A DYNAMIC MODEL FOR EVALUATING THE SUCCESS OF CONSTRUCTION MEGA PROJECTS IN CHINA

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A Dynamic Model for Evaluating the Success of Construction Mega Projects in China

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CERTIFICATE OF ORIGINALITY

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ABSTRACT

Megaprojects are typically defined as large-scale investments that cost at least one billion US dollars, take many years to build, involve many stakeholders and affect millions of people. Over the past years, the investment and construction of megaprojects throughout the world remarkably increased. However, the performance of megaprojects is not always satisfactory. “Over budget, over time, under benefits, over and over again” seems to have become the iron law of megaproject management. One of the most influential factors is the lack of a scientific evaluation model for construction megaproject success (CMS). Therefore, in-depth research is necessary to develop such a model.

This research aims to develop a systematic and dynamic model for evaluating and enhancing the success of construction megaprojects in China by satisfying five specific objectives: (1) identify a set of key performance indicators (KPIs) for measuring the CMS, (2) identify the critical success factors (CSFs) that exert strong effects on the CMS, (3) explore the relationships between the identified CSFs and KPIs, (4) establish a model that will dynamically evaluate the success level of construction megaprojects and (5) conduct scenario analysis to identify the effective managerial strategies for enhancing the success level of construction megaproject management. A mixed research methodology is adopted in this study, including literature review, interview and questionnaire survey, Cronbach’s alpha technique, mean score ranking, factor

analysis, fuzzy set theory, factor analysis, partial least squares structural equation modelling (PLS-SEM) and system dynamic (SD) model.

To construct the theoretical background, a holistic assessment of the project success in the field of construction and engineering management in the past decade was conducted through a comprehensive literature review. The literature revealed four underpinning concepts for this study, namely, megaproject success, project success in developing countries, relationships between CSFs and successful outcomes, and dynamic evaluation of project success. Then, a comprehensive literature review on the identification of success criteria and critical factors for CMS was conducted. Twenty success criteria grouped into four dimensions and 33 CSFs were identified, which represent the lists of potential success criteria and critical factors that are crucial to the development of the questionnaire.

Expert interviews were subsequently conducted to explore the optional list of performance indicators and success factors in evaluating the success of construction megaprojects. A survey was conducted to determine the importance of the selected performance indicators and success factors. The fuzzy set theory was adopted to identify the KPIs. Nine KPIs were obtained, namely, meeting regulations or specifications; health, safety and environmental goals; meeting designed function and delivering value/services that the public needed, owner's satisfaction; government's satisfaction; improved brand/reputation; enhancing people's national pride and confidence; social–economic benefits to the community/local. Using the factor analysis technique, the 32 identified CSFs were grouped into six clusters: effectiveness of project management action, project participant-related factors, application of innovation management approaches, external factors, economic factors and organisational factors.

Next, the PLS-SEM method was used to investigate the causal relationships between the identified CSFs and KPIs to evaluate the success of construction megaprojects. The results revealed that only the economic and organisational factors are positively correlated with the KPIs supported in the hypothesised model. Then, the CSF organisational citizenship behaviour (OCB) in the megaproject was selected from the group of organisational factors to examine its effects on the success of construction megaprojects. Lastly, the SD approach was used in this research to develop a model for evaluating the success of construction megaprojects. Three policy scenarios, that is, two single-policy scenarios and a multi-policy one, were adopted to simulate the success level of megaprojects under various policy scenarios. The simulation results indicated that an increase in the actual increasing rate of potential promotion (AIRPP) exhibits more evident effects on the improvement of OCB and the megaproject success than the increase in the actual increasing rate of project culture (AIRPC). Moreover, the simulation results of the multi-policy scenario showed that if the value of the AIRPP in combinations (the total value has been restricted) is high, then the value of OCB adoption and the success of the project will also be high. This phenomenon highlights the priority of improving AIRPC first before the other factors, specifically when the resources are limited.

This study contributes to the theoretical and practical knowledge of construction megaproject management. To date, this study is the first to comprehensively explore the KPIs and CSFs of construction megaprojects. This study is also the first to develop a dynamic model that will consider the interrelationships between the CSFs and KPIs in evaluating the success of construction megaprojects. The findings can provide an insightful reference for practitioners in delivering satisfactory construction megaproject management. Furthermore, decision-makers can establish relevant policies according to the research results to implement the construction megaproject management effectively.

PUBLICATIONS

(1) Journal papers (published or accepted)

Qinghua He, **Ting Wang***, Albert P.C Chan and Junyan Xu (2020). Developing a List of Key Performance Indicators for Benchmarking the Success of Construction Megaprojects. *ASCE Journal of Construction Engineering and Management*, Accepted.

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(2) Journal papers (under review)

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Qinghua He, Junyan Xu, **Ting Wang*** and Albert P.C Chan (2019). Identifying driving factors of construction megaproject success based on three Chinese cases. *The CIB*

World Building Congress 2019, 17-21 June, Hong Kong.

Qinghua He, **Ting Wang***, Daoan Fan and Dongqi Wang (2018). Research on the allocation of excess revenue between public and private sectors in mega construction projects. *Proceedings of 23th International Conference on Advancement of Construction Management and Real Estate*, August, Guiyang, Guizhou Province, China.

Qinghua He, Mian Zheng and **Ting Wang*** (2017). Resilience for construction project-based organizations: definition, critical factors and improvement strategies. *Proceedings of 22nd International Conference on Advancement of Construction Management and Real Estate*, November, Melbourne, Australia.

(4) Research Projects

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Title: Research on the Formation Cause, Effectiveness Emergence and Cultivation of Organizational Citizenship Behavior in Construction Megaproject (重大工程组织公民行为形成动因、效能涌现及培育研究) which is supported by the

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Table of Contents

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1 INTRODUCTION

1.1 Research background

1.2 Research problems

1.3 Research aims and objectives

1.4 Research methodology and process

1.5 Structure of the thesis

1.6 Research significance and value

1.7 Chapter summary

1.1 Research background

Megaprojects are typically defined as large-scale investments that cost at least one billion US dollars, take many years to build, involve many stakeholders and affect millions of people (Flyvbjerg, 2014). These projects are intrinsically complex, risky and characterised with large uncertainty. The common examples of megaprojects include airports, seaports, dams, high-speed railways, offshore oil and gas extraction, defence projects, the Olympic games, information and communications technology systems and new aircraft development (Flyvbjerg, 2017). Megaprojects are not magnified versions of normal projects but actually comprise interdependent subsystems (Flyvbjerg, 2017). Over the past few decades, the number of megaprojects being built around the world is increasing. Approximately US$2.25 trillion has been spent annually on infrastructures in emerging markets from 2009 to 2012 (Caldas and Gupta, 2017). Until now, the market of infrastructure construction still prospects no less than US$57 trillion for future investments by 2030 (Garemo *et al.*, 2015).

Megaprojects are referred to as the 'wild beast' of the project world (Zarina Alias *et al.*, 2014), which are inflicted with disadvantages, such as excessive budget and duration and insufficient benefits (Flyvbjerg, 2017). The reported average cost overrun ratios of road, bridge and railway megaprojects are roughly 20%, 30% and 40%, respectively (Cantarelli, 2011). Meanwhile, the average delay ratio of dam megaprojects reaches 45% (Ansar *et al.*, 2014). The poor capabilities of the owner (Winch and Leiringer, 2016) and high technological complexities (Giezen, 2013, Kardes *et al.*, 2013) were pinpointed as the causal factors in these cases. Recent studies reported the lack of a scientific evaluation model for construction megaproject success (CMS) as one of the most influential reasons contributing to the poor performance of megaprojects (Shenhar and Holzmann, 2017, He *et al.*, 2019a). Developing a model for evaluating CMS is the foundation of the effective management of megaprojects (Boynton and Zmud, 1984, Chan *et al.*, 2001, Jonas Söderlund *et al.*, 2017). Therefore, conducting in-depth research to develop an appropriate evaluation model for CMS is essential.

1.1.1 Why study construction megaprojects?

Construction megaprojects possess many interesting and unique characteristics. The objectives for studying such projects include understanding how these projects create value and determining strategies for successful project implementation (Merrow, 2011). Greiman (2013b) enumerated six compelling reasons to investigate construction megaprojects.

(1) Delivery of lessons from practice

We cannot undo the past, but we are bound to pass it in review in order to draw from it such lessons as may be applicable to the future…….

——*Sir Winston Churchill*

Experience is a great teacher. One of the main reasons for project management research is the accumulation of lessons and experience that can be applied to future projects in different industries and continents (Greiman, 2013b). All lessons from megaprojects, either the good or the bad ones, must be imparted to guide future projects. In the past decades, various research topics on construction megaprojects, such as cost overruns, delays and stakeholder conflicts, have been performed to guide project development.

(2) Advancement of knowledge and innovation

The nature of megaprojects brings together important tacit knowledge embedded within the particular groups in the project (Bresnen *et al.*, 2003). In project-based activities, social processes, including flows of personnel, material and information, are crucial in the diffusion and transfer of knowledge and technology (Greiman, 2013b). For example, the mission of the Boston Central Artery/Tunnel megaproject is the advancement of knowledge and innovation.

(3) Engine for economic development

According to the US Department of Transportation, rebuilding roads, bridges, transit systems and airports can stimulate the creation and development of small businesses, which is the economic engine of the US (Greiman, 2013b). Many studies have shown that infrastructure investment can raise economic growth and productivity and result in positive spill overs, such as energy efficiency and public health, to several areas (Sheng, 2018).

(4) Global expansion and improvement of societal benefits

According to the statistics of the World Bank, the total demand for infrastructure investment and maintenance in developing countries per year is more than $900 billion, which is extremely high (World Bank, 2012). In some developing countries, projects are the only way to deliver societal benefits and sustainable development, including environmental sustainability, quality of life and economic viability. Thus, understanding how to utilise projects is the key to address major global issues, such as poverty, food security and global health.

(5) Fulfilling the growing need for major investment, specifically in transportation and energy

The global society now connects us in ways that we could never have imagined. Major investments are required for various projects to build pipelines for the supply of natural gas; develop alternative energy resources; relieve traffic congestion and rebuild bridges, highways and airports after reaching the originally designed service life. The core business of the World Bank is financing the infrastructures, which accounted for 46% of the total assistance in 2011 (World Bank, 2012).

(6) Improving transparency and oversight

Megaprojects have attracted many scrutiny and public concern. The National Bureau of Corruption Prevention of China reported that from 2009 to 2011, 15,010 cases of corruption in the public construction sector were recorded, involving 1,167 suspects and incurring a loss of RMB 3 billion (approximately USD 0.42 billion)[1] (Le *et al.*, 2014a). In 2009, the US Department of Transportation Office of Inspector General reported 235 convictions and issued more than US$737 million fines related to infrastructure contracts (Barnet and Russell, 2009). Therefore, megaprojects should be studied to properly monitor and oversee the crucial aspects of the project.

1.1.2 What are key characteristics of evaluation model for CMS?

(1) Lack of success indicators and critical factors for CMS

Megaprojects have high uncertainties that risk the interests of multilateral stakeholders and a long life-cycle period, which are the main difference amongst normal construction projects (Marrewijk *et al.*, 2008). Therefore, the current research findings on normal projects cannot be directly applied to evaluate the success of megaprojects. The indicators and critical factors that influence the success of construction projects should be comprehensively explored to establish a scientific and suitable model for the CMS.

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[1]One RMB is approximately equal to 0.14 US dollars.

(2) Interdependency between the indicators and factors for CMS

In conventional project management research, scholars treat the indicators and factors as independent variables. However, existing studies have shown that the indicators and critical success factors (CSFs) for CMS are largely interdependent and share complex interactions. For example, cost overruns and delays are not independent, instead, they are interacted. According to existing research, the delays in the construction phase can further lead to the problem of cost overruns. A 1-year delay in the implementation phase of construction project reportedly led to a 4.64% increase in cost overrun (Flyvbjerg *et al.*, 2004). Leon *et al.* (2018) stated that the effective measurement of the CMS should predict the interdependency and complex interactions that occur between the indicators and CSFs.

