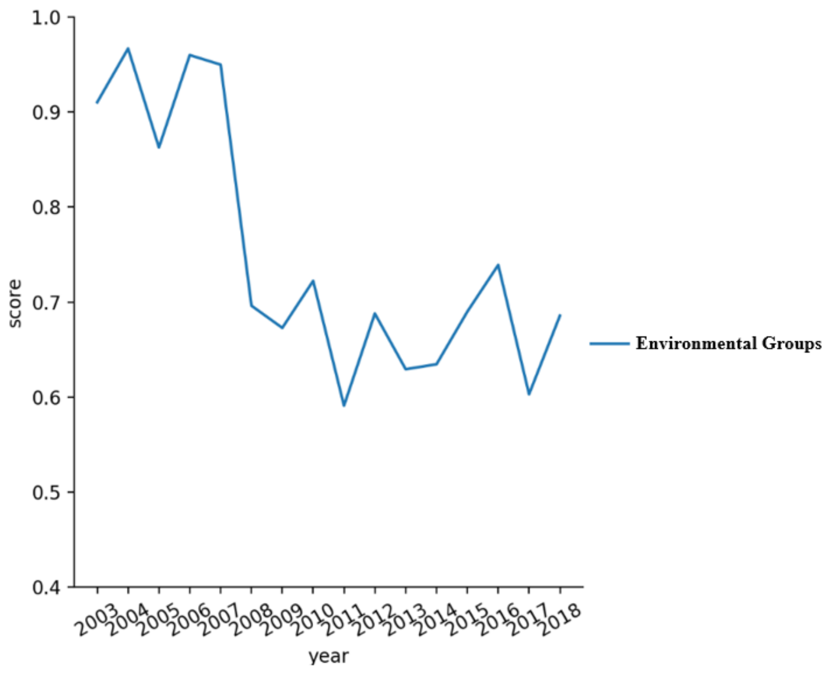


Figure 6.19 The evolution of environmental groups' performance on relationship management in HZMB

Local industry groups

As Figure 6.20 shows, the performance of local industry groups plummets in the mid-construction stage and handover stage, respectively. The plunge in 2013 was caused by the worries from the local industry groups on severe lag-behind local links connected with HZMB. The local logistic and tourism industries had heavy pressures on negotiating with government and residents to speed up the construction of local connections, to ensure their economic benefits after the completion of HZMB. The other plunge was in 2018 when the HZMB was in the handover stage. The local industry groups had a wide range of discussions with three regional governments among Hong Kong, Macao, and Guangdong on the operational arrangement of HZMB for maximizing the industrious economic benefits before the project initiated to operate. Hence, the heavy workload and tight schedule downgraded relationship management performance of local industry groups.

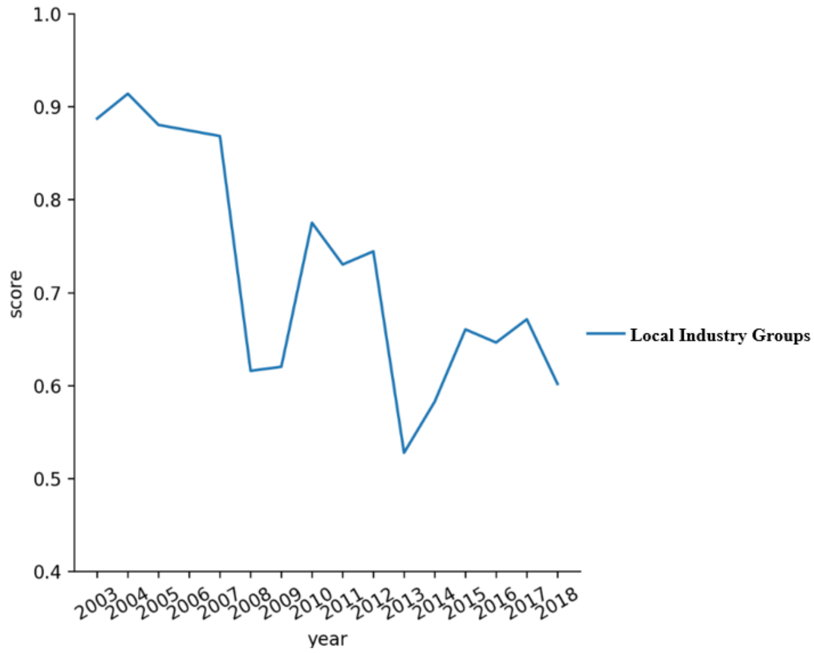


Figure 6.20 The evolution of local industry groups' performance on relationship management in HZMB

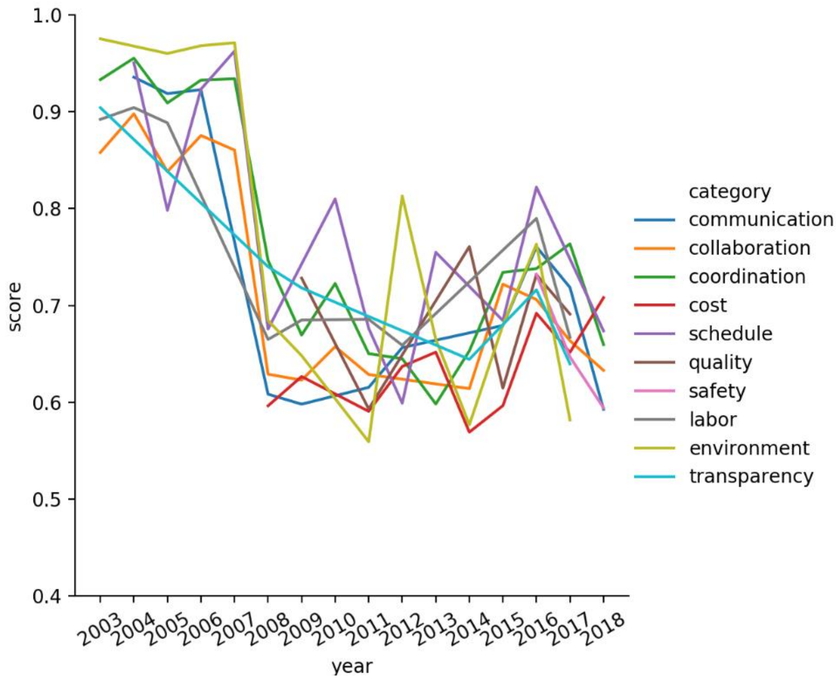


Figure 6.21 The evolution of conflict performance on relationship management in HZMB

(2) Evolution analysis of conflict performance

As stated in the section 6.2.5 of the model design, the conflict performance derived from the Network-NK simulative model reflects the risky level of the stakeholder conflicts. The higher performance score indicates the lower risky level of the conflicts. While the lower performance score means more serious consequences caused by conflicts.

As Figure 6.21 shows, the general longitudinal trend of conflict performance is in line with the first trend of stakeholder performance, which includes the significant decrease of performance scores from the early stage to the late phase of the project. However, compared to the three plunges in the figure of stakeholder performance (shown in Figure 6.15), the conflict performance only had one fall in 2008 (shown in Figure 6.21). Since then, it keeps at a relatively low level.

The dramatic decrease in conflict performance in 2008 alerts the decision-makers to take the particular caution on relationship management at the late planning stage. The conflict performance plunges, indicating the stakeholder-conflict intensified, which is coincided with the development history of HZMB. According to the conflict study by Xue et al. (2020d), in 2008, the number of each kind of conflict surges as the feasible analysis report of HZMB was submitted to the National Congress of China for voting. The suddenly increased number of conflicts caused the tensions on the relationships among stakeholders, which dragged the performance of the conflicts down.

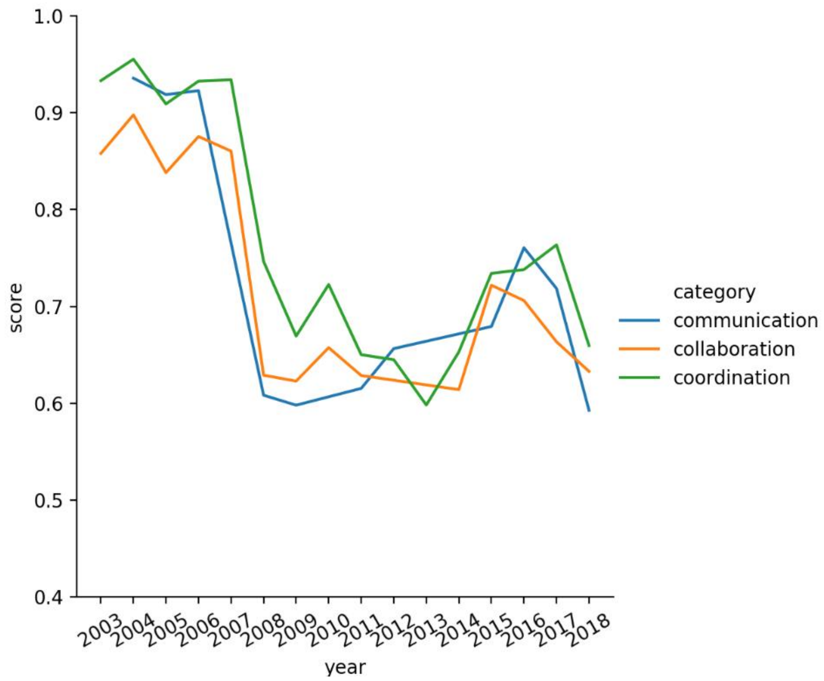


Figure 6.22 The evolution of organizational conflict performance on relationship management in HZMB

As Figure 6.22 shows, the organizational conflicts had two significant plunges in 2008 and 2018, which reveals the conflict eruption concentrated at the late planning stage and the handover stage, respectively. Unlikely to other project periods when most organizational contacts are within internal stakeholders (construction and organization groups), the two burst points refer to the broad stakeholder participation between internal and external stakeholders (environmental and pressure groups). In 2008, the decision-making of the bill for HZMB in National Congress required the extensive joint work among stakeholders. While in 2018, the operational arrangement of HZMB involved the negotiations among various stakeholders across three regions between

Hong Kong, Macao, and Guangdong Province. The frequent contacts among a large number of stakeholders cause the challenges of relationship management for each stakeholder group.