(3) Dynamic characteristics of construction megaprojects

The traditional evaluation of CMS is static rather than dynamic (Abotaleb and El-adaway, 2018). However, real construction projects are complex and dynamic (He *et al.*, 2015, Leon *et al.*, 2018). Complexity, in the context of this study, refers to the multiple interrelated feedback systems and dynamics in the sense of the ever-changing systems (Taylor and Ford, 2008). Thus, the dynamic characteristics should be considered to understand and measure the CMS from a holistic perspective for megaprojects.

1.1.3 Why focus on China?

China is the largest emerging market in terms of the investment and construction of megaprojects, including the Hong Kong–Zhuhai–Macau Bridge, the Three Gorgers Dam and the Beijing–Shanghai High-speed Railway. With the largest population in the world, China strives to facilitate the construction of megaprojects to support long-term social and economic development. Moreover, through the Belt and Road initiative, China is entering the age of the 'tera-project', which involves trillion-dollar projects that can affect at least one billion people. These facts have rendered China a superpower in the megaproject market (Sheng, 2018). For instance, in 2016[2], the total amount of construction contracts signed between China and the countries along the Belt and Road reached US$126 billion. China is now the biggest spender on fixed assets in absolute terms in the world (Ansar *et al.*, 2016). **Figure 1.1** shows the gross fixed capital formation (US$) in China from 1982 to 2014 in comparison with that in the US, Japan and Germany. The scale and speed of China's investment are staggering. In 1982, China's total domestic investment was only 2.1% of the world total. Then, in 2014, China spent US$4.6 trillion, accounting for 24.8% of the total investments in the world (Ansar *et al.*, 2016). In conclusion, China has been in the 'biggest investment boom in

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[2]The data are collected from the Infrastructure Development Division, which is under the National Development and Reform Commission (http://jtyss.ndrc.gov.cn/zdxm/).

history' for the past two decades (Flyvbjerg *et al.*, 2009).

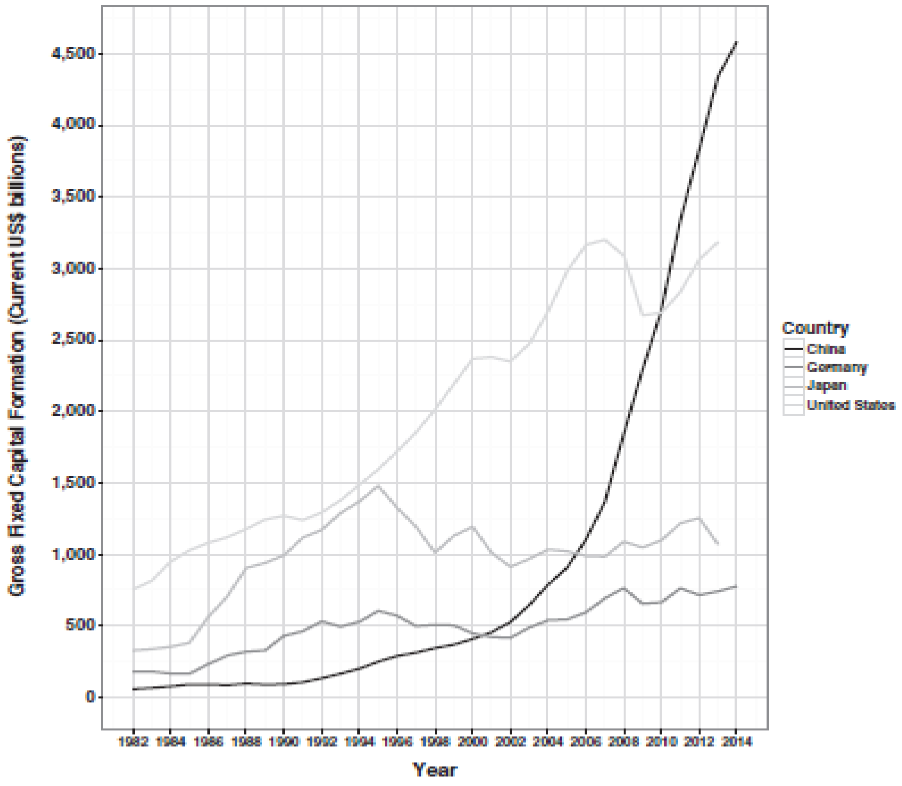

Figure 1.1 China's investment boom

*Source: the figure is cited from Ansar *et al.* (2016). The data is from World Bank, World Development Indicators as of 17 February 2016 update. http://data.worldbank.org/indicator/NE.GDI.FTOT.CD

However, the performance of the proposed megaprojects is not always satisfactory. Ansar *et al.* (2016), who collected and analysed China's 95 railroad and railway projects between 1984 and 2008, noted that the average rate of cost overruns is 30.6%, and the delay rate of railways is 25%. **Table 1.1** shows the cost overruns of the 95 investigated projects in China. Huo *et al.* (2018) discovered that more than 50 megaprojects constructed in Hong Kong exhibited a cost overrun rate of 39.18% on the average, in which 34.83%, 32.52% and 37.48% are the shares of railways, road projects and fixed-link projects, respectively.

Table 1.1 China—cost overruns by project type

Type	Number	Average cost overrun (%)	Standard deviation	Level of significance (*p*)	Median cost overrun (%)	Frequency of projects cost overrun (%)
Road	74	27.5	47.7	<0.0001	16.1	70
Rail	21	41.5	43.2	<0.0001	28.5	90
Total	95	30.6	46.9	<0.0001	18.5	75

*Source: the table is adopted from Ansar *et al.* (2016).

Institutional differences should also be considered in megaproject research. China's megaprojects are under the co-effects of governments and markets, which is the most characteristic of construction management (Li *et al.*, 2018). In China, the most active organisations are from stated-owned entrepreneurs (Hu *et al.*, 2015a). Yang *et al.* (2018) investigated and classified the organisational citizenship behaviour (OCB) in Chinese megaprojects into four categories: harmonious relationship maintenance, contingent collaboration, compliance, initiative behaviour and conscientiousness. The harmonious relationship maintenance is a more important behaviour in China than in western countries because a harmonious culture is a long standing tradition in China (Farh *et* *al.*, 2004). Although some related studies on CMS have been conducted in China, a comprehensive evaluation of the CMS has not been reported. Therefore, this study will focus on the establishment of a dynamic model for evaluating the CMS within the context of China.

1.2 Research problems

To establish a systematic and dynamic model, the following research questions are formulated:

(1) What are the Key Performance Indicators (KPI) for measuring the CMS in China?

(2) What are the critical factors for affecting the CMS in China?

(3) What are the casual relationships between the CSFs and KPIs in China?

(4) How can we evaluate the overall success of construction megaprojects in China?

1.3 Research aims and objectives

This study aims to develop a systematic and dynamic model for evaluating and enhancing the success of construction megaprojects in China. The specific objectives are as follows:

(1) To identify a set of KPIs for the measurement of the CMS;

(2) To identify the CSFs that exert strong effects on the CMS;

(3) To explore the relationships between the identified CSFs and KPIs;

(4) To establish a model that can dynamically evaluate the success level of construction projects; and

(5) To conduct scenario analysis to identify the effective managerial strategies for enhancing the success level of construction megaproject management.

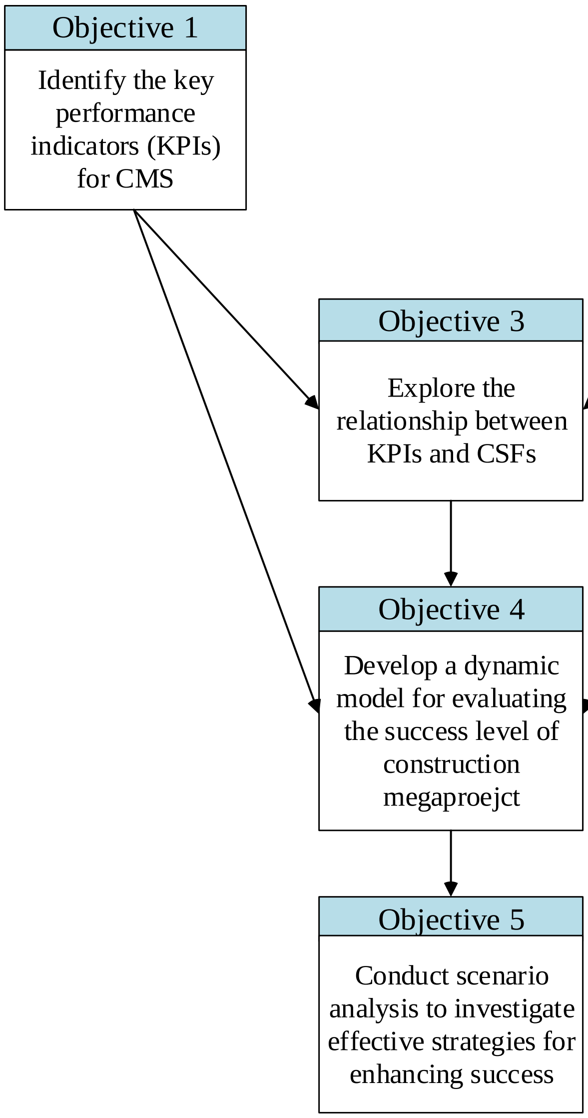

Figure 1.2 Relationships amongst the objectives

1.4 Research methodology and process

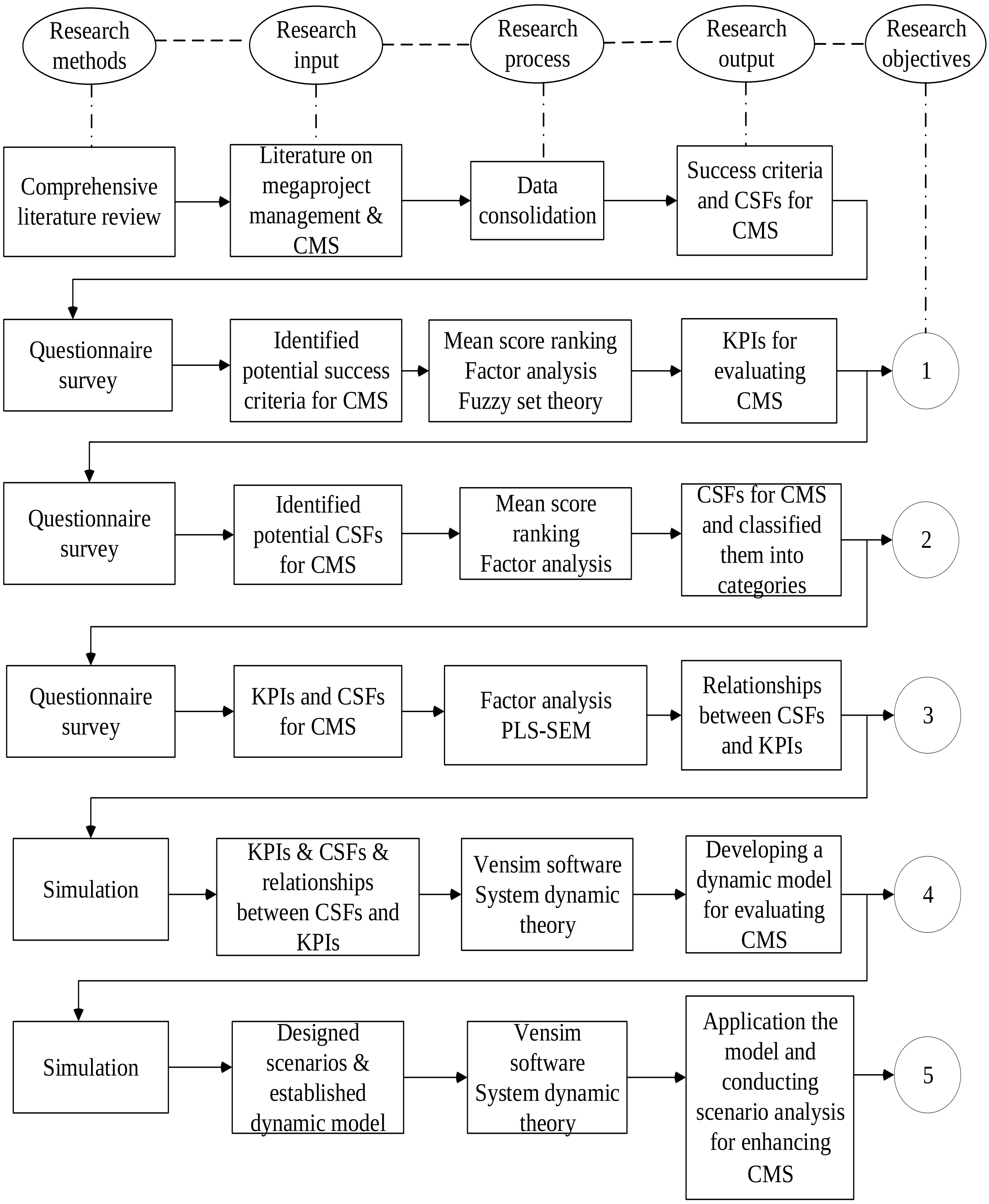

Figure 1.3 Research flow

1.5 Structure of the thesis

This thesis is divided into ten chapters:

Chapter 1: Introduction

This chapter outlines the framework of the thesis, including the research background, statement of the problems, research objectives, methodology, structure of the thesis and research significance and value.

Chapter 2: Literature Review: Gaps in Project Success Development

This chapter aims to provide a comprehensive and systematic investigation of project success in the field of construction and engineering management. A total of 164 relevant papers published in the last decade were reviewed. This chapter also lays a solid foundation for the identification of the research gaps.

Chapter 3: Literature Review: Success Criteria and Critical Factors for CMS

This chapter comprehensively reviews 38 renowned journal articles on success criteria and CSFs for CMS from 2000 to 2018. The identified success criteria and CSFs for CMS will be assessed in terms of the fitness in the success of construction megaprojects in this study. This chapter serves as the basis for the development of the survey questionnaire, which will be used for this study.

Chapter 4: Research Methodology

This chapter illustrates and presents a detailed description of the research methodology, including data collection and analysis methods. The research methods used in this study include the following: Cronbach's alpha technique, mean score ranking, analysis of variance, fuzzy set theory, factor analysis, partial least squares structural equation modelling (PLS-SEM) and SD model.

Chapter 5: KPIs for Assessing the Success of Construction Megaprojects in China

In this chapter, a questionnaire is designed on the basis of the potential success criteria and critical factors for CMS obtained through literature review and interviews in Chapters 2 and 3. A questionnaire survey, descriptive analyses, mean score ranking and factor analyses are used to explore the KPIs for CMS. The fuzzy set theory is also utilised to determine the final KPIs.

Chapter 6: CSFs for the Success of Construction Megaprojects in China

The survey is discussed in this chapter to investigate the CSFs for CMS in China. CSFs are selected according to the mean values of the importance of each factor and then classified into categories through factor analysis.

Chapter 7: Investigation of the Relationships between CSFs and CMS in China

The datasets collected from the survey are initially analysed through descriptive statics before examining using PLS-SEM to determine which CSFs are significantly associated with the KPIs.

Chapter 8: Establishing a Dynamic Model for Evaluating the Success of Construction Megaprojects in China

Basing on the results in Chapters 5, 6 and 7, the key variables and interrelationships in the CMS system are identified. A dynamic CMS evaluation model is then established using the Vensim software.

Chapter 9: Application of the SD-Based Model for Evaluating the Success of Construction Megaprojects in China

Several scenarios will be constructed and simulated using Vensim to identify the effective policy scenarios for the enhancement of the CMS degrees.

Chapter 10: Conclusions

This chapter will conclude the main research findings and discuss the limitations and implications of future research.

1.6 Research significance and value

Megaprojects are milestones of human history and are viewed as ‘privileged particles of the social and economic development’. From the Pyramid of Giza and the Great Wall of China to the Three Georges Dam and the Hong Kong-Zhuhai-Macau Bridge, history is decorated with an impressive array of megaprojects. A boom in the construction and investment of construction megaprojects is evident, but the unsatisfactory delivery performance (e.g. over budget, poor quality and safety issues) has not been addressed yet. No feasible models can be applied to guide the construction of megaprojects, which possess high complexities and uncertainties. Given China's burgeoning megaproject market and unique social, economic and cultural characteristics, a China-characterised CMS megaproject model should be urgently developed.

The significances and values of the proposed research lie in three main aspects: (i) extension of project success to megaproject success, specifically on the study of the multiple dimensions, KPIs and CSFs of CMS, which are expected to expand the theoretical project and megaproject management; (ii) identification of the relationships between the KPIs and CSFs of construction megaprojects. A clear understanding of such relationships will benefit the project control and improve the construction megaproject management; (iii) exploration and quantitative measurement of the dynamics, complexities and uncertainties in the CMS system from the perspective of system thinking and theory of systems engineering. System thinking provides managers insights into the interactions within the CMS system and helps control the overall success. Moreover, the SD model can simulate and explore effective managerial strategies for CMS, which will be beneficial in developing practical strategies and improving the performance of construction megaprojects in practice.

1.7 Chapter summary

This chapter summarised the framework and highlighted the significance and value of this study.

CHAPTER 2 LITERATURE REVIEW: GAPS IN PROJECT SUCCESS DEVELOPMENT[3]

2.1 Introduction

2.2 Review of project success

2.3 Research gaps in project success research

2.4 Chapter summary

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[3] This chapter is largely based upon the following publication:

Qinghua He, Ting Wang*, Albert P.C Chan, Hanzhang Li and Yangxue Chen (2019). Identifying the gaps in project success research: a mixed bibliographic and bibliometric analysis. Engineering, Construction and Architectural Management, 26 (8), 1553-1573, Doi: ECAM-04-2018-0181.

2.1 Introduction

This chapter conducts a comprehensive review of identifying the gaps in project success research. Definitions of project success and a retrospective look at the development of project success are discussed first. Finally, four underpinning concepts of this study, namely, megaproject success, project success in developing countries, relationships between CSFs and success outcomes, and dynamic evaluation of project success are highlighted. This chapter is important as it provides a solid foundation for identifying research gaps and research questions for this study.

2.2 Review of project success

2.2.1 Definition of project success

The concept of project success began in the 1980s, but there is no uniform definition of it (Ika, 2009). Researchers defined it from different perspectives which makes it difficult to assess and define the level of project success. For example, Tuman J. (1986) stated that the full use of resources and achievement of the desired goal define a successful project (He *et al.*, 2019a). By contrast, some researchers viewed project success based on the "Golden Triangle" of cost, quality, and schedule (Ika, 2009). For instance, Ashley *et al.* (1987) advocated that a successful project must meet expected goals in terms of cost, schedule, quality, and safety. Some researchers argued that assessment of project success needs a multidimensional thinking instead of based on the view of the "Golden Triangle" (Machado and Martens, 2015, Shenhar *et al.*, 2001). For example, the PMI stated that project management success is determined and assessed with respect to the project implementation phase, while project success is usually determined by the whole life cycle (Khan *et al.*, 2011).

One of presentative research work was conducted by Cooke-Davies (2002) who identified and distinguished three "levels" of success. This first level was project management success, is aimed to answer the question "was the project done right?" It was the dominant measure of project success in previous studies, and the main indicators included time, cost and quality which usually called the "Iron Triangle" (Pinto and Morris, 2004). Generally, at this level, the principle of success is simple, that is, to deliver the project so that it meets the objectives within the project constraints. However, this may not explicate the entirety of project management success. It is necessary to step to the second level of project success, which answers the question "was the right project done?" It was Wit (1988) who first distinguished the concept of project success and project management success. This level of project success is noted as one of the most preferred to the owners, developers or sponsors. Typically, it measures "value for money" (Pinto and Morris, 2004). There is no suggestion that project success is a "better" level of establishing success criteria. Both project success and project management success are important to any project. The next level is consistent project success, which is intended to answer the question "were the right projects done right, time after time?" The consistency mainly refers to be competitive in markets for scarce resources, such as customers (Pinto and Morris, 2004).

2.2.2 A retrospective look at the development of project success

Over the years, the literature and our understanding of project success keep evolving (Müller and Jugdev, 2012); thus, it is useful and meaningful to see how the area of project success develops. During the first period, namely Period 1 (1960s-1980s), the theoretical and empirical works were lacking (Belassi and Tukel, 1996). This epoch primarily focused on project management success, which only concentrated on the project implementation and delivery period and measured success based on the criteria of "Iron Triangle"(Ika, 2009). Time and cost were viewed as the most important criteria for measuring project success. This was understandable as the implementation phase was generally long and consumed the most resources (Jugdev and Muller, 2005). Meanwhile, quality as a key factor for determining project success remained a subjective criterion (Chan *et al.*, 2002, Jugdev and Muller, 2005). Near the end of this period, the literature indicated a gradual trend towards including client satisfaction as a variable in measuring project success (Shenhar *et al.*, 1997, Atkinson, 1999).

Period 2 begun from the 1980s to 1990s and was characterized by the development of CSFs list for project management. CSFs refer to the "elements required to create an environment where projects are managed consistently with excellence" (Kerzner, 1987).

In the year of 1986, Slevin and Pinto (1986) proposed a list of ten key success factors, including project mission, top management support, project plan, client consultation, personnel, technical tasks, client acceptance, monitoring and feedback, troubleshooting, and communication. This list enabled the project team to benchmark their projects' status, which improved the management of projects significantly. Pinto and Slevin (1988) then added four critical external factors, namely, characteristics of the project team leader, power and politics, environmental events, and urgency. These 14 CSFs were significantly related to the project success, and important to projects and their governance at the organizational level (Müller and Jugdev, 2012). During this period, although the "Iron Triangle" was still the most significant criteria for assessing success, the emphasis shifted project management success to project success, and different stakeholders' perspectives were considered into the measurement (Ika, 2009, Müller and Jugdev, 2012).

Period 3 (1990s-2000s) witnessed one significant contribution to the literature with the emergence of an integrated framework on project success (Jugdev and Muller, 2005). Morris and Hough (1987) pioneered the investigation of the preconditions of project success in the context of major projects. According to their research results, project success was grouped into four categories, including project functionality, project management, contractors' commercial performance, and project termination. Belassi and Tukel (1996) developed a holistic framework of CSFs and classified them into four groups, namely factors related to the project, factors related to the project manager and team, factors related to the organization, and factors related to the external environment. The classification of CSFs provided readers with a clear understanding of what category certain critical factors belong to and facilitated decision-makers and project managers to manage projects more effectively.

Additionally, at the end of this period, the literature indicated there was a trend of research on project success of specific types of projects instead of overall success. For example, Chan *et al.* (2002) established an assessment framework of Design and Build projects. The framework included two main categories of success criteria, objective measures, and subjective measures. Objective measures consisted of time, cost, health and safety, and profitability. Subjective measures included quality, technical performance, functionality, productivity, satisfaction, environmental sustainability.

During the Period 4 (2000s-current), scholars have a more in-depth understanding and more systematic research on project success. Project success dimension is argued to include benefits to the organization and preparing for the future, such as innovating, and developing core competencies (Jugdev and Muller, 2005). That is, we need to consider project success from a strategic perspective. Besides, systematic studies have been conducted to explore and portray the relationships between CSFs and success outcomes. It is worth noting that the literature shows an emerging trend of shifting project success to megaproject success (He *et al.*, 2019a). This emergence originated from the boom of investment and construction of megaprojects worldwide since the early 2000s (Hu *et al.*, 2015b). Flyvbjerg *et al.* (2003) stated that megaproject management faces many challenges, such as cost overruns, safety incidents, and quality defects. Thus, how to achieve successful management of megaprojects is a global challenge to both developing and developed regions.

2.3 Research gaps in project success research

This work adopted a mix bibliographic and bibliometric method to identify and assess the major outputs of project success research in construction engineering and management (CEM) published in peer-reviewed journals from 2007 to 2017. Based on the analysis of these articles, four research gaps were identified as follow.