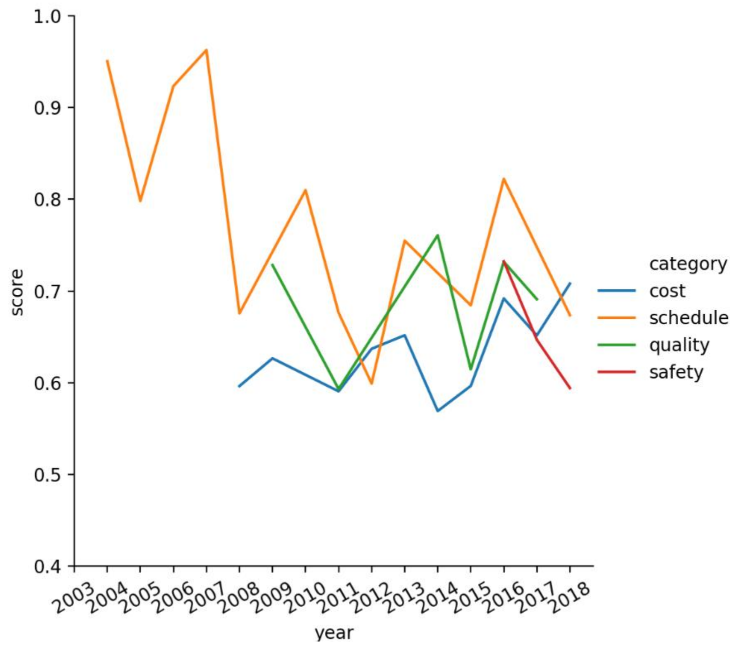


Figure 6.23 The evolution of project conflict performance on relationship management in HZMB

Besides, after comparing the position of each line in Figure 6.23, it is found the conflict related to cost issues has lower scores than other conflicts in the period of 2008 to 2016, which covers the late planning phase and the most of the construction phase. The simulation results are also verified by the stakeholder-conflict study, in which most conflicts triggered by cost issues are considered as the most severe conflicts (located in Zone One) in the planning and construction phase of HZMB (Xue et al., 2020d). The reason is explained that the cost issues are highly related to stakeholders' core interest, thus referring to a large number of involved stakeholders in the relevant conflict, which increases the difficulties on relationship management to balance the interests among various stakeholders.

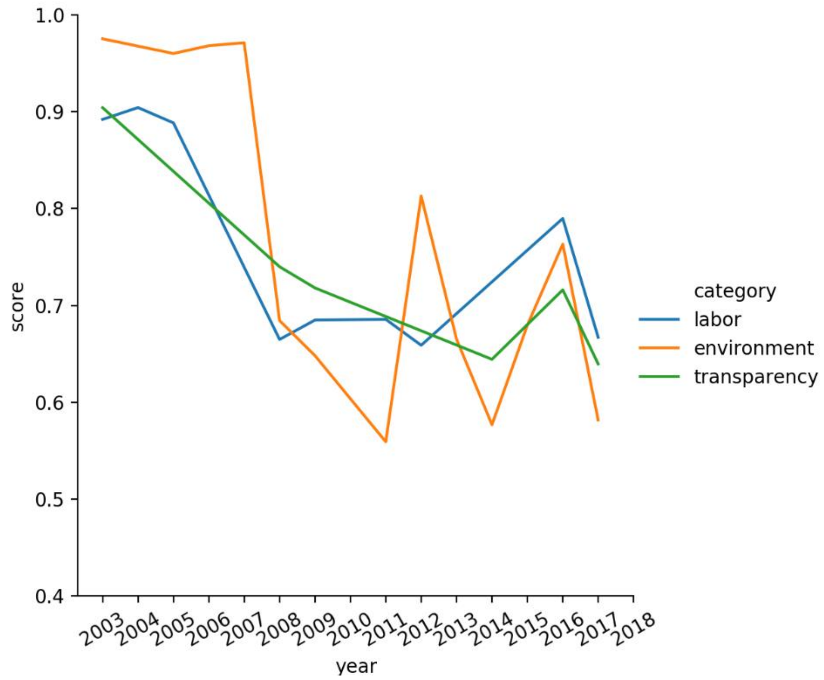


Figure 6.24 The evolution of societal conflict performance on relationship management in HZMB

As Figure 6.24 shows, the performance score of environmental conflicts reaches the bottom in 2011 and 2014, respectively. The low performance is evident by the influential events that occurred at each time point of HZMB (Xue et al., 2020b). In 2011, the severe environmental conflicts happened as the project was appealed to the court due to the worries on the environmental impact assessment report. The incident caused the suspension of the project for one year, triggering the tensions between government, environmental groups, and the general public. In 2014, another round of environmental conflicts escalated due to the construction pollution in the project of local links connected with the HZMB in Hong Kong. The relationship between government, residents, and environmental groups were struck by the conflicts introducing the delay of the local links.

6.3.5 Output Two: Stakeholder resilience analysis

The stakeholder resilience analysis is helpful for project stakeholders to understand how serious the conflict would influence relationship management in megaprojects. In the study, it is explored the stakeholder resilience in three phases from the start to the end of the project: planning, construction, and handover. Three stakeholder groups are selected as examples to validate the proposed method, including the government, construction groups, and pressure groups.

(1) Government

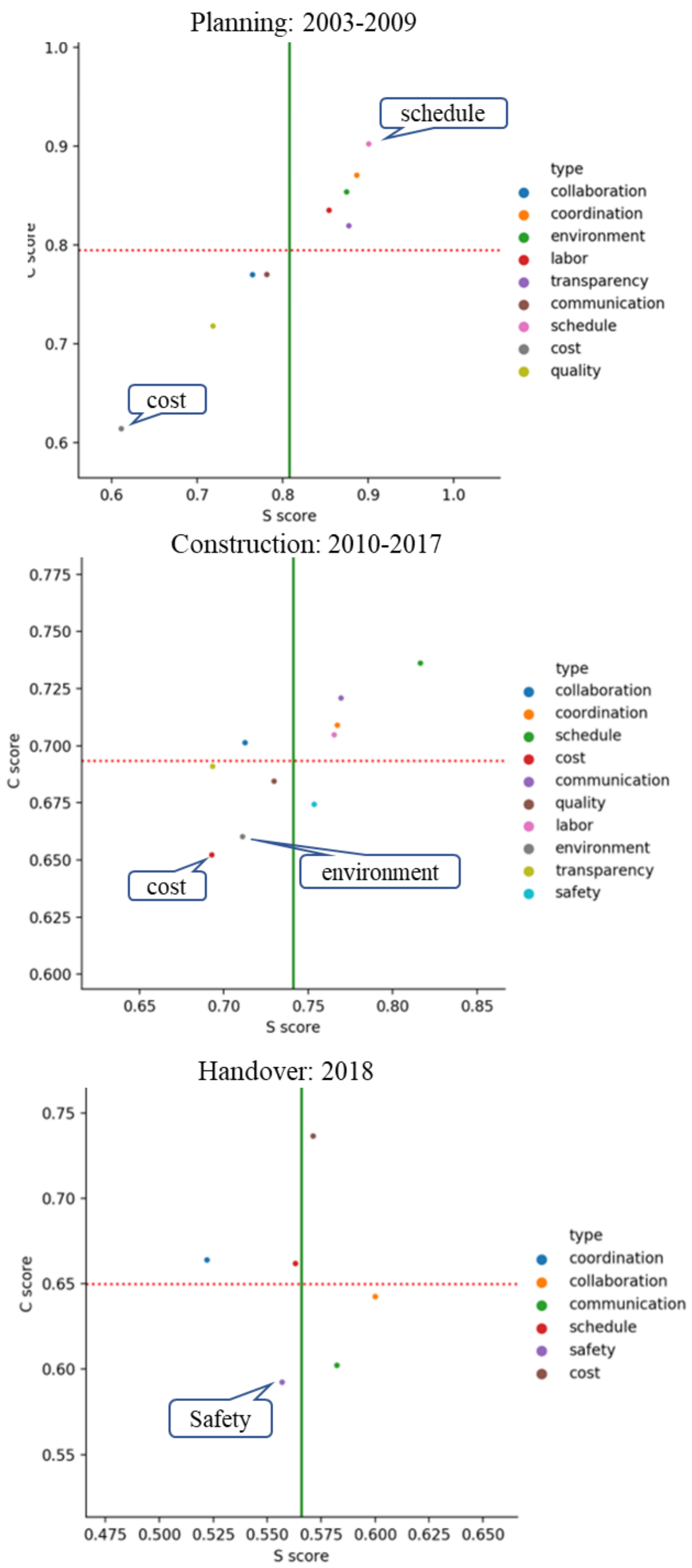


Figure 6.25 The resilience map of the government in HZMB

As Figure 6.25 shows, conflicts caused by cost issues are in the left bottom of Zone One, indicating they are dangerous for government on relationship resilience in the planning stage. The phenomenon of weak stakeholder resilience is consistent with reality in HZMB. The cost issues stimulated the tensions between the government and the legislative council. The cost-sharing was a focal issue fiercely debated in the council. Although the Hong Kong government tried to smooth the conflict, the government could not take full control of the cost issue. As HZMB is a cross-boundary project, the cost-sharing should be negotiated among three governments: Hong Kong, Zhuhai, and Guangdong, not handled only by the Hong Kong government. Therefore, the Hong Kong government had low-level resilience to improve the relationship between government and council members on cost issues. Compared to cost issues, most conflicts on schedule issues are placed in the right-up of Zone Three, implicating the safety of stakeholder resilience for the government. As the project was in the early stage, the schedule arguments were not an urgent issue for the project, since most stakeholders understand the megaproject is a long-term project. The stakeholders had the patience to listen to the government's explanation of its capability to ensure the project completed on time. Therefore, the government enables to recover from the damaged relationship struck by schedule issues among stakeholders.

In the construction stage, the conflicts on cost and environmental issues are the first and second low-resilience issues in the left-bottom of Zone One, indicating they are dangerous for the government on relationship management. The environmental conflicts caused the tension between the government, local community, and environmental groups in the early stage of the construction stage. After the project bill was passed in National Congress, it is little space for the Hong Kong government to suspend the commencement of the project to reconsider the environmental assessment, which downgraded the capability for the government to reach the compromise with the local community and environmental groups. Consequently, the resident from the local community appealed the government to the court on the suspicious misconduct of the environmental assessment report, leading to the time delay and cost overrun of HZMB. The fierce anti-project movement and the lack of compromising solutions made the stakeholder resilience fragile. Furthermore, the conflicts on cost issues introduced the tensions between government and supervision powers (legislative council, the general public, and media) throughout the construction period. The government received harsh criticism whenever seeking the extra bills to aid the cost overrun of the project. For keeping the project at a planned pace, it was difficult for the government to tackle the confrontations with opponents through long-term patient dialogues, which led to the weak resilience on the relevant relationship management.

In the handover stage, the conflict of safety issues is the only group in Zone One, implicating the incapability of relationship management for the government, evident by the history of HZMB. The conflicts on safety issues were escalated in the construction period and erupted in the handover stage. The deaths and injuries of construction workers due to safety incidents received the attention of the media and the general public. As the project was in trouble with the cost overrun in the late construction stage, the safety issues stimulated the doubts and anger of the general public towards the government, leading to the harsh review of safety issues in the handover stage. As the safety conflicts were co-effected with the poor project performance on schedule and cost issues of HZMB, the compensation and apologies of government were still ineffective to cure the damaged relationship between the government, general public, and media. Therefore, the stakeholder resilience for the government on safety issues was weak in the handover phase.

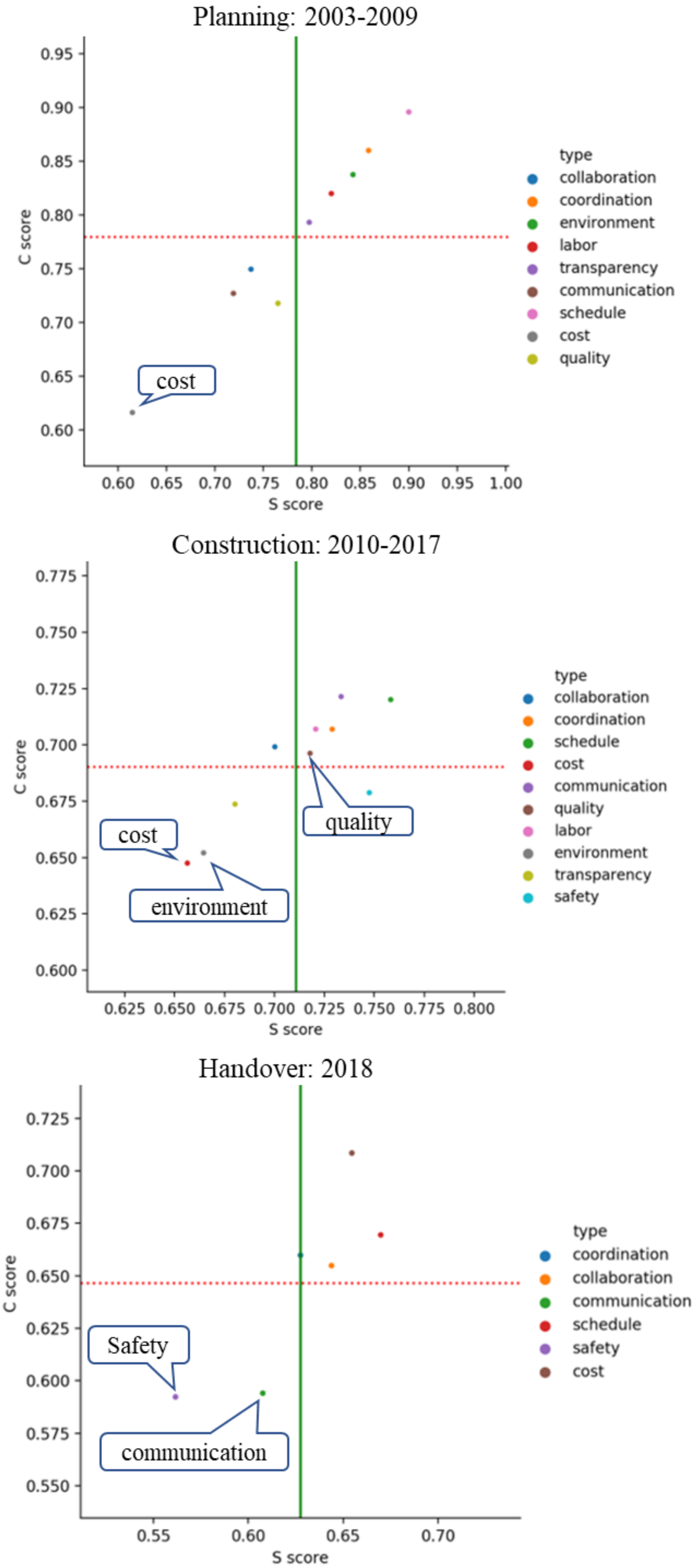


Figure 6.26 The resilience map of construction groups in HZMB

(2) Construction groups

As Figure 6.26 shows, in the construction stage, the conflicts of cost and environmental issues are two primary issues in the dangerous zone of construction groups' resilience map. The cost-overrun was the vulnerable issue for construction groups on relationship management in HZMB. The waiting for extra bills funded by the government might lead to the interruption of the construction works, which exerted the heavy pressure of construction groups. Meanwhile, the construction groups have limited capability to fix the damaged stakeholder relationship on cost issues. On the one hand, it was difficult for them to smooth the anger from the public and media on the escalated overrun of the project budget in the construction phase. On the other hand, they were powerless to negotiate with the government on financial reimbursement due to the extra cost of HZMB.

The environmental conflicts directly led to the project suspension of HZMB at the start of the construction phase, which increased the financial burden of construction groups. As most environmental protection measures should strictly follow the government's instructions, it has limited room for construction groups to set back and upgrade the protection measures on their own decisions, thus causing the difficulties of repairing the damaged relationship with environmental groups and local communities. Compared to the weak resilience of cost and environmental conflicts, the conflict of quality issues was located in the safe zone, with strong stakeholder resilience for construction groups. There were several quality incidents that occurred in HZMB, including the falsification of the cement test report, the seawall movement of the artificial island, and the quality problem of precast components. However, the primary target of criticism was the government, which shared the most burden of stress for construction groups on relationship management. Moreover, the government actively assisted construction groups in making up the mistakes and resuming the regular construction work for keeping the project at a planned pace.

In the handover stage, the conflicts of safety and communication issues are located in the dangerous zone. The review of safety incidents caused the tension between construction groups and worker unions in HZMB. The tension was stimulated by the media and opposition party, which had the political intention to criticize the project. Therefore, the construction groups were unable to smooth the tension, the cause of which was manipulated politically rather than protecting the workers' safety. Another low-resilience issue came from the efficient communication between construction groups and government. As the HZMB is a cross-boundary transport project, the handover process referred to the frequent communications with three governments with different political systems, which increased the difficulty of relationship management for construction groups. The communication conflicts were caused by the contradictions of regulations among three governments, thus construction groups having few methods besides complying with them.

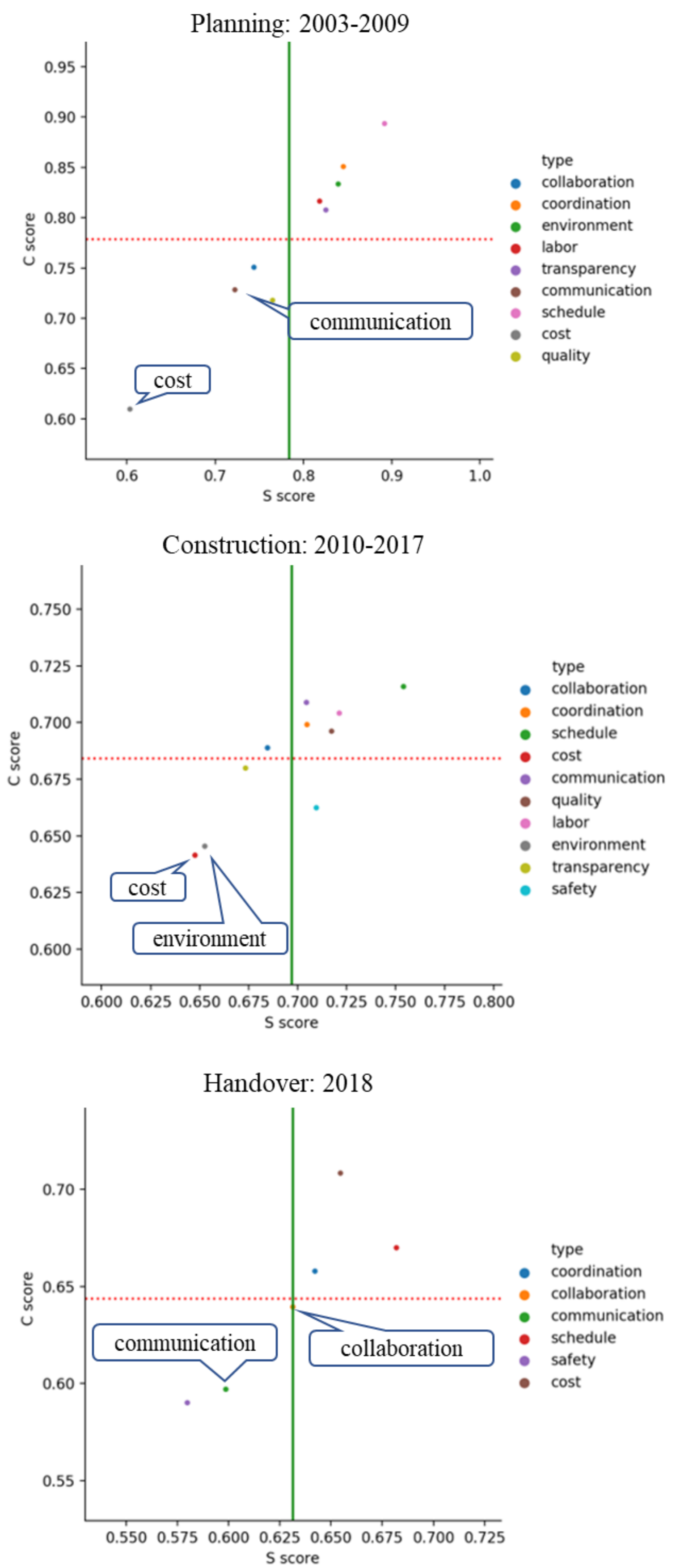


Figure 6.27 The resilience map of pressure groups in HZMB

(3) Pressure groups

As Figure 6.27 shows, in the planning stage, the conflicts of cost and communication issues are the top two issues with the lowest stakeholder capability scores for pressure groups. The sharing of project costs among three regional governments around HZMB caused the tensions between pressure groups and government. The pressure groups doubted about the balance between the cost-sharing of Hong Kong and project benefits brought by HZMB. Although the opposition views of the budget plan delivered by council members and media, few efficient official accesses were established for pressure groups to communicate with the government, causing the stakeholder relationship at a low resilience level. A similar situation occurred on the conflicts of communication issues, which pressure groups called for the government to incorporate the public representatives into the coordination group of the HZMB project but receiving no positive response. Therefore, it was hard for pressure groups to improve the trust of the government when misunderstandings and worries happened.