2.3.1 Construction megaproject success

Most journal articles addressing project success in the field of CEM have focused on normal construction projects (He *et al.*, 2019a). However, rapid global urbanization has triggered an investment boom in construction megaprojects for both renewal activities in developed countries and new construction activities in developing countries (Le *et al.*, 2014b, He *et al.*, 2019a) . Since the early 2000s, megaproject management has become an emerging area in construction management (Hu *et al.*, 2015b)(Hu *et al.*, 2015b)(Hu *et al.*, 2015b). They do not simply represent magnified versions of normal construction projects, but have their own unique characteristics (Flyvbjerg, 2014).

Obviously, megaproject management is a big challenge worldwide. Considering the characteristics of megaprojects significantly distinguish them from normal-size projects, thus they require a new approach to ensure success. Therefore, it is of great value to emphasize project success within the field of megaprojects in future research. This specific target area should cover criteria or dimensions that reflect and indicate megaproject success, critical factors in the success of megaprojects (He *et al.*, 2019a).

2.3.2 Project success in developing economies

During the past few decades, in developed countries such as the United Kingdom a lot of effort has been devoted to solving obstacles to project success and strategies in construction practice. However, in developing regions, these factors that increase the probability of success of construction projects have not been fully addressed. Additionally, institutional differences are likely to result in errors in the application of project success theories or may require more region-specific strategies. In China, for example, organizations of construction megaprojects usually adopt a centralized leadership strategy. This kind of mode can guarantee megaprojects to be performed with high efficiency (Le et al. 2014). This situation obviously differs from that in western countries (Hu *et al.*, 2015a). Therefore, suggestions for research implications include that identify differences in the criteria and CSFs in developed and developing areas, identifying the barriers and strategies for project success in developing countries.

2.3.3 Relationships between CSFs and project success

CSFs are one of the hottest project success subtopics in the construction project field. Generally, existing studies that have addressed the issue of trust (Jiang *et al.*, 2016) and stakeholder management (Rowlinson and Cheung, 2008) in project success have facilitated a better understanding and management of factors that contribute to a project's success in practice. Research outcomes on how CSFs affect project goals can provide decision-makers and managers to manage projects efficiently. A lack of overall understanding or systematic investigation of CSFs that contribute to project success hinders real-world practice (Locatelli *et al.*, 2017a). Although some key factors regarding project success outcomes have been studied, exploration is still needed that links the correlation of and possible causation by CSFs with project success (Locatelli *et al.*, 2017d).

In addition, previous studies usually adopted methods like the Delphi approach to identify factors and rank their importance to project success, whereas computer-based methods could be emphasized to facilitate data collection and analysis. Hence, future research considerations should ask: What are the relationships between CSFs and project success? Might there be a more robust method by which to conduct this research?

2.3.4 Dynamic evaluation of project success

There are some existing studies on evaluating project success, but they normally to view from the static perspective rather than a dynamic viewpoint. However, construction projects are complex and dynamic. Complex refers to that they are composed of multiple interrelated feedback systems and the dynamic in the sense that states of these systems are always changing. Thus, it is necessary to consider the dynamic characteristics in order to understand and measure the project success from a holistic perspective especially for megaprojects which are have a very long-life cycle.

2.4 Chapter summary

This literature review conducted a comprehensive assessment of project success in the context of the construction and engineering management, which reviewed a total number of 164 relevant papers published in the past decade. This chapter is really important as it provided a solid foundation for identifying research gaps in the body of knowledge that this research aims to address. Based on the comprehensive literature review, research questions and research gaps for this study were identified eventually.

CHAPTER 3: LITERATURE REVIEW-SUCCESS CRITERIA AND CRITICAL FACTORS FOR CONSTRUCTION MEGAPROJECT SUCCESS

3.1 Introduction

According to the research implications identified in last chapter, a comprehensive literature review on identification of success criteria and critical factors for CMS conducted in this chapter. Theoretical basis, including definitions of construction megaprojects and performance of construction megaprojects is introduced first. Then, 38 relevant journal articles published between 2000 and 2018 are selected to conduct this comprehensive literature review. Finally, a total of 20 success criteria which grouped into four dimensions and 33 CSFs are identified. The chapter provides lists of potential success criteria and critical factors that are crucial to developing the questionnaire for this study.

3.2 Review of construction megaprojects[4]

3.2.1 Definition of megaproject

The term "megaproject" has no standardized definition, but can be defined as "large-scale, vast investments that typically cost one billion dollars or more, take many years to build, involve many stakeholders, and impact millions of people" (Flyvbjerg, 2014). While the term "mega" means great, large, vast, big, high, tall, mighty, or important,

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[4] Section 3.2 and 3.3 are largely based upon the following article:

Ting Wang*, Albert P.C Chan, Qinghua He and Junyan Xu (2020). Identifying the gaps in construction megaproject management research: A bibliographic analysis. *International Journal of Construction Management,* Doi: 10.1080/15623599.2020.1735610. (Accepted) the use of terms “Giga”, “Tera” and “Peta” are used to classify projects relatively bigger than megaprojects (Flyvbjerg, 2014). Additionally, in academic publications, other words used to connote megaprojects mainly include “major projects”, “complex projects”, “large-scale projects”, “large projects”, “public works projects”, “transportation infrastructure projects”, “public construction projects” and “Tera, Giga, giant project and program” (Volden and Samset, 2017, Hogle and Moberg, 2014, Cantarelli, 2011, Hu *et al.*, 2016).

Other than the three primary constructs, including project size, cost and duration used to define megaprojects, some researchers explicated megaprojects from the viewpoint of project complexity. For example, Caldas and Gupta (2017) pointed out that megaprojects can be defined as projects with any of the following complexity criteria, including many stakeholders, numerous interfaces, challenging project location, inadequate resources, new technologies, potential regulatory constraints, extensive infrastructure requirements, geographically and culturally dispersed teams, and significant institutional influences. In addition, the different social, economic and cultural environment could lead to different definitions of megaprojects. The Federal Highway Administration of United States defined megaprojects as “major infrastructure projects that cost over one billion dollars or projects with a significant cost that attract a high level of public attentions or interests since their substantial direct or indirect impacts on the community” (Greiman, 2013b). Megaproject can also be defined as "initiatives that are physical, very expensive, and public"(Altshuler and Luberoff.D, 2003). In China, major national projects usually involve government-funded projects approved by the National Development and Reform Commission, with a total investment of RMB 5 billion (approximately USD 0.7 billion)[5]; thus, Hu *et al.* (2015b) pointed out that 0.01% of GDP could be viewed as a reasonable criterion to define megaprojects. Sykes (1998) pointed out nine characteristics that distinguish megaprojects from other large-scale but less complicated projects. They are (1) project size and likelihood of multiple owners; (2) public opposition due to possible social, economic, political, and environmental impacts; (3) time, including decision-making, design, finance and build; (4) located in remote/inhospitable areas; (5) potential to destabilize markets due to the demand on labor and suppliers; (6) unique risk; (7) financing difficulties; (8) insufficient experience; and (9) career risks. Although most megaprojects could contain the nine characteristics mentioned above, there are still some exceptions.

3.2.2 Definition of construction megaproject

As stated by Sheng (2018), megaprojects can be divided into three types, namely scientific and technological megaprojects, military and national defense megaprojects,

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[5] One RMB is approximately equal to 0.14 US dollars.

and construction megaprojects. Scientific and technological megaprojects refer to those projects which focus on exploring the scientific rules or achieving major technological breakthroughs, such as material microstructure study projects. Military and national defense megaprojects are with the aim to the research and development of weaponry and military equipment. The National Missile Defense system developed by the USA is one of the presentative military and national defense megaprojects. Construction megaprojects refer to those permanent constructions, equipment, facilities and the services they provide for people's living and social production. The primary purpose of this type of megaprojects is to improve people's lives and facilitate social development.

Comparatively, construction megaprojects are more closely related to people's livelihood. Although there are no standardized definitions of such projects, the following significant characteristics of these projects can be suggested as the descriptive definition of them (Sheng, 2018).

(1) Normally, the government or the state is the major investor and decision-maker for these projects. That is, the government or the state often plays a leading role in the process of decision-making, planning and construction, such as whether the project should be funded (Cairns, 2004).

(2) This kind of projects generally have huge construction scale. Taking the Three Gorges Dam as an example, this megaproject costed a gross investment of RMB 332

billion with a total construction period of 17 years (around USD 46.86 billion)[6] (Wang, 1999).

Figure 3.1 The pictures of Qinghai-Tibet Railway

(3) Construction megaprojects are often located in complex environmental conditions. For example, the main part of Qinghai-Tibet Railway (shown in **Figure 3.1**) is located in the Tibetan Plateau which is known as “the roof of the world” (Sun, 2005).

(4) Construction megaprojects are characterized by their huge and far-reaching impacts on the social and economic developments in regional or national level (Flyvbjerg, 2007).

(5) These projects usually have long life cycles. The reasons leading to this phenomenon would be various, including vast construction scales, complex construction conditions, very long period from the initial design to the final completion

[6] One RMB is approximately equal to 0.14 US dollars.

etc.

(6) Various partnerships are involved in the implementation of construction megaprojects (Sheng, 2018).

In summary, construction megaprojects are defined in this research as complex, embedded in institutional frames and large-scale sociotechnical undertakings that cost over 1 billion RMB (Chinese currency) (Zheng et al., 2019).

3.2.3 Definition of construction megaproject success

Megaprojects are totally different from normal projects. They are completely different in terms of their level of project aspiration, delivery time, complexity and stakeholders involvement (Flyvbjerg, 2014). Consequently, it is necessary to take a broader perspective of project success when evaluating megaprojects (Jonas Söderlund *et al.*, 2017). As a result, using only the "Iron Triangle" indicators as the yardstick for evaluating megaprojects will not enough (Lehtonen, 2014). For instance, compared to normal construction projects, one of the main characteristics of CMS that stands out in extant literature is its huge impact on society. According to Shenhar and Holzmann (2017), this indicator draws the thin line between megaprojects and regular projects. In some studies, the impact on society can be interpreted and expressed as the social harmony in the context of construction megaprojects (Yan *et al.*, 2019). Meanwhile, the social harmony primarily examines the CMS from the considerations of satisfying both the government and the public. The reason could be that, for such projects, project leaders and teams would like to invest more resources to maintain a harmonious relationship with the community, rather than only focus on maximizing economic benefits, which could in turn enhance corporate reputations and increase future business opportunities (Yang *et al.*, 2018). Another reason for social harmony could be determined by project goals and visions. For example, the Qinghai-Tibet Railway was constructed partly with the vision of promoting national unity and social stability (Li *et al.*, 2018)

3.2.4 Performance of construction megaprojects

Although the rapidly increasing number of megaprojects has been invested and constructed worldwide, the performance of megaproject management and delivery are not always satisfactory. According to the work done by Merrow (2011), majority of 318 industrial megaprojects were considered as failures if they all were comprehensively assessed against the requirements of schedule, budget, and benefits in the operation phase. Similarly, according to the research results of Flyvbjerg (2017), nine out of ten megaprojects are subject to bad cost overruns. This poor performance in megaproject delivery so-called "megaproject paradox" was first identified by Bent as well

Figure 3.2 illustrates the overrun rate of 22 megaprojects in the world, and the average rate was as high as 140%. The overruns of construction megaprojects are universally international phenomena and this problem in developing countries are more serious than those in developed countries (Flyvbjerg *et al.*, 2003). In China, taking the major bridge projects as an example, the statistics of cost overruns of typical projects are shown in **Table 3.1**.