In the construction stage, the conflicts of cost and environment issues triggered the weak stakeholder resilience for pressure groups on relationship management. First, the pressure groups are sensitive to environmental issues, which lead to the fierce confrontations between pressure groups and government. In HZMB, the environmental conflicts were erupted in the early construction stage, with a local community resident appealing the Hong Kong government to the higher court for the potential misconduct of the environmental impact assessment. The movement deteriorated the trust between the pressure group and the government, posing the long-term negative influence on the relationship between them. As environmental protection was the core interest of the pressure groups, it has little space for pressure groups to reach a compromise with the government, causing the low resilience of environmental issues. Second, the dramatic cost-overrun of HZMB received the attention among the media and the general public of Hong Kong in the late construction phase, which brought harsh criticism towards the government. The radical council members of the opposition party called HZMB as a "white elephant," which stimulated the tension between the government and the pressure groups. There was a lack of communication accesses repairing the damaged relationship between pressure groups and the government since the conflict was politically manipulated.

In the handover stage, the conflicts of communication and collaboration allocate in the dangerous zone for pressure groups. The communication conflicts were caused by the different regulations between the mainland and Hong Kong, such as the driving regulation and patrol standard of vehicles. The various rule standards between two regions led to the communication problems on the understandings of technical arrangements of HZMB. The collaboration conflicts happened in the joint working arrangement between mainland and Hong Kong departments on operations of HZMB, such as the rescue arrangement and traffic insurance arrangement. As those abovementioned conflicts refer to the trade-off between regulations of the mainland and Hong Kong, it activated the worries of pressure groups on the autonomous political status of Hong Kong. In reality, the pressure groups raised the serious concerns of too-close political integration with the mainland, which caused the tensions between pressure groups and government (Xue et al., 2020d).

6.4 Summary of the Chapter

In this chapter, a Network-NK simulative model is proposed to analyze the stakeholder performance in dynamic and complex environment of megaprojects. The integrated simulative model is made up of two parts. On the one hand, the network model presents the complex structure between stakeholders and stakeholder issues. On the other hand, the NK model simulates the dynamic stakeholder interactions faced with various stakeholder issues. Through the modeling analysis, there are two outputs for stakeholders to learn the features of stakeholder performance in dynamic and complex environment of megaprojects. First, the general trend of stakeholder evolution in various project phases is detected to understand the weak moments for each stakeholder group. Second, the level of stakeholder resilience is assessed, which is useful to understand the stakeholder capability after the strike of stakeholder issues.

With the case of stakeholder performance studies on relationship management in Hong Kong – Zhuhai – Macao Bridge, the proposed analytical approach is validated by analyzing stakeholder performance with the dynamic stakeholder interactions under the complex stakeholder structures. Regarding the inputs, the influence distribution of formal and informal relational strategies is considered as the inner mechanism of stakeholder relationship management. At the same time, the two-mode stakeholder-conflict network is regarded as the complex outer environment that potentially hurts the stakeholder relationship in megaprojects. Through the modeling analysis, the dynamic stakeholder interactions are simulated between the inner mechanism and external environment of stakeholder relationship management in megaprojects. As a result, the evolution of stakeholder performance on relationship management is detected, and the stakeholder resilience level of associated issues is evaluated. The validation results are in line with the development history of HZMB, which proves the validity of the proposed model.

Chapter 7 Conclusions

7.1 Review of Research Objectives

The dynamic and complex project environment requires the reliable method of stakeholder analysis in megaprojects, which leads to the two research objectives as follows.

(1) To propose an analytical approach to evaluate stakeholder dynamics in the megaprojects.

(2) To propose an analytical approach to evaluate stakeholder complexities in the megaprojects.

(3) To propose an analytical approach to evaluate stakeholder performance in dynamic and complex environment of megaprojects.

To achieve the first objective, the dynamic stakeholder-associated topic model is proposed in Chapter 4. The text-mining based model assists in detecting the dynamic patterns of project stakeholders from large quantities of text official project documents automatically, which is beneficial for understanding the stakeholder dynamics in the megaprojects.

To achieve the second objective, the longitudinal stakeholder-associated network model is proposed in Chapter 5. The two-mode network-based model is useful to address the stakeholder complexity by prioritizing the critical positions of stakeholders and their relevant issues in various project phases from network perspectives.

To achieve the third objective, the Network-NK based stakeholder simulative model is proposed in Chapter 6. The Network-NK stakeholder performance simulative model is designed to reveal the stakeholder evolution and resilience in dynamic and complex environment of megaprojects. On the one hand, the Network model reflects the complexity of stakeholders and their relevant issues in megaprojects. On the other hand, the NK model describes how stakeholder performance is influenced by dynamic stakeholder interactions around the stakeholder issues. With the integration of Network and NK models, the simulative model accomplishes the modeling of stakeholder performance in dynamic and complex environment of megaprojects.

7.2 Summary of Research Findings

The research findings are presented as follows.

First, as the efficient dynamic analysis is a bottleneck of stakeholder studies, the research proposes a dynamic stakeholder-associated topic model approach to fill the gap by using longitudinal text data from official documents relevant to the project. The proposed method is composed of three modules. First, the TOT model identifies critical stakeholder issues and automatically tracks their trends within the development of megaprojects. Second, a stakeholder relevance scoring system is used to assess the relationship between stakeholder issues and project stakeholders in each time point of the project duration. Third, a managerial map of stakeholder issues is developed based on the issue's trend and stakeholder relevance derived from the first and second modules in three different stages of the project: planning, construction, and handover. According to the managerial map, determining the management priority through "Mirror Z" and "Letter N" strategies is beneficial for decision-makers and project stakeholders when facing various kinds of relevant stakeholder issues.

Second, as it is essential but lack of longitudinal network analysis to evaluate the stakeholder complexity in megaprojects, the research proposes a stakeholder-associated network model to analyze the complexity of stakeholders and associated issues throughout the whole project duration, beginning from the planning stage to the construction and handover stage. The framework is based on the two-mode network model, through which it provides the method to prioritize the critical stakeholder issues and the most affected stakeholder relationships, as well as to propose the stakeholder issue map to present the "Mirror Z" management strategies.

Third, as few methods have been designed to analyze the stakeholder performance in dynamic and complex environment, the research proposes a Network-NK simulation model to evaluate the stakeholder evolution and resilience in the development of megaprojects. The model input includes the two-mode stakeholder-issue network and the influence distribution of stakeholder strategies. The model processing is followed by the upgraded searching regulation of the NK model, in consideration of both planning and learning organizational behaviors towards the dynamic project environment. The model output comprises two analytical functions. One is the modular of stakeholder evolutions, which assists the decision-makers to understand the variations of stakeholder performance towards the changeable stakeholder-associated issues in the project duration. Another one is the modular of stakeholder resilience, which is beneficial for decision-makers to understand the stakeholder capability faced with the vulnerability due to the stakeholder issues in the megaprojects.

7.3 Contributions of the Research

7.3.1 Contributions to Knowledge

The proposed dynamic stakeholder-associated topic model fills the gap of lacking data for analyzing stakeholder dynamics by using longitudinal text data from the official documents relevant to the project. Specifically, first, a new method is proposed to generate the managerial map by detecting the dynamic patterns and stakeholder relevance of stakeholder issues from large quantities of unstructured text documents in megaprojects. Second, “Mirror Z” and “Latter N” strategies are proposed to manage stakeholder issues in three stages during the project duration in megaprojects considering the stakeholder-issue popularity and stakeholder relevance. The automated analytical model will provide useful guidelines for future megaprojects in the view of dynamic stakeholder management.

The proposed longitudinal stakeholder-associated network model fills the gap of lacking longitudinal network studies to provide a full picture of stakeholder complexities in the whole lifecycle of megaprojects. The model upgrades the traditional network analysis in the domain of construction management by systematically providing a series of methods to prioritize criticalness of stakeholder issues, affected stakeholder relationships, and stakeholder management strategies. Moreover, the proposed "Mirror Z" approach transforms the measurement results of longitudinal network analysis to the management strategies of stakeholder issues, solving the problem of stakeholder complexity by bridging the knowledge domain between stakeholder management and network analysis.

Third, the proposed Network-NK model introduces the complex adaptive system modeling technique into the evaluation of stakeholder performance, which provides a simulative method to understand the stakeholder evolution and resilience in dynamic and complex environment of megaprojects. The component of the network model presents the complexity of stakeholders and their relevant issues in megaprojects by using the network structure rather than the traditional linear relationship structure. While the modular of the NK model describes the adaptive behavior of stakeholder interactions in the dynamic project environment, which solves the difficulty of reflecting changeable stakeholder interactions in the development of megaprojects. The model deepens the understanding of stakeholder evolutions in the project life cycle. Furthermore, it gives birth to a new concept termed "stakeholder resilience," which reflects the stakeholder capability when faced with challenges in the megaprojects.

7.3.2 Practical contributions to the industry

First, the proposed dynamic stakeholder-associated topic model provides a method for decision-makers to undertake dynamic stakeholder management in megaprojects with exploring knowledge from unstructured official documents relevant to the project. The "Mirror Z" approach is useful for decision-makers to determine the managerial priority of stakeholder issues, while the "Letter N" approach is to guide the managerial priority for each specific project stakeholder.

Second, the proposed longitudinal stakeholder-associated network model could serve for the researchers and decision-makers to learn critical stakeholder issues, stakeholder relationships, and management strategies from the complex stakeholder structures in the historic megaprojects, summarizing the rules and lessons for the better development of megaprojects in the future.

Third, the proposed Network-NK model is beneficial for decision-makers to forecast stakeholder performance in the development of megaprojects. Besides, the simulative model is also useful for researchers to review the stakeholder performance of completed megaprojects with detecting the weakness of stakeholder performance and assessing the stakeholder issues with poor resilience for each project stakeholder.

7.4 Limitations and future directions of the Research

Although the proposed models do not have regional restrictions, the case scenarios are mainly in Hong Kong, waiting for broad applications in various regions to further test models' robustness. In future studies, more cases in multiple areas could be investigated to generalize and validate this research's proposed models.

The proposed dynamic stakeholder-associated topic model could be extended to investigate the experience of various megaprojects with timestamped official documents in different regions. Moreover, the proposed method can be applied to data from news websites, social media, and other text sources, for the comprehensive understanding of stakeholder dynamics in megaprojects from various data sources.

The proposed longitudinal stakeholder-associated network model is much dependent on the source of the stakeholder information. The insufficient stakeholder information may lead to the deviated research results, which is an inborn weakness of the network analysis. Although the information of the study is extracted from the official documents considering as a reliable dataset, some stakeholder information may still not be fully covered if they are not mentioned in the collected official documents. Thus, more information access is recommended in future studies, such as the project information on the mainstream website and social media, to reveal the changeable stakeholder complexity of megaprojects more comprehensively.

The proposed Network-NK model requires the reliable information as inputs to make simulative analysis precisely. In future studies, the official documents of multiple similar projects may be a valuable source to provide accurate information for the generation of influence distribution of stakeholder strategies and the establishment of the stakeholder-associated issue networks. Therefore, an efficient text-mining approach to extract useful information from the official documents relevant to the similar type of megaprojects will be the next step to improve the application of the proposed model.

7.5 Final Conclusions of the thesis

The research achieves the aim to develop robust approaches for analyzing stakeholder interactions in dynamic and complex environment of megaprojects. There are three approaches developed to improve the methods of stakeholder analysis in megaprojects.

To evaluate stakeholder dynamics in megaprojects, the proposed dynamic stakeholder-associated topic model provides a text-mining based method, which can analyze the stakeholder dynamics by exploring the knowledge from large quantities of unstructured official documents relevant to the project.

To reveal stakeholder complexity in megaprojects, the proposed longitudinal stakeholder-associated network model provides a systematic method, which can prioritize the critical stakeholder issues and the most affected relationships from the complex stakeholder structures.

To analyze stakeholder performance in dynamic and complex environment of megaprojects, the proposed Network-NK model provides a simulative method to reveal the evolution and resilience of stakeholder performance by simulating dynamic interactions in the complex structure between stakeholders and their relevant issues.

The proposed analytical approaches realize stakeholder analysis in dynamic and complex environment of megaprojects by bridging knowledge domains of stakeholder management, text-mining techniques, network analysis, and complex adaptive system. The research contributes new methods to stakeholder analysis in the field of construction project management.

Appendix A The program codes for dynamic stakeholder-associated topic modeling

Note: The codes below are written in Python 3.7. The codes include the data pre-processing, TOT modeling, and the calculation of stakeholder relevance scores.

```
from nltk.stem.porter import PorterStemmer
from sklearn.feature_extraction.text import TfidfVectorizer, CountVectorizer,
TfidfTransformer
from sklearn.decomposition import NMF, LatentDirichletAllocation
from time import time
import pandas as pd
import matplotlib.pyplot as plt
import fileinput
import random
import scipy.special
import numpy as np
import scipy.stats
import copy
import re
import time
import csv
ifidf_thres=0.02

class TopicsOverTime:
    def GetPnasCorpusAndDictionary(self, documents_path, whitelist_path,
stopwords_path, stopstems_path, synonyms_path):
        temp=[]
        documents=[]
        dictionary=set()
        stopwords=set()
        whitelist=[]
        stopstems=[]
        synonyms=[]
        target=[]
        porter_stemmer = PorterStemmer()
        for line in fileinput.input(whitelist_path):
```

```
            whitelist.append(line.lower().strip())
        for word in whitelist:
            target.append(word.replace(' ', '$'))
        for line in fileinput.input(stopwords_path):
            stopwords.update(set(line.lower().strip().split()))
        for line in fileinput.input(stopstems_path):
            stopstems.append(line.lower().strip())
        synonyms_df = pd.read_csv(synonyms_path, encoding='UTF-8')
        r1 = '[0-9’!"#$%&\'()*+,-./:;<=>?@，。?★、…【】《》？“”‘’！
[\\]^_`{|}~]+'
        orig = [word.strip() for word in list(synonyms_df.columns)]
        orig = [word.replace(' ', '') for word in orig]
        synonyms.append([re.sub(r1, '', word.lower()) for word in orig])
        for i in range(len(synonyms_df)):
            orig = list(synonyms_df.iloc[i,1:])
            _list = []
            for word in orig:
                if isinstance(word,str):
                    word = word.strip()
                    word = word.replace(' ', '')
                    _list.append(re.sub(r1, '', word.lower()))
                else:
                    _list.append(None)
            synonyms.append(_list)

        #csvFile.close()
        print("Conducting word segmentation and stemming for documents...")
        docnum=0
        t0=time.time()
        for doc in documents_path:
            for line in fileinput.input(doc,
openhook=fileinput.hook_encoded("utf8")):
                t = line.lower()
                for i in range(len(whitelist)):
                    t = t.replace(whitelist[i], target[i])
                r1 = '[0-9’!"#$%&\'()*+,-./:;<=>?@，。?★、…【】《》？“”‘’！
[\\]^_`{|}~]+'
                t=re.sub(r1,'',t)
```

```
            # temp=filter(str.isalpha, t)
            # t = re.split(r'[!|?|\.|\,|\s|(|)|{|}|\]|\[\'\"\;\:]', t.strip())
            t=re.split(' ', t.strip())

            for i in range(len(t)):
                for synls in synonyms[1:]:
                    for j in range(len(synls)):
                        if t[i] == synls[j]:
                            t[i] = synonyms[0][j]

            words=[word for word in t if word not in stopwords and
len(word) > 3 and word.isalpha()]
            words=list(map(porter_stemmer.stem, words))
            words=[word for word in words if word not in stopstems]
            temp=temp + words
        documents.append(temp)
        print("Document #"+str(docnum)+" complete!")
        docnum+=1
    corpus=[]
    print("All documents segmented! Time elapse: "+str(time.time()-t0)+"s\n")
    t0=time.time()
    print("Extract if-idf features for each documents...")
    for item in documents:
        dictionary.update(set(item))
        corpus.append(' '.join(item))
    vectorizer=CountVectorizer()
    transformer=TfidfTransformer()
    tfidf=transformer.fit_transform(vectorizer.fit_transform(corpus))
    word=vectorizer.get_feature_names()
    weight=tfidf.toarray()
    documents=[]
    for i in range(len(weight)):
        temp=[index for index in range(len(weight[i])) if
weight[i][index]>ifidf_thres]
        temp2 = [index for index in range(len(weight[i]))]
        documents.append([word[item] for item in temp])
    print("All features extracted! Time elapse: "+str(time.time()-t0)+"s\n")
    dictionary=list(dictionary)
```

```
        return documents, dictionary

    def CalculateCounts(self, par):
        for d in range(par['D']):
            for i in range(par['N'][d]):
                topic_di = par['z'][d][i]    # topic in doc d at position i
                word_di = par['w'][d][i]    # word ID in doc d at position i
                par['m'][d][topic_di] += 1
                par['n'][topic_di][word_di] += 1
                par['n_sum'][topic_di] += 1

    def InitializeParameters(self, documents, timestamps, dictionary, maxiter,
docnum, topicnum):
        par = {}    # dictionary of all parameters
        par['dataset'] = 'pnas'    # dataset name
        par['max_iterations'] = maxiter    # max number of iterations in gibbs
sampling
        par['T'] = topicnum    # number of topics
        par['D'] = len(documents)
        par['V'] = len(dictionary)
        par['N'] = [len(doc) for doc in documents]
        par['alpha'] = [50.0 / par['T'] for _ in range(par['T'])]
        par['beta'] = [0.1 for _ in range(par['V'])]
        par['beta_sum'] = sum(par['beta'])
        par['psi'] = [[1 for _ in range(2)] for _ in range(par['T'])]
        par['betafunc_psi'] = [scipy.special.beta(par['psi'][t][0], par['psi'][t][1]) for t
in range(par['T'])]
        par['word_id'] = {dictionary[i]: i for i in range(len(dictionary))}
        par['word_token'] = dictionary
        par['z'] = [[random.randrange(0, par['T']) for _ in range(par['N'][d])] for d in
range(par['D'])]
        par['t'] = [[timestamps[d] for _ in range(par['N'][d])] for d in range(par['D'])]
        par['w'] = [[par['word_id'][documents[d][i]] for i in range(par['N'][d])] for d
in range(par['D'])]
        par['m'] = [[0 for t in range(par['T'])] for d in range(par['D'])]
        par['n'] = [[0 for v in range(par['V'])] for t in range(par['T'])]
        par['n_sum'] = [0 for t in range(par['T'])]
        par['docnum']=docnum
```

```
        np.set_printoptions(threshold=np.inf)
        np.seterr(divide='ignore', invalid='ignore')
        self.CalculateCounts(par)
        return par

    def GetTopicTimestamps(self, par):
        topic_timestamps = []
        for topic in range(par['T']):
            current_topic_timestamps = []
            current_topic_doc_timestamps = [[(par['z'][d][i] == topic) *
par['t'][d][i] for i in range(par['N'][d])] for
                                                            d in range(par['D'])]
            for d in range(par['D']):
                current_topic_doc_timestamps[d] = filter(lambda x: x != 0,
current_topic_doc_timestamps[d])
            for timestamps in current_topic_doc_timestamps:
                current_topic_timestamps.extend(timestamps)
            assert current_topic_timestamps != []
            topic_timestamps.append(current_topic_timestamps)
        return topic_timestamps

    def GetMethodOfMomentsEstimatesForPsi(self, par):
        topic_timestamps = self.GetTopicTimestamps(par)
        psi = [[1 for _ in range(2)] for _ in range(len(topic_timestamps))]
        for i in range(len(topic_timestamps)):
            current_topic_timestamps = topic_timestamps[i]
            timestamp_mean = np.mean(current_topic_timestamps)
            timestamp_var = np.var(current_topic_timestamps)
            if timestamp_var == 0:
                timestamp_var = 1e-6
            common_factor = timestamp_mean * (1 - timestamp_mean) /
timestamp_var - 1
            psi[i][0] = 1 + timestamp_mean * common_factor
            psi[i][1] = 1 + (1 - timestamp_mean) * common_factor
        return psi

    def ComputePosteriorEstimatesOfThetaAndPhi(self, par):
        theta = copy.deepcopy(par['m'])
```

```
        phi = copy.deepcopy(par['n'])

        for d in range(par['D']):
            if sum(theta[d]) == 0:
                theta[d] = np.asarray([1.0 / len(theta[d]) for _ in
range(len(theta[d]))])
            else:
                theta[d] = np.asarray(theta[d])
                theta[d] = 1.0 * theta[d] / sum(theta[d])
        theta = np.asarray(theta)

        for t in range(par['T']):
            if sum(phi[t]) == 0:
                phi[t] = np.asarray([1.0 / len(phi[t]) for _ in range(len(phi[t]))])
            else:
                phi[t] = np.asarray(phi[t])
                phi[t] = 1.0 * phi[t] / sum(phi[t])
        phi = np.asarray(phi)

        return theta, phi

    def ComputePosteriorEstimatesOfTheta(self, par):
        theta = copy.deepcopy(par['m'])

        for d in range(par['D']):
            if sum(theta[d]) == 0:
                theta[d] = np.asarray([1.0 / len(theta[d]) for _ in
range(len(theta[d]))])
            else:
                theta[d] = np.asarray(theta[d])
                theta[d] = 1.0 * theta[d] / sum(theta[d])

        return np.matrix(theta)

    def ComputePosteriorEstimateOfPhi(self, par):
        phi = copy.deepcopy(par['n'])

        for t in range(par['T']):
```

```
            if sum(phi[t]) == 0:
                phi[t] = np.asarray([1.0 / len(phi[t]) for _ in range(len(phi[t]))])
            else:
                phi[t] = np.asarray(phi[t])
                phi[t] = 1.0 * phi[t] / sum(phi[t])

        return np.matrix(phi)

    def TopicsOverTimeGibbsSampling(self, par):
        t0=time.time()
        for iteration in range(par['max_iterations']):
            for d in range(par['D']):
                for i in range(par['N'][d]):
                    word_di = par['w'][d][i]
                    t_di = par['t'][d][i]

                    old_topic = par['z'][d][i]
                    par['m'][d][old_topic] -= 1
                    par['n'][old_topic][word_di] -= 1
                    par['n_sum'][old_topic] -= 1

                    topic_probabilities = []
                    for topic_di in range(par['T']):
                        psi_di = par['psi'][topic_di]
                        topic_probability = 1.0 * (par['m'][d][topic_di] + par['alpha'][topic_di])
                        topic_probability *= ((1 - t_di) ** (psi_di[0] - 1)) * ((t_di) ** (psi_di[1] - 1))
                        topic_probability /= par['betafunc_psi'][topic_di]
                        topic_probability *= (par['n'][topic_di][word_di] + par['beta'][word_di])
                        topic_probability /= (par['n_sum'][topic_di] + par['beta_sum'])
                        topic_probabilities.append(topic_probability)
                    sum_topic_probabilities = sum(topic_probabilities)
                    if sum_topic_probabilities == 0:
                        topic_probabilities = [1.0 / par['T'] for _ in range(par['T'])]
```