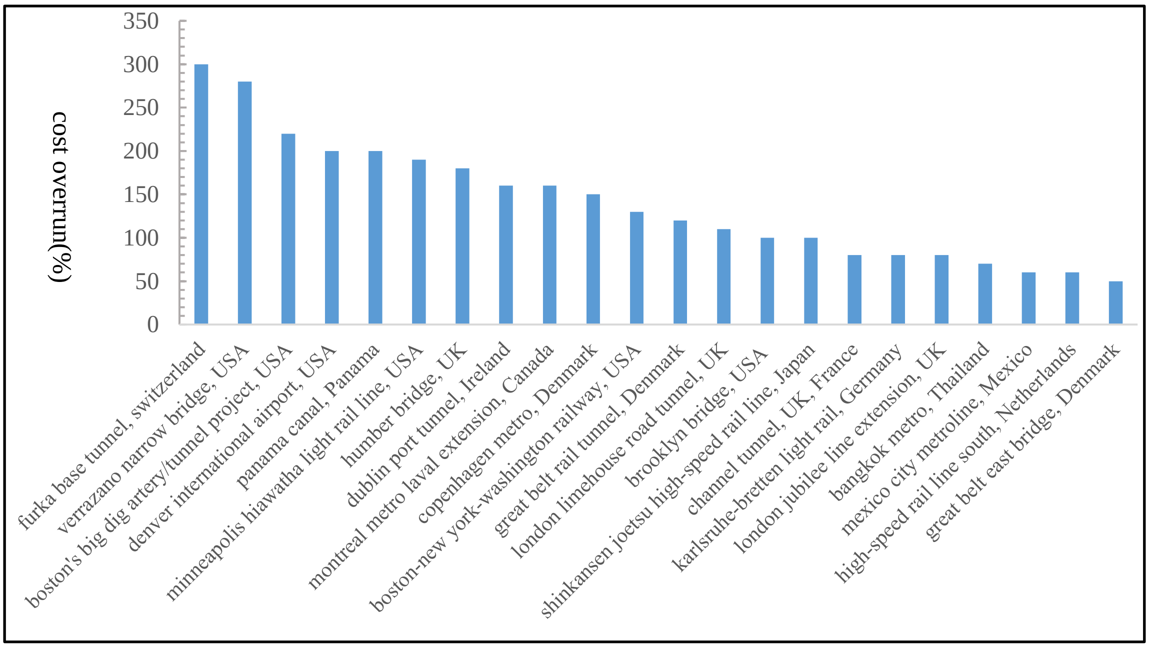

Figure 3.2 Overrun rate of 22 megaprojects worldwide (Flyvbjerg, 2017)

Table 3.1 Typical cost overrun cases of major bridge projects in China (Sheng, 2018)

No.	Project name	Estimate	Budget	Final cost	Overrun rate (%)
1	Langqi Bridege over Minjiang River	19.60	NA	22.56	15.10
2	Aizhai Bridge	7.20	NA	15.00	108.33
3	Jiangyin Bridge	NA	20.87	27.30	30.82
4	Taizhou Bridge	89.90	NA	93.70	4.23
5	Jiaozhou Bay Bridge	NA	90.40	100.00	10.62
6	Hangzhou Bay Bridge	NA	117.60	134.50	14.37
7	Jiaxing-Shaoxing Bridge	NA	62.50	63.50	1.60
8	Xiamen Zhangzhou Bridge	30.00	NA	47.10	57.00
9	Longjiang Bridge in Tengchong	NA	14.60	18.00	23.29
10	Man’anshan Bridge	NA	60.00	70.80	18.00
11	Nanpu Bridge	NA	14.00	21.50	53.57
12	Xupu Bridge	7.30	NA	20.00	173.97
13	Yangpu Bridge	13.20	NA	14.53	10.08
14	Shanghai Donghai Bridge	NA	70.00	110.00	57.14

*Note: the unit is 0.1 billion RMB; NA refers to non-available

Similar with cost overrun, delay is another common issue in construction megaprojects. Currently, some researchers have investigated the reasons why megaprojects usually fail into the dilemma of cost overruns and delays. For example, Flyvbjerg (2014) stated four major points, including 1), technical factors, which refers to poor project design, uncertainty and inappropriate organizational structure; 2) psychological factors, such as cognitive bias and cautious attitudes towards risk; 3) underestimation of costs, mainly caused by strategic misrepresentation; 4) poor financing/contract management. And the underestimation of costs and psychological aspect are considered as the major reasons. Chinese scholars have identified three main causes in the context of China, namely (1) variations; (2) increased compensation and other fees for land use, house removal and resettlement; (3) increased price of goods (Wang *et al.*, 2008). Moreover, project environment (Locatelli *et al.*, 2017b) and project complexity (Bjorvatn and Wald, 2018) could also be closely related to the performance of megaproject management.

3.3 Review process

3.3.1 Selection of target articles

To fully review and analyze the findings of relevant studies, a methodical and systematic analysis of publications in academic journals is necessary. A similar methodical and systematic approach adopted by Ke *et al.* (2009) and Yu *et al.* (2018) was adopted in this study to realize the stipulated aim as objectives of this research. **Figure 3.3** presents a flowchart of the methodology of the review process. The entire research process and methodology involved in this study are discussed in the subsequent sections.

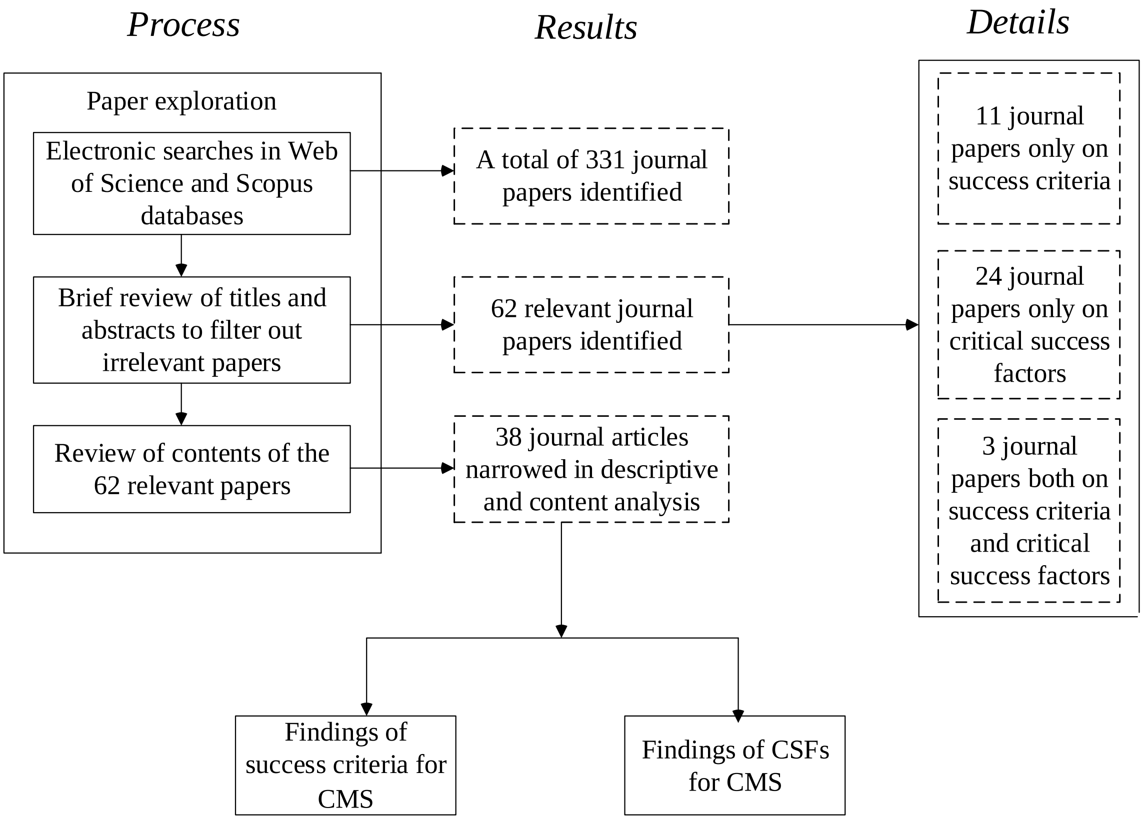

Figure 3.3 The research framework for this review (Zhang *et al.*, 2019)

Authors conducted a comprehensive literature review using two academic databases, namely Web of Science and Scopus. These two electronic search engineers are the world's largest web sources of peer-reviewed literature and have already demonstrated as robust tools to facilitate the review work, such as the previous review publications of Zheng *et al.* (2016) and Hu *et al.* (2015b). According to the Section of definitions of MICP, the following full search codes were selected, TITLE-ABSTRACT-KEYWORD ("success" OR "successful") AND TITLE-ABSTRACT-KEYWORD ("megaproject" OR "megaprojects" OR "major project" OR "major projects" OR "complex project"

OR "complex projects" OR "large project" OR "large projects" OR "large-scale project" OR "large-scale projects" OR "public works project" OR "public works projects" OR "transportation infrastructure project" OR "transportation infrastructure projects" OR "public construction project" OR "public construction projects" OR "Tera, Giga, giant project and program" or "Tera, Giga, giant projects and programs"). Meanwhile, only peer-reviewed journal articles published from 2000 to 2018 were considered in this study. The time period of literature review in this chapter is wider than that in the last chapter. The reasons would lie in two parts. First, Hu *et al.* (2015b) stated construction megaprojects have become an emerging area in the field of construction engineering and management since the early 2000s. Thus, in the review of success criteria and CSFs in the context of construction megaprojects, the author started from the year of 2000. Second, according to the initial search of target articles, the relevant publications were very limited. Thus, the author selected a wider time period, namely, from 2000 to 2018 instead of 2007 to 2017 in the review process of success criteria and CSFs in this chapter.

The first round of search identified a total of 331 journal articles. Afterwards, two main criteria were considered in the second round of paper selection. The first criteria focused on the retrieval at papers mainly on construction megaprojects. Thus, papers not related to this kind of projects, such as IT projects, were excluded. The second criteria centered on papers that had reported on the success criteria and CSFs. Thus, following the two filtering criteria, a total of 62 relevant journal articles were regarded valid for filter examination. The following stage involved a deep review of the contents of the selected papers to discard irrelevant papers. The search result was narrowed to 38 papers eventually, including 11 journals articles on success criteria, 24 papers on CSFs and 3 articles both on success criteria and CSFs. The detailed information on selected articles can be seen in **Appendix A.**

3.3.2 Contributions assessment

The articles identified were subjected to the content analysis to analyze the annual trend of publications, distributions of publication sources, contributors' origin/country, regions/countries of research focus, findings from the publications and involved methods. In this study, a widely adopted formula, as proposed by Howard *et al.* (1987) was employed. The formula is used to score the contributors from different countries (or regions) and institutes (or universities) in a multi-authored paper, as shown in equation (3.1). This formula assigns scores based on the assumption that the actual contribution of authors in a multi-authored paper varies. The formula assumes that the first author contributes more than the second one, and so on (Antwi-Afari *et al.*, 2018). Previous review articles that adopted this formula to identify research trends or directions in the construction engineering and management area have already confirmed its suitability and reliability, such as the work done by Hong *et al.* (2012) and Zheng *et al.* (2016).

$$\text{Score}=\frac{1.5^{n-i}}{\sum_{i=1}^{n}1.5^{n-i}} \quad (3.1)$$

where n is the number of authors in the article, and i is the order of the specific author.

Table 3.2 shows details regarding the scoring matrix

Table 3.2 Scoring matrix for multi-author articles

	Order of specific authors				
Number of authors	1	2	3	4	5
1	1.00	-	-	-	-
2	0.60	0.40	-	-	-
3	0.47	0.32	0.21	-	-
4	0.42	0.28	0.18	0.12	-
5	0.38	0.26	0.17	0.11	0.08

3.4 Discussions of bibliographic analysis on success criteria and critical factors

3.4.1 Discussions of annual publications

Figure 3.4 shows the annual number of the selected publications. The figure reveals a significant increase in yearly publications between 2004 and 2018. It is worth noting that the figure only illustrates years with publications in this study. As illustrated in the figure, during the selected period of 2000 to 2018, the number of publications shows an increasing trend from one article in 2004 to seven articles in 2018. The result indicates the gradual rising of interest in exploring the ways of delivering successfully.