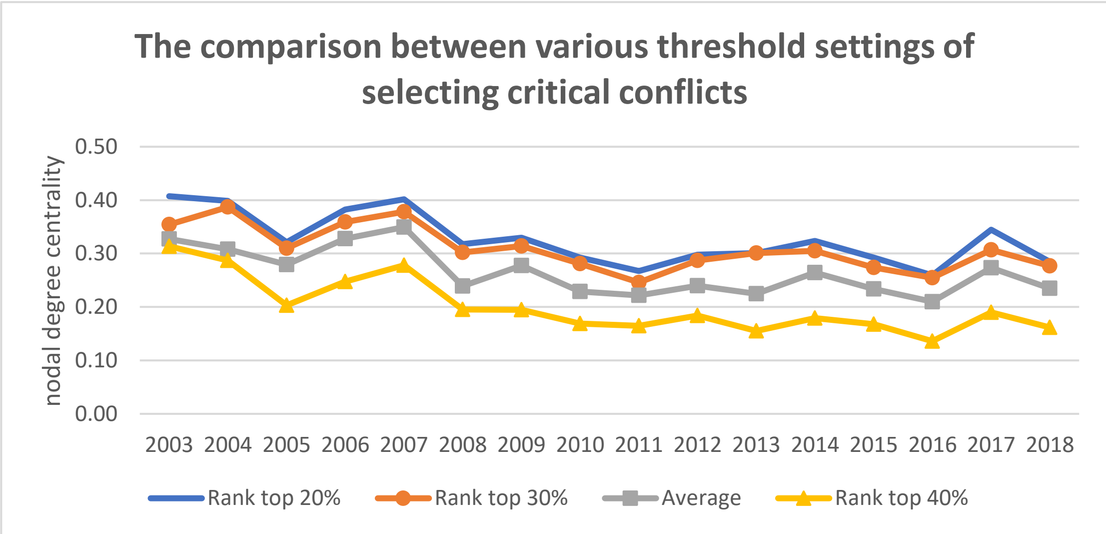
```
                    else:
                        topic_probabilities = [p / sum_topic_probabilities for p
in topic_probabilities]
                    new_topic = list(np.random.multinomial(1,
topic_probabilities, size=1)[0]).index(1)
                    par['z'][d][i] = new_topic
                    par['m'][d][new_topic] += 1
                    par['n'][new_topic][word_di] += 1
                    par['n_sum'][new_topic] += 1
                # print('Done with iteration {iteration} and document
{document}, Time elapse:
{timelen}'.format(iteration=iteration,document=d,timelen=time.time()-t0))
                # print('{topicnum} topics: Done with iteration {iteration} and
document {document}, Time elapse:
{timelen}'.format(topicnum=par['T'],iteration=iteration,document=d,timelen=time.tim
e()-t0))
            par['psi'] = self.GetMethodOfMomentsEstimatesForPsi(par)
            par['betafunc_psi'] = [scipy.special.beta(par['psi'][t][0], par['psi'][t][1])
for t in range(par['T'])]
        par['m'], par['n'] = self.ComputePosteriorEstimatesOfThetaAndPhi(par)
        return par['m'], par['n'], par['psi']

    def topicAnalyze(self, documents_path, size):
        bow_corpus = []
        index = sorted(random.sample(range(len(documents_path)), size))
        paths = [documents_path[k] for k in index]
        for doc in paths:
            for line in fileinput.input(doc,
openhook=fileinput.hook_encoded("gbk")):
                bow_corpus += line.split()
        print(len(bow_corpus))
        train_size = int(round(len(bow_corpus) * 0.8))    ###分解训练集和测试集
        train_index = sorted(random.sample(range(len(bow_corpus)), train_size))
###随机选取下标
        test_index = sorted(set(range(len(bow_corpus))) - set(train_index))
        train_corpus = [bow_corpus[i] for i in train_index]
        test_corpus = [bow_corpus[j] for j in test_index]
```

```
n_features = 2000

print(len(train_corpus))
print("Extracting tf features for LDA...")
tf_vectorizer = CountVectorizer(max_df=0.95, min_df=2,
max_features=n_features,
                                stop_words='english')   ###选取至
少出现过两次并且数量为前 2000 的单词用来生成文本表示向量
t0 = time()
tf = tf_vectorizer.fit_transform(train_corpus)   ###使用向量生成器转化测
试集
print("done in %0.3fs." % (time() - t0))
# Use tf (raw term count) features for LDA.
print("Extracting tf features for LDA...")
tf_test = tf_vectorizer.transform(test_corpus)
print("done in %0.3fs." % (time() - t0))
grid = dict()
t0 = time()
for i in range(18, 36, 2):   ###100 个主题，以 5 为间隔
    grid[i] = list()
    n_topics = i

    lda = LatentDirichletAllocation(n_components=n_topics, max_iter=5,
learning_method='online',
                                    learning_offset=50.,
random_state=0)   ###定义 lda 模型
    lda.fit(tf)   ###训练参数
    train_gamma = lda.transform(tf)   ##得到 topic-document  分布
    train_perplexity = lda.perplexity(tf_test)   ###s 计算测试集困惑度
    print('sklearn preplexity: train=%.3f' % (train_perplexity))

    grid[i].append(train_perplexity)

print("done in %0.3fs." % (time() - t0))

df = pd.DataFrame(grid)
df.to_csv('sklearn_perplexity.csv')
print(df)
```

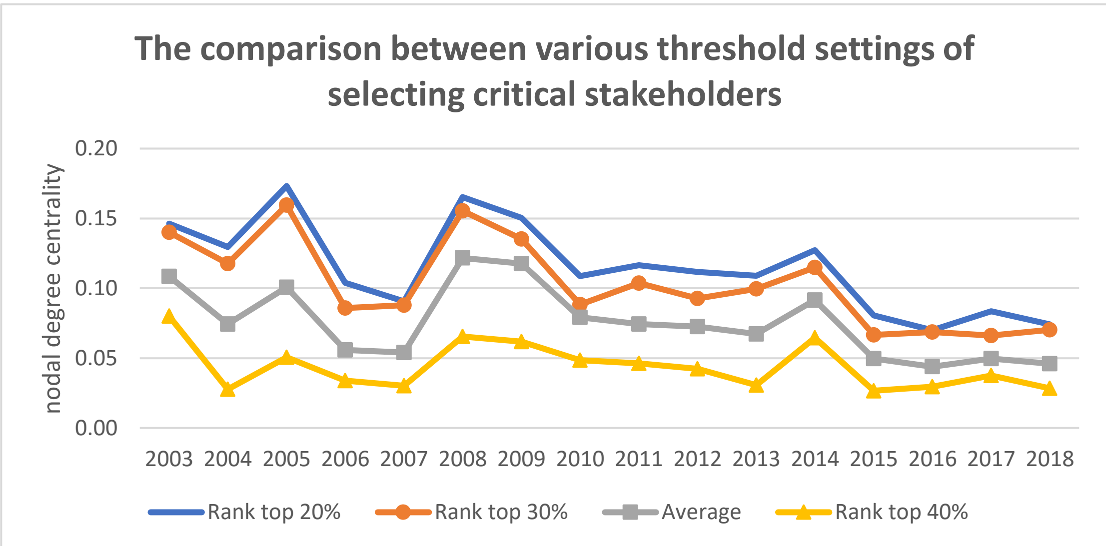
```
plt.figure(figsize=(14, 8), dpi=120)
# plt.subplot(221)
plt.plot(df.columns.values, df.iloc[0].values, '#007A99')
plt.xticks(df.columns.values)
plt.ylabel('train Perplexity')
plt.show()
plt.savefig('lda_topic_perplexity.png', bbox_inches='tight', pad_inches=0.1)
```

Appendix B The supplemental materials for longitudinal stakeholder-associated network modeling

Note: The figures and tables below are the supplemental materials of the stakeholder-conflict studies in HZMB, which are helpful to show the research details of the case study.



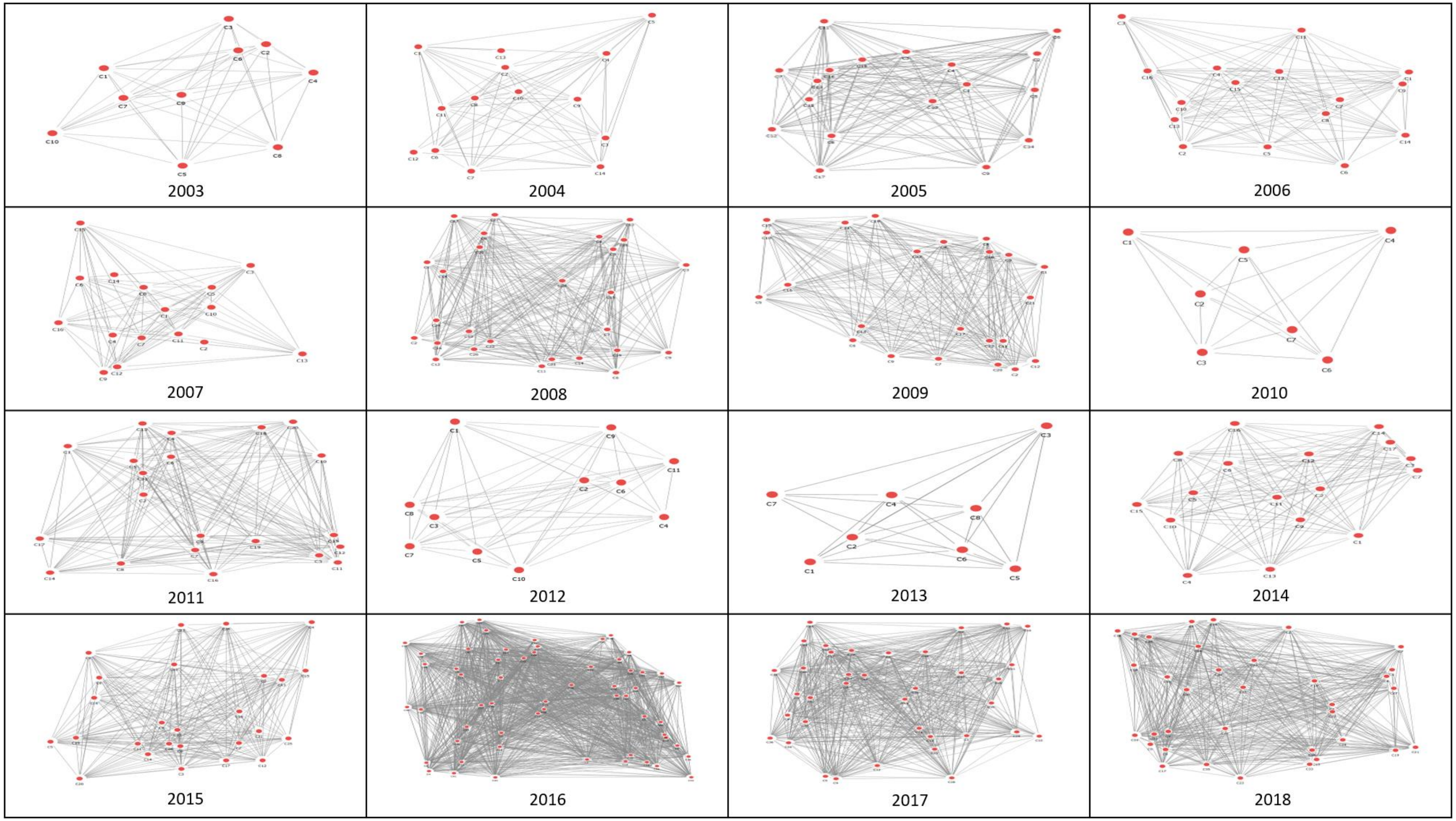
Appendix B.1 The comparison between various threshold settings of selecting critical conflicts



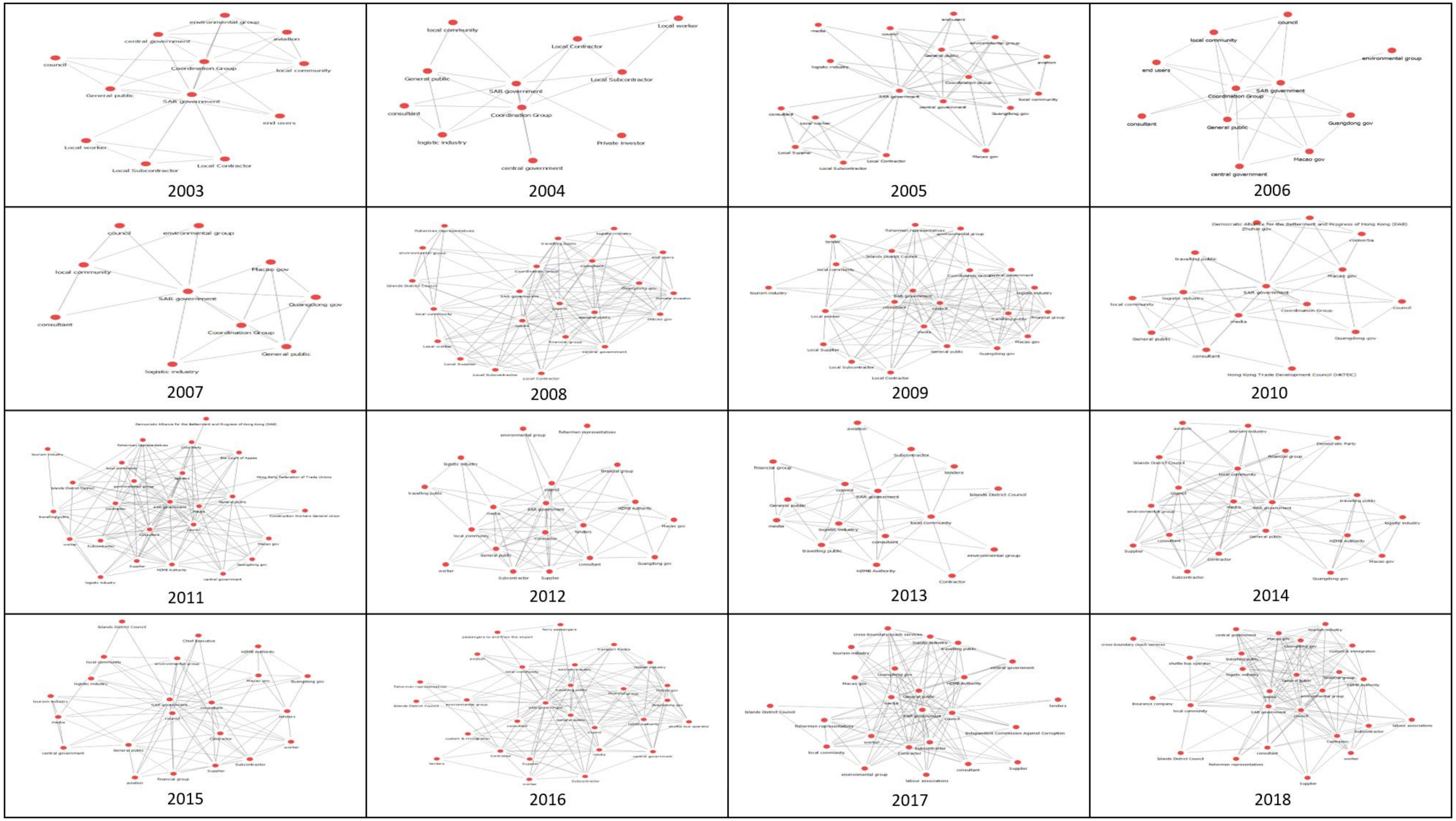
Appendix B.2 The comparison between various threshold settings of selecting critical stakeholders

Appendix B.3 Profiles of participants in the review of data collection

Participant Type	Quantity	Job Experience (years)	Job Position	Project Involvement Period
Government officer	1	25	Senior	2003-2018
Contractor	1	23	Senior	2003-2018
Community leader	1	22	Senior	2003-2018



Appendix B.4 The projected conflict networks on HZMB from 2003 to 2018



Appendix B.5 The projected stakeholder networks on HZMB from 2003 to 2018

Appendix B.6 The critical conflict topics in HZMB from 2003 to2018

Year	Top 30% critical conflict topics	NDC
2003	the impact of the project on Chinese White Dolphins	0.407
	green groups participation in the planning of the Bridge	0.407
	disclose certain information among three governments.	0.354
2004	adding railway links to the HZMB	0.460
	cross-boundary infrastructural facilities lag behind the actual requirements.	0.460
	change the original design of the HZMB	0.399
	co-location arrangement to boundary crossings	0.387
2005	the project should not be pursued in a hasty manner	0.363
	alignment options for NLHC	0.330
	environmental and transport considerations	0.326
	alignment options for HZMB	0.321
	the financing arrangements for the HZMB.	0.318
	financial support for the HZMB among three governments	0.310
2006	expedite planned HZMB	0.419
	the completion date of the HZMB has been postponed	0.414
	expensive bridge tolls because of high project cost	0.382
	whether the HZMB can be equipped with a railway.	0.363
	expedite the progress of the project.	0.359
2007	the construction progress of TMWB	0.443
	wider and longer-term development of HZMB	0.443
	upgrade roads as appropriate to prepare for the traffic flow arising from HZMB.	0.402
	the environmental impact of the tunnel design	0.378
2008	the split of contribution from the three governments to the funding gap of the project.	0.365
	financing arrangements	0.365
	toll level	0.324
	economic benefits and cost sharing	0.322
	the methodology and the accuracy of the traffic volume forecast for HZMB	0.318
	financial viability and related arrangements	0.317
	ownership of the HZMB	0.310
	costs to be borne by Hong Kong	0.302
2009	management body of HZMB	0.352
	the patronage and the cost-effectiveness of HZMB	0.341
	connectivity of the Bridge	0.338
	financing arrangement of HZMB	0.332
	financing arrangements and management responsibilities	0.330
	design of the passenger clearance building	0.319
	the toll level and the authority for HZMB	0.314

Year	Top 30% critical conflict topics	NDC
2010	the reconsideration of bridgehead economy	0.292
	environmental effect from the connecting places	0.281
2011	impact of the judicial review on EIA	0.291
	cost increase for the HZMB related local projects due to EIA judicial review	0.277
	the delay of HZMB HKBCF and HKLR projects due to EIA judicial review	0.277
	the progress of cross-boundary transport infrastructure projects.	0.267
	reclamation works	0.250
	quality control of works	0.246
2012	project claims caused by EIA judicial review	0.313
	timeframe of project completion after EIA review	0.298
	cost increase due to the assessment of the risks	0.287
2013	the provision of public transport support facilities.	0.311
	HZMB's related local infrastructure projects	0.301
2014	development options of commercial facilities	0.345
	environmental implications of the Project	0.339
	development on the Hong Kong boundary crossing facilities island	0.323
	the impact of the reclamation works on ecology.	0.316
	public consultation	0.305
2015	commercial development on the HKBCF island	0.350
	consultancy studies on HKBCF island topside development	0.337
	work progress of HKBCF, HZMB Main Bridge	0.308
	delay in the implementation of the project	0.307
	settlement and lateral movements of the reclaimed	0.293
	approach in the study for the topside development	0.286
	the technical difficulties currently encountered in the construction of HZMB	0.278
	project cost of HKBCF, HZMB Main Bridge and other related local projects	0.274
2016	industrial safety	0.292
	cost overruns and delays	0.288
	sub-contractors failing in safety assessment	0.287
	whether the reclamation works for the project might cause the problem of structural movement	0.285
	importation of labour	0.284
	monitoring the expenditure of contractors	0.284
	importation of foreign labour	0.284
	provision of parking space at Hong Kong Boundary crossing Facilities	0.272
	necessary but not absolutely essential facilities	0.268
	project cost overruns and delays	0.260
	industrial accidents and site safety	0.259
	quality of precast units	0.259
	precast units in HZMB	0.259