It is also not surprising to note that data as after the 2008 global economic crisis, many countries implemented a series of economic stimulus policies, especially on the investment and construction of mega infrastructures. Hence, greater efforts were expended on the research of effective and successful delivery of such megaprojects. According to the research results between 2000 and 2010, only four journal articles were published on success criteria and CSFs, which reveals that during these years, research on construction megaprojects was at the infancy stage. However, after 2010, 34 journal articles were published on success criteria and CSFs; this also indicated the continuous increase in research efforts on construction megaprojects between these years. The results, however, reveals the likelihood of an increase in the research of the subject matter (Garemo *et al.*, 2015). Thus, spurring more studies on the success of such projects for implementing future projects.

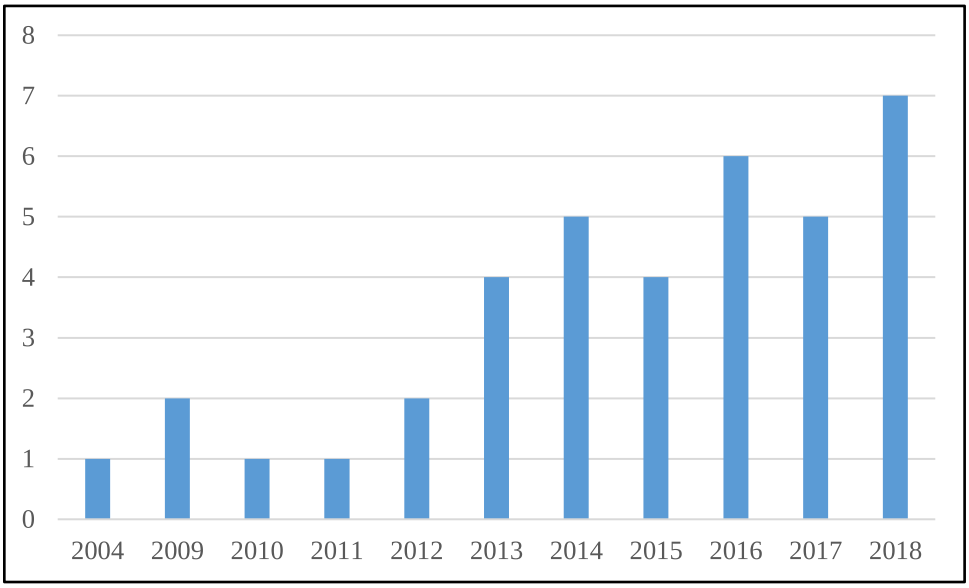

Figure 3.4 The annual number of relevant publications from 2000 to 2018

3.4.2 Discussions of the distribution of selected journals

The number of selected articles published in the 22 journals between 2000 and 2018 is presented in **Table 3.3.** According to the statistics presented in table, the first six journals published the highest number of publication within the selected period, namely International Journal of Project Management, Journal of Management in Engineering, Journal of Construction Engineering and Management, Project Management Journal, Construction Innovation, and Engineering, Construction and Architectural Management. In all, 22 papers were published by the leading six journals representing approximately 58% of the total selected papers. The list of identified journals can be regarded as a source to publish and acquire success criteria and CSFs.

Table 3.3 Distribution of selected journals

No.	Journal	Number of selected papers
1	International Journal of Project Management	7
2	Journal of Management in Engineering	5
3	Journal of Construction Engineering and Management	3
4	Project Management Journal	3
5	Construction Innovation	2
6	Engineering, Construction and Architectural Management	2
7	Environmental Management	1
8	South African Journal of Industrial Engineering	1
9	International Journal of Managing Projects in Business	1
10	Research in Transportation Economics	1
11	Evaluation and Program Planning	1
12	Journal of Business Research	1
13	Civil Engineering Journal	1
14	International Business Review	1
15	California Management Review	1
16	Progress in Planning	1
17	Proceedings of the Institution of Civil Engineers: Municipal Engineer	1
18	Journal of Performance of Constructed Facilities	1
19	Australian Journal of Civil Engineering	1
20	Urban Policy and Research	1
21	Construction Economics and Building	1
22	Management, Procurement and Law	1
	Total	38

3.4.3 Discussions of authors' origin/country contribution

Following the papers' distribution in the identified journals is the contributions by countries. The result of the contributions is presented in **Table 3.3.** As shown, Australia, USA, the U.K., mainland China and Hong Kong with scores of 7.27, 5.12, 4.81, 3.52

and 2.27 respectively. Thus, representing the top five with the highest number of researchers contributing to the studies of criteria and CSFs for construction megaprojects from 2000 to 2018. In Australia, 19 researchers from 8 different research centers have contributed to 11 journal articles. Similarly, in the USA, the U.K. and China, 14 researchers from 10 research centers have published 10 papers, 15 researchers from 7 research centers have published 7 papers and 12 researchers from 7 different research centers have published 8 papers respectively. While in the Hong Kong, 5 researchers from 2 research centers have only published two journal articles on success criteria and CSFs, ranking the fifth place with a score of 2.27. The statistics from **Table 3.3** indicate a wide distribution of papers across many countries, revealing a greater level of interest in studying the success criteria and CSFs from researchers around the world. However, it is noticeable that China is the only country in the Top 5 list from the developing context, indicating that contributions from researchers in the developing countries are very low.

Table 3.4 Authors' origin/country contribution on target studies

No.	Country/region	Research centers	Number of researchers	Publications	Scores
1	Australia	8	19	11	7.27
2	USA	10	14	10	5.12
3	U.K.	7	15	7	4.81
4	China (mainland)	7	12	8	3.52
5	Hong Kong	2	5	2	2.27
6	Singapore	1	4	1	1.6
7	Norway	1	2	1	1.47
8	France	1	1	2	1.2
9	United Arab Emirates	2	4	2	1.2
10	Netherlands	1	1	1	1
11	South Africa	2	2	2	1
12	India	2	2	2	1
13	Spain	2	4	2	1
14	Malaysia	1	2	1	1
15	Italy	1	2	1	0.43
16	Finland	1	1	1	0.42
17	Vietnam	1	1	1	0.42
18	Israel	1	1	1	0.4
19	Thailand	1	1	1	0.32
20	Serbia	1	1	1	0.12

3.4.4 Discussions of analysis of selected publications by country or region focus

The analysis of the number of publications in a research area in a country or region can be viewed as an indicator of which academic and industrial practices progress in that place (Osei-Kyei and Chan, 2015). To identify countries or regions with the most relevant publications, a simple counting method was employed to carry out the research results (shown in **Figure 3.5**). It is worth noting that publications with a research focus in more than one area were considered as 'International'. Besides, four articles could not identify the specific area of focus. Thus, they were noted as 'Non-Available'.

As illustrated in **Figure 3.5**, the top five areas of the main focus of the selected publication were China, Australia, United Kingdom, Thailand, and Iran apart from the areas regarded as 'International' and 'Non-Available'. The number of publications of abovementioned areas was 5, 3, 2, 2, and 2 respectively. It is not surprising that China revealed to be the leading country for relevant publications. This is mainly owed to China's leading performance of investment and construction of mega infrastructure projects in the past few decades. Especially, after four trillion RMB economic stimulus plan in 2008 and the "Belt and Road" program in 2013, which mainly focus on infrastructure construction and significantly spurred researchers to conduct studies on success criteria and CSFs (Le *et al.*, 2016b). Australia is one of the leading countries according to the results as well. It also echoes with the findings of English (2006) and Osei-Kyei and Chan (2015) who stated especially since the rebirth of the Build-Own-Operate-Transfer to Design-Build in the year 2000; there was impressive progress in the Australian construction market. Meanwhile, explorations of success criteria and CSFs with case studies indeed provided practitioners with insightful practices. Additionally, it cannot be ignored that most articles, with the number of 9, focus on international rather than being one country or region specific. Studies involved in the 'International' mainly were case studies, such as the study of Lopez del Puerto and Shane (2014). Although researchers pointed out the difference of contextual environment, such as social, economic and cultural backgrounds in megaproject studies cannot be ignored (Hu *et al.*, 2015a), successful experience and practices still can be learned worldwide.

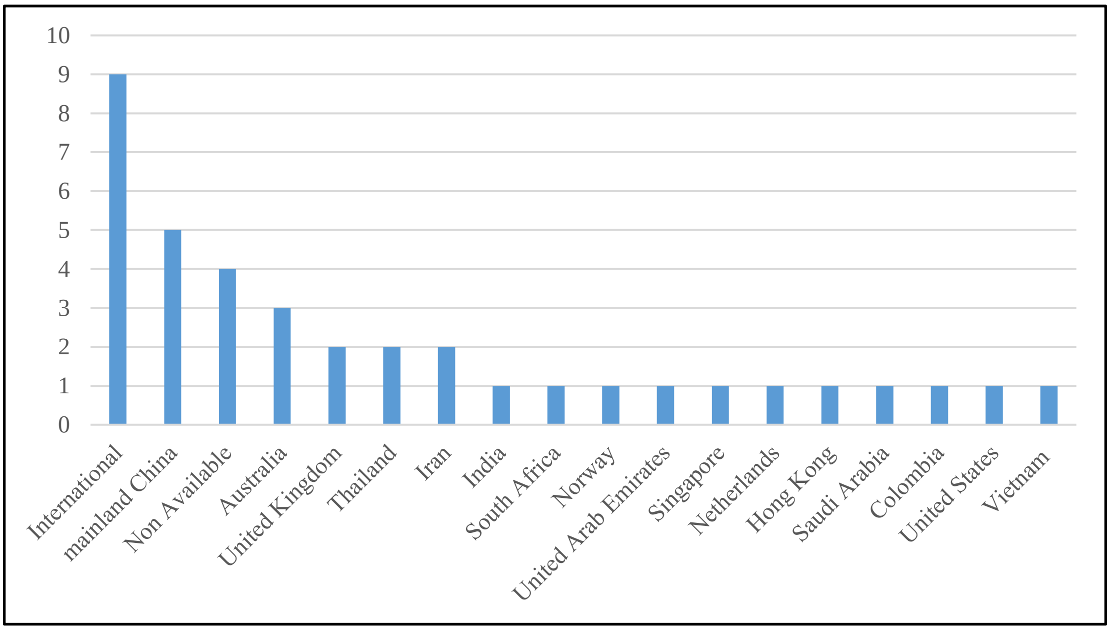

Figure 3.5 Selected publications by country or region focus

3.5 Findings from previous studies on success criteria and critical factors

After a comprehensive review and analysis of the 38 publications, the summary of findings is presented in **Figure 3.6** (findings of success criteria) and (findings of CSFs) respectively. The total number of criteria identified from 14 articles is 20 and classified into four dimensions. And the number of CSFs identified from 27 articles is 33. The factors captured under the success criteria construct and the CSFs were ranked according to the accumulated number of citations in the identified journals. It is noted that considering the limited studies on success criteria and CSFs for construction megaprojects, even the criteria or factor that only mentioned once was not excluded.

3.5.1 Analysis of findings from previous studies on success criteria

Project success criteria refer to the use of a group of principles or standards to determine or judge project success. While megaproject contributes enormously to global investment and construction, it is still for being susceptible to bad cost overruns and delays (Love *et al.*, 2015, Love *et al.*, 2016). All megaprojects may be argued to be unsuccessful if the threshold for assessing their success is attributed to the traditional measurement criteria, such as on time, on budget, on specifications (Pitsis *et al.*, 2017). Thus, there is a need to explore success criteria and CSFs for construction megaprojects (Shenhar and Holzmann, 2017). Yan *et al.* (2019) pointed out that four dimensions of CMS, including organizational strategic goals, construction program performance, social harmony, and project stakeholders' satisfaction should be highlighted. Similarly, Turner and Xue (2018) defined four levels of CMS. The first level was called megaproject management success which refers to delivering output with desired functionality and performance within a defined timeframe, cost and other requirements. The second level was megaproject success level 1A, meaning the project should deliver the desired outcome. Then followed by megaproject success level 1B, referring to delivering positive net present value, that is, the project should make profits. The fourth level refers to megaproject success level 2 and it is often characterized by meeting the desired business or public need.

The findings regarding the success criteria for CMS was presented in Figure 3.6. As mentioned, the indicators are captured under four categorical construct and then the constructs are employed to develop the framework of the study. Obviously, the framework included four circles representing the four dimensions of the CMS, and the number after each criterion indicated the accumulated number of times mentioned in the selected publications. The inner construct represented the most fundamental dimension summarized as ‘project efficiency’ in this study. At this level, three criteria were identified, namely meeting the ‘Iron triangle’, meeting safety goals and meeting regulations and specifications, with their frequencies as 11, 3 and 2 respectively. The second construct was defined as ‘stakeholders' satisfaction’, with 6 criteria, namely: a) public satisfaction (7 times mentioned), b) delivering publicly needed value or services (6), c) owner’s satisfaction (3),d) government satisfaction (3), e) establishing good cooperation & relationships and f) other stakeholders’ satisfaction (1). The third construct was called “organizational strategic goals” which also encapsulated 6 criteria, namely: a) new technologies (4), b) benefits or profits realization (4), c) increased market share (3), d) new organizational capability and competency (3), e) improved brand/reputation (2) and f) building standards and nurture experts (1). The final construct was ‘impact on society’. The indicators captured under this construct included delivering social-economic benefits to the community (6), sustainability in the environment (4), society and economy, maintaining social cohesion or society harmony (2), meeting audit regulations and transparency (2) and job creation (1).

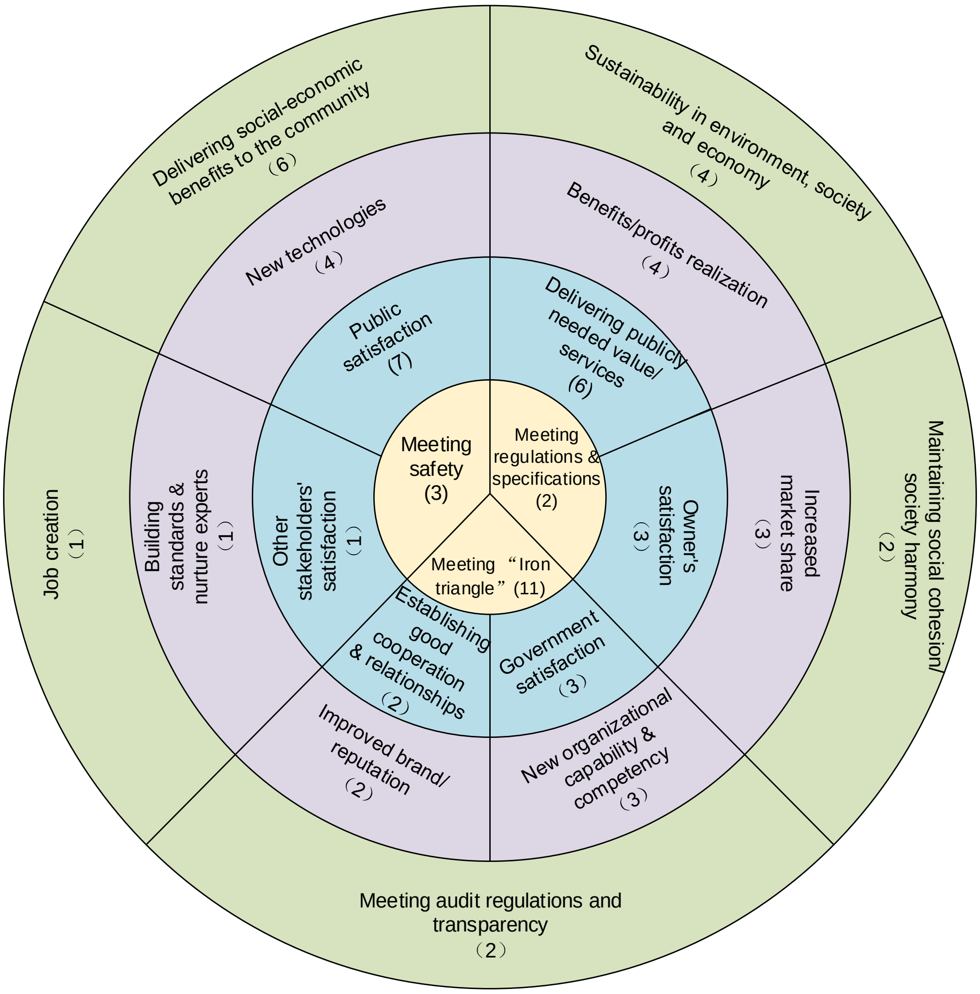

Figure 3.6 Findings from studies on success criteria for CMS from 2000 to 2018

(Summarized by the author)

As discussed above: project success and CMS in this study, Cooke-Davies (2002) identified three levels of success in project success studies. The first was project management success, the second was project success and the third was consistent project success. The framework presented in this study can be interpreted by the abovementioned three success levels. The 'project efficiency' is interpreted as project management success, and the second dimension 'stakeholders' satisfaction' can correspond with project success, the third dimension is interpreted as ‘organizational strategic goals’ and fourth dimension ‘impact on society’ can be interpreted as consistent project success. Additionally, these four dimensions should not be considered in isolation. As suggested by Yan *et al.* (2019), a system thinking can help to avoid optimizing one success dimension that causes failure in other dimensions, so that overall success would be realized.

Moreover, according to the frequency of each criterion, the top four were (1) meeting the ‘Iron triangle’, (2) public satisfaction, (3) delivering publicly needed value or services, and (4) delivering socio-economic benefits to the community. The ‘Iron triangle’ was revealed as the most mention. This criterion was highlighted by 14 publications. In short, the result indicated that the ‘Iron Triangle’ criteria (time, cost and quality goals) played the basic role of measuring the megaproject management success. The reason could be that there is always disappointing megaproject performance, such as cost overruns and delays in megaproject construction (Love *et al.*, 2015), thus, fundamental ‘Iron triangle’ criteria was still highlighted in studies of CMS. This was succeeded by the ‘public satisfaction’ criteria which ranked second place. Construction projects bring about socio-economic benefits. However, it is also known for some negative impacts at the same time, such as significant noise, dust, and waste generation. Hence, engaging in the quest for public satisfaction is noted as a critical criterion to the smooth construction of projects. Apart from negative impacts mentioned above, construction megaprojects usually involve the large-scale land acquisition or even immigration work which also pose huge negative impacts on the on the well-being of the public (Jia *et al.*, 2011, Liu *et al.*, 2016). Additionally, the large sum of monies expended on megaprojects are often generated from tax revenue from taxpayer. Thus, it is not surprising that the criteria of public satisfaction played the second important role in measuring CMS.

Delivering publicly needed value or services ranked third place among of all the 20 criteria. Kessides (1993) asserted that the benefits of construction megaprojects for economic development and well-being of the public come largely from the services provided by the project asset rather than from the asset itself. For instance, the high-speed railways essentially provide commuting, transporting, business and leisure, and travel services. Therefore, if construction megaprojects cannot provide good value and services to the public, then it may be considered unsuccessful (Chang *et al.*, 2013). The 'delivering of social-economic benefits to the community' was as important as the 'delivering publicly needed value/services' according to the research results. Flyvbjerg (2014) used to introduce four driving factors to the development of megaprojects, namely technological, political, economic and aesthetic factors. Besides, Frey added the 'community pride' criterion, which refers to "everyone loves to tell stories about the big things their community accomplished and to make this particular community is superior to all others" (Jonas Söderlund *et al.*, 2017). For example, the Sydney Opera

House did not only become a symbol in Sydney city, but it attracts thousands of visitors every year which brings huge profits to the community.

3.5.2 Critical factors for construction megaproject success

CSFs, first proposed in 1979 (Fortune and White, 2006), and could refer to a list of factors that could be necessary for a project to get a favorable result (Martin, 1982). In project management research, during the past few decades, many studies have been done to explore CSFs for project success.

Compared with the research of CSFs in the context of normal construction projects, existing studies on CSFs for CMS are relatively limited. For example, Lopez del Puerto and Shane (2014) studied cases in Mexico and United States, and identified four common critical factors to success. They are (1) early agency agreements and commitments; (2) understanding about the cultural and socio-political circumstances; (3) public outreach and (4) recognition of circumstances that have an impact on the project. Klakegg *et al.* (2016) investigated cases in three countries (United Kingdom, Norway, the Netherlands) and pointed out project governance played a critical role in reducing cost overruns. Additionally, Caldas and Gupta (2017) mainly used the questionnaire survey to quantitatively examine the frequency and impact levels of these factors. And a total of 34 factors were identified and divided into five categories eventually. Shenhar and Holzmann (2017) stated that successful megaprojects are distinguished by three major elements: clear strategic vision, total alignment, and adapting to complexity.

Table 3.5 shows the findings from previous publications on CSFs for CMS between 2008 and 2018. They are divided into four categories by the authors, including project-related factors, project participants-related factors, economic and managerial factors, and external factors. It is observed that a total of 33 factors account for successful construction megaprojects, however, the top five factors were adequate resource availability, partnering/relationships with key stakeholders, adequate communication and coordination among related parties, public support or acceptance, and clear strategic vision, with their frequencies as 9, 8, 7, 7, 6 respectively.

- Project-related factors

The group of project-related factors includes a total number of seven CSFs, namely clear strategic vision, aligned perceptions of project goals and success, clear goals, effective strategic planning, project size, accurate project identification, and project technical feasibility, and project organization structure, with their respective frequencies as 6, 5, 5, 4, 3, 3, 1. In this category, clear strategic vision was mentioned by six publications. A vision can be defined as a simple and exciting expression of project results. The strategic part refers to the establishment of the desired long term goal which is expected to have a lasting impact beyond its immediate outcome (Shenhar and Holzmann, 2017). A strategic vision of construction megaprojects is always presented in a visual and emotional way and can be acted as a strong link to exceptional leadership. Good leaders know how to use the strategic vision to effectively motivate the people involved in the construction projects, and meanwhile, they are able to combine the vision with the right strategy to implement (Patanakul and Shenhar, 2012). It is worth mentioning that the vision of megaprojects does not always involve profits or financial performance and even not described in technical terms. Instead, it is simple and easy to evoke emotional reactions (Shenhar and Holzmann, 2017). For example, the strategic vision of the famous Apollo program in 1961 was "put a man on the Moon and bring him back before the end of the decade."

The factors "aligned perceptions of project goals and success" and "clear goals" were ranked as the second place in this group. Both of them are very important success factors to achieve project success (Toor and Ogunlana, 2009). Megaproject organizations are typically large and complex, with multiple parties working together. Thus, clear goals and a well-defined responsibility matrix should be prepared with the agreement of the entire team. Besides, to prevent misalignment on project goals and success, organizations should define goals clearly at first (Caldas and Gupta, 2017).

- Project participants-related factors

This group obtains a total number of ten CSFs, including partnering/relationships with key stakeholders, adequate communication and coordination among related parties, project manager's competency, top management support from key stakeholders, ethical leadership, positive organizational culture for effective project management, capabilities of the owner, mutual trust among project stakeholders, capabilities of contractors, and great organizational support, with their respective frequencies as 8, 7, 5, 5, 4, 3, 3, 2, 1, 1.

Partnering or maintaining good relationships with key stakeholders was first place with a total frequency number of 8 mentions in this group. Generally, formal contracts stipulate clear rights and responsibilities of participants in construction projects to ensure the progress of construction activities. Nevertheless, existing studies show partnering and good relationships, which may extend beyond contracts, play important roles in improving project governance and project efficiency, and contribute to project success finally (Zhai *et al.*, 2017, Ning and Ling, 2014). Moreover, for the consideration of long-term cooperation, partnering or good relationships is encouraged to be implemented. In the Hong Kong-Zhuhai-Macau Bridge, a kind of partnering that called a partnership based on the strict implementation of contractual agreements was encouraged to implement. Under this kind of collaboration, organizations involved in the megaproject were expected to be viewed as a union and made their best efforts to complete this super bridge (Gao *et al.*, 2018b).

Adequate communication and coordination among related parties were mentioned in seven publications. Communication and coordination are generally regarded as critical factors for project success (Chan *et al.*, 2004b). Lacking cross-functional communication is identified as one of the main obstacles to maintaining the effectiveness of organization. On the contrary, timely and effective communication between project teams can significantly improve project success (Shehu and Akintoye, 2010). Considering the construction of megaprojects, which involve numerous participants, during the project execution, it is not surprising that communication and coordination are of great importance to successful outcomes. Moreover, as pointed out by Hu *et al.* (2015a), regular and informal meetings, newsletters, training programs, joint working activities, and emergency drills with government agencies and contractors were highlighted to improve communication and coordination among key stakeholders in mega infrastructure projects.

The competence of project managers has been mentioned as an essential success factor in several past studies (Nguyen *et al.*, 2004a). A team with expert, knowledgeable, experienced, and proficient team members are necessary for the successful accomplishment of project goals (Toor and Ogunlana, 2009). Different from the typical construction projects, megaprojects are usually managed by a management team called top management team, which plays an essential and dominant role in managing megaprojects, and their support is regarded as an essential role of enhancing the performance of megaproject management (Lundrigan *et al.*, 2015).

- Economic and managerial factors

This group includes twelve CSFs, namely adequate resource availability, effective risk management, competitive and transparent procurement process, good governance, effectively address complexities, scope management, well-formulated and detailed contracts, learning from previous experiences, innovation strategies and practices, systematic control and integration mechanisms, using up to date technologies, and awarding bids to the right designers/contractors, with their respective frequencies as 9, 5, 5, 5, 4, 4, 4, 4, 3, 2, 2, 1.

The adequate resource availability was identified as a significant factor, with nine times mentioned, accounting for one-third of all selected articles. The resource in the megaprojects generally refers to adequate workers, construction materials, machines, and funding as well. Sufficient resources (for example, sufficient funds available in projects), is vital to the progress of megaprojects (Asgari *et al.*, 2017). Project funds can be used to purchase construction materials, machines, and hiring workers, which are the basis for the smooth construction of megaprojects. In practice, interruptions in the supply of project funding could happen for some reasons, such as untimely issued bank loans, and private or governmental funding not in place, which finally affecting the smooth progress of construction or even failing.

Complex megaprojects could face emergent risks that are not usually present in traditional projects, including political risks, the potential for catastrophic loss, sophisticated engineering and design risk, and substantial unknowns that could impact budget and schedule (Greiman, 2013a). Thus, effective risk management would help to achieve project goals and success. Additionally, a competitive and transparent procurement process, which can effectively reduce corruption in megaprojects, also plays a vital role in making project success (Locatelli *et al.*, 2017b). The issue of megaproject governance is getting more and more attention with the expansion of globalization. In large-size projects or megaprojects, multiple governance structures that coexist within an organization are very common. Taking the Big Dig megaproject as an example, in this case, the governance structure includes federal oversight, owner's board of directors, an owner's project director, and a program manager (Greiman, 2013a).

- External factors

This group obtains four CSFs, including public support or acceptance, government support, full understanding of cultural, financial and legislative requirements, and economic and political stability, with their respective frequencies as 7, 4, 3, 1.

Public support or acceptance was also one of the most significant factors for the success of construction megaprojects, also with a total frequency of 7 and ranked first place. The recognition and understanding by the public are rather crucial in ensuring a harmonious and stable environment for the construction of megaprojects, especially when some construction work that may have a severe adverse impact on people's living surroundings. Moreover, the public support at initial stages could reduce delays, such as land acquisition and immigration work for project development (Osei-Kyei and Chan, 2015). For instance, the Three Gorges Dam in China involved a large amount of immigration work, and the support of immigrants became one of the critical factors determining the success of this project (He *et al.,* 2019). Additionally, in megaprojects, the government usually plays diverse roles, such as decision-makers, funder, project managers, and operators (Greiman, 2013a). For example, in the Hong Kong-Zhuhai-Macau Bridge, governments, including central government, local government (Guangdong government, Hong Kong government, Macau government), and related governmental sectors (e.g. National Development and Reform Commission) are involved in this megaproject. Thus, government support is critical to achieving project success (Qiu *et al.*, 2019).

3.6 **Chapter Summary**

This chapter comprehensively reviewed a total number of 38 journal articles on success criteria and CSFs for CMS from 2000 to 2018, aiming to identify success criteria and CSFs for CMS. The research results of this chapter are fundamental for the development of the survey questionnaire used for this research. Besides, criteria and critical factors for measuring the success of construction megaprojects were also explored as a research foundation of following objectives.

Table 3.5 Findings from studies on critical success factors for CMS

No.	Category	CSFs	Resource	Total mentioned times
1	Project-related factors	Clear strategic vision	Hu *et al.* (2015a); Asgari *et al.* (2017); Toor and Ogunlana (2009); Hosseini et al .(2017); Nguyen et al.(2004); Shenhar and Holzmann (2017)	6
2		Aligned perceptions of project goals and success	Toor and Ogunlana (2009); Caldas and Gupta (2017); Crosby (2017); Hosseini et al. (2017); Shenhar and Holzmann (2017)	5
3		Clear goals	Hu *et al.* (2015a); Toor and Ogunlana (2009); Crosby (2017); Locatelli *et al.* (2017c); Nguyen et al. (2004)	5
4		Effective strategic planning	Hosseini et al. (2017); Cepeda et al. (2018); Nguyen et al. (2004); Al-Nahyan et al. (2012)	4
5		Project size	Asgari et al (2017); Verweij et al. (2015); Cepeda et al. (2018)	3
6		Right project identification and project technical feasibility	Asgari et al (2017); Toor and Ogunlana (2009); Crosby (2017)	3

7		Project organization structure	Hu *et al.* (2015a)	1
1	Project participants-related factors	Partnering/relationships with key stakeholders	Hu *et al.* (2015a); Asgari *et al.* (2017); Ning and Ling (2014); Mazur *et al.* (2014); Crosby (2017); Hosseini et al. (2017); Cepeda et al. (2018); Nguyen et al. (2004)	8
2		Adequate communication and coordination among related parties	Hu *et al.* (2015a); Asgari *et al.* (2017); Toor and Ogunlana (2009); Caldas and Gupta (2017); Bubshait et al. (2014); Crosby (2017); Al-Nahyan et al. (2012)	7
3		Project manager's competency	Asgari *et al.* (2017); Toor and Ogunlana (2009); Crosby (2017); Hosseini et al. (2017); Nguyen et al. (2004)	5
4		Top management support from key stakeholders	Asgari *et al.* (2017); Toor and Ogunlana (2009); Crosby (2017); Fahri *et al.* (2015); Nguyen et al. (2004)	5
5		Good leadership	Hu *et al.* (2015a); Mazur *et al.* (2014); Crosby (2017); Sturup and Low (2015)	4
6		Positive organizational culture for effective project management	Toor and Ogunlana (2009); Puerto and Shane (2014); Hosseini et al. (2017)	3
7		Capabilities of the owner	Asgari *et al.* (2017); Winch and Leiringer (2016); Fahri *et al.* (2015)	3
8		Mutual trust among project stakeholders	Toor and Ogunlana (2009); Li et al. (2018)	2

9		Capabilities of contractors	Asgari *et al.* (2017)	1
10		Great organizational support	Fahri *et al.* (2015)	1
1	Economic and managerial factors	Adequate resource availability	Asgari *et al.* (2017); Toor and Ogunlana (2009); Caldas and Gupta (2017); Crosby (2017); Hosseini et al. (2017); Locatelli *et al.* (2017c); Nguyen et al. (2004); Al-Nahyan et al. (2012)	9
2		Effective risk management	Asgari *et al.* (2017); Kardes *et al.* (2013); Dimitriou *et al.* (2013); Crosby (2017); Sturup and Low (2015)	5
3		Competitive and transparent procurement process	Toor and Ogunlana (2009); Hosseini et al. (2017); Cepeda et al. (2018); Nguyen et al. (2004)	5
4		Good governance	Hu *et al.* (2015a); Klakegg *et al.* (2016); Li et al. (2018); Hosseini et al. (2017); Locatelli *et al.* (2017c)	5
5		Effectively address complexities	Kardes et al. (2013); Dimitriou *et al.* (2013); Crosby (2017); Cepeda et al. (2018)	4
6		Scope management	Hu *et al.* (2015a); Verweij et al. (2015); Hosseini et al. (2017); Cepeda et al. (2018)	4
7		Well-formulated and detailed contracts	Toor and Ogunlana (2009); Verweij et al. (2015); Hosseini et al. (2017); Cepeda et al. (2018)	4
8		Learning from previous experiences	Toor and Ogunlana (2009); Crosby (2017); Hosseini et al. (2017); Nguyen et al. (2004)	4

9		Innovation strategies and practices	Hu *et al.* (2015a); Davies *et al.* (2009); Kwak et al. (2013)	3
10		Systematic control and integration mechanisms	Crosby (2017); Nguyen et al. (2004)	2
11		Using up to date technologies	Toor and Ogunlana (2009); Nguyen et al. (2004)	2
12		Awarding bids to the right designers/contractors	Toor and Ogunlana (2009)	1
1	External factors	Public support or acceptance	Asgari *et al.* (2017); Puerto and Shane (2014); Ng et al. (2014); Crosby (2017); Hosseini et al. (2017); Locatelli *et al.* (2017c); Rodríguez-Segura et al. (2016)	7
2		Government support	Hosseini et al. (2017); Locatelli *et al.* (2017c); Nguyen et al. (2004); Al-Nahyan et al. (2012)	4
3		Full understanding of cultural, financial and legislative requirements	Hu *et al.* (2015a); Crosby (2017); Rodríguez-Segura et al. (2016)	3
4		Economic and political stability	Hosseini et al. (2017)	1

CHAPTER 4 RESEARCH METHODOLOGY

4.1 Introduction

4.2 Research design and process

4.3 Overview of the research methods for this study

4.4 Data collection techniques

4.5 Data analysis techniques

4.6 Chapter summary

4.1 Introduction

The influence of methodology on the outcomes and contributions of any research study cannot be undermined. This chapter introduces the research methodologies adopted in this study. The research methods are explained to highlight the corresponding strengths and weaknesses, including the justifications for usage in the current study.

4.2 Research design and process

This study addresses four major aspects, including the questions to study, the relevance of the data, the data collection methods, and the analyses of the collected data (Creswell (2003). The research methods are proposed to be conducted via various procedures. In general, these methods are divided into qualitative, quantitative or mixed methods. The qualitative methods include the interview, observation and documented data (texts or images) (Grbich, 2012), whereas the quantitative ones feature instrument-based questions that include performance- and attitude-related information that will be further processed through statistical analyses (Creswell, 2003, Neuman, 2015). The 'mixed methods' refer to the combinations of qualitative and quantitative methods, which allow the triangulation of the data sources to determine the convergence of the qualitative and quantitative methods (Creswell, 2003).

In this research, a mixed-method approach was adopted, which comprises a literature review, structured interviews, questionnaire survey, factor analysis, PLS-SEM, fuzzy set theory, SD theory and case study. **Figure 4.1** depicts the specific steps and flow of the research methods.

Step 1: Overall understandings of CMS

A comprehensive literature review is introduced to help identify the research gaps and provide an in-depth understanding and basis to pinpoint the objectives with scientific significance.

Step 2: Identification of potential criteria and critical factors for CMS

The main research methods in this step include a literature review and interviews. A comprehensive literature review is conducted to identify the potential success criteria and critical factors for CMS, followed by structured interviews to evaluate the identified criteria and critical factors.

Step 3: Study of the KPIs for CMS

A questionnaire is designed on the basis of the selected criteria and critical factors for CMS in Step 2. A questionnaire survey, descriptive analysis, mean score ranking and factor analysis are used to identify all KPIs for CMS, and fuzzy set theory is adopted to determine the final KPIs.

Step 4: Study of the CSFs for CMS

This step involves the survey. The delivered questionnaire contains two main parts for the investigations of the KPIs and CSFs. The latter is selected according to the mean