Year	Top 30% critical conflict topics	NDC
2016	estimates of vehicular flow of HZMB and its cost-effectiveness	0.255
2017	lack of transparency in disclosing the incident	0.417
	level of penalty of accidents	0.417
	seawall extensions in the HKLR reclamation site	0.354
	responsibilities of the Administration in the incident	0.350
	impact on construction costs	0.344
	scope of reclamation works and seabed loss	0.338
	site safety practitioners	0.327
	occupational injuries and counter measures	0.323
	road safety concerns	0.307
2018	progress of the Tuen Mun Western Bypass project	0.299
	the traffic and transport arrangements of the HZMB	0.298
	traffic volume of the HZMB	0.290
	the estimate for the HZMB was again found to be wrong	0.290
	the debt incurred by the HZMB Authority for constructing the Main Bridge of HZMB	0.286
	detention facilities at HZMB Hong Kong Port	0.285
	technical difficulties encountered in the Tuen Mun-Chek Lap Kok Link	0.285
	adoption of right-driving arrangement on Hong Kong Link Road	0.277

Note: *NDC: Node degree centrality*

Appendix C The program codes for Network-NK stakeholder performance simulation modeling

Note: The codes below are written in Python 3.7. The codes include the generation of stakeholder-issue networks, the probabilistic distribution of stakeholder strategies, and NK modeling.

```
import time
import pandas as pd
import networkx as nx
from networkx.algorithms import bipartite, centrality
import matplotlib.pyplot as plt
import csv
from landscape_creation import createNK
from local_search import local_search, local_search_normalize
from learning_search import learning_search, learning_search_normalize


def getGraph(filename, sheetname):
    df = pd.read_excel(open(filename, 'rb'), sheet_name=sheetname)
    G = nx.Graph()

    # add nodes
    c_clusters = df.iloc[1:, 0].tolist() # C's clusters
    for i in range(len(c_clusters)):
        if c_clusters[i] == 0 or pd.isnull(c_clusters[i]): # drop node if cluster is 0 or
nan
            del c_clusters[i]
            df = df.drop([i+1], axis=0)
            break
    C = df.iloc[1:, 1].tolist()            # node C
    S = list(df.head(0))[2:]               # node S
    c_name = df.iloc[1:, 2].tolist()       # conflict
    s_name = df.iloc[0, 2:].tolist()       # stakeholder
    G.add_nodes_from(C, bipartite=0)
    G.add_nodes_from(S, bipartite=1)
    conflicts = dict(zip(C, c_name))       # C: conflict
```

```
    stakeholders = dict(zip(S, s_name)) # S: stakeholder
    clusters = dict(zip(C, c_clusters)) # C: c_cluster, new added

    # add edges
    data = df.iloc[1:, 2:]
    data.index = C
    for i, row in data.iterrows():
        rowList = list(row)
        for j in range(len(rowList)):
            if rowList[j] == 1:
                G.add_edge(i, S[j])

    # return G, conflicts, stakeholders
    return G, conflicts, stakeholders, clusters


def save(file_name, conflicts, stakeholders, strategies, c_adj, s_scores, c_scores,
c_scores_s, systemScore, c_iter, c_s_n):
    with open(file_name, 'w', newline='', encoding='utf-8') as f:
        writer = csv.writer(f, quoting=csv.QUOTE_ALL)
        writer.writerow(["Node", "Iteration", "Fitness Score", "Strategy",
"Stakeholder", "Conflict"])
        c_keys = list(c_scores.keys())
        for key in c_keys:
            writer.writerow([key, c_iter[key], c_scores[key], strategies[key],
c_adj[key], conflicts[key]])
        writer.writerow("\n")

        writer.writerow(["Node", "Fitness Score", "Stakeholder"])
        for key in list(s_scores.keys()):
            writer.writerow([key, s_scores[key], stakeholders[key]])
        writer.writerow(['System Score', systemScore])
        writer.writerow("\n")

        row = list(stakeholders.keys())
        row.insert(0, ' ')
        writer.writerow(row)
        for c_key in c_keys:
```

```
            row = c_key+","
            count = 0
            for s in list(stakeholders.keys()):
                if s in c_adj[c_key]:
                    row += str(c_scores_s[c_key][count])+","
                    count += 1
                else:
                    row += ","
            f.write(row+"\n")
        writer.writerow("\n")

        writer.writerow(c_keys)
        for i1 in range(len(next(iter(c_s_n.values())))):
            row = ""
            for key in c_keys:
                row += "\"" + ','.join(str(n) for n in c_s_n[key][i1]) + "\"" + ","
            f.write(row+"\n")
    f.close()


def getProbabilityData(filename, sheetname): # read Probability sheet to get
    df = pd.read_excel(open(filename, 'rb'), sheet_name=sheetname)
    clusters = df.iloc[1:, 1].dropna().tolist()
    data_df = df.iloc[1:, 3:7].dropna()
    data_df.index = clusters
    data_df.columns = ['avg1','std1','avg0','std0']
    data_dic = data_df.to_dict('index')
    return data_dic

def getKvalue(s_G, nodes):
    s_subG = s_G.subgraph(nodes)
    K = s_subG.number_of_nodes()-1
    return K

def localSearch(G, conflicts, stakeholders, C, S, s_G, year, i): # K: density
    c_scores = {}
    c_scores_s = {}
    s_scores = {}
```

```
    strategies = {}
    c_adj = {}
    c_iter = {}
    c_s_n = {}

    for c in C:
        N = G.degree[c]
        K = getKvalue(s_G, list(G.adj[c]))
        if N > 0:
            NK_filepath = 'output\\NK_landscape\\NKland_' + year + '_' + c + '_N'
+ str(N) + '_K' + str(K) + '_i' + str(i) + '.npy'
            # fit_s, strategy, fit, iteration, s_n = local_search(N, i, NK_filepath)
            fit_s, strategy, fit, iteration, s_n = local_search_normalize(N, i,
NK_filepath)
            c_scores[c] = fit
            c_scores_s[c] = fit_s
            strategies[c] = strategy
            c_adj[c] = list(G.adj[c])
            c_iter[c] = iteration
            c_s_n[c] = s_n
            #print(c, ': N =', N, 'K =', K, 'Strategy:', strategy, 'Score =', c_scores[c])

    for s in S:
        if G.degree[s] > 0:
            ls = [c_scores[c] for c in list(G.adj[s])]
            s_scores[s] = sum(ls) / len(ls)
            #print(s, ': Score =', s_scores[s])

    ls = list(s_scores.values())
    systemScore = sum(ls) / len(ls)
    print('The system score is:', systemScore)

    # save to csv file
    save('output\\local_search\\'+year+'.csv', conflicts, stakeholders, strategies, c_adj,
s_scores, c_scores, c_scores_s, systemScore, c_iter, c_s_n)


def learningSearch(G, conflicts, stakeholders, C, S, s_G, year, i): # K: density
```

```
    c_scores = {}
    c_scores_s = {}
    s_scores = {}
    strategies = {}
    c_adj = {}
    c_iter = {}
    c_s_n = {}

    for c in C:
        N = G.degree[c]
        K = getKvalue(s_G, list(G.adj[c]))
        if N > 0:
            NK_filepath = 'output\\NK_landscape\\NKland_' + year + '_' + c + '_N'
+ str(N) + '_K' + str(K) + '_i' + str(i) + '.npy'
            # fit_s, strategy, fit, iteration, s_n = learning_search(N, i, NK_filepath)
            fit_s, strategy, fit, iteration, s_n = learning_search_normalize(N, i,
NK_filepath)
            c_scores[c] = fit
            c_scores_s[c] = fit_s
            strategies[c] = strategy
            c_adj[c] = list(G.adj[c])
            c_iter[c] = iteration
            c_s_n[c] = s_n
            #print(c, ': N =', N, 'K =', K, 'Strategy:', strategy, 'Score =', c_scores[c])

    for s in S:
        if G.degree[s] > 0:
            ls = [c_scores[c] for c in list(G.adj[s])]
            s_scores[s] = sum(ls) / len(ls)
            #print(s, ': Score =', s_scores[s])

    ls = list(s_scores.values())
    systemScore = sum(ls) / len(ls)
    print('The system score is:', systemScore)

    # save to csv file
    save('output\\learning_search\\'+year+'.csv', conflicts, stakeholders, strategies,
c_adj, s_scores, c_scores, c_scores_s, systemScore, c_iter, c_s_n)
```

```
def main():
        filename = 'network for NK clusters.xlsx'
        i = 1000 # num of itertaion
        avg_std = getProbabilityData(filename, 'Probability')
        for year in range(2003,2019):
                sheetname=str(year)
                print("============================================= " +
sheetname + " =============================================")
                G, conflicts, stakeholders, clusters = getGraph(filename, sheetname)
                C = list(conflicts.keys())
                S = list(stakeholders.keys())
                s_G = bipartite.projected_graph(G, S)
                print("-------------------- Running Module 1: NK landscape creation and
analysis --------------------")
                for c in C:
                        N = G.degree[c]
                        K = getKvalue(s_G, list(G.adj[c]))
                        cluster = clusters[c]
                        if N > 0:
                                NK_filepath = 'output\\NK_landscape\\NKland_' + sheetname +
'_' + c + '_N' + str(N) + '_K' + str(K) + '_i' + str(i) + '.npy'
                                createNK(N, i, avg_std[cluster], NK_filepath)
                print("-------------------- Running Module 2.1: Local search --------------------
")
                localSearch(G, conflicts, stakeholders, C, S, s_G, sheetname, i)
                print("-------------------- Running Module 2.2: Learning search ----------------
----")
                learningSearch(G, conflicts, stakeholders, C, S, s_G, sheetname, i)

if __name__ == "__main__":
        main()
```

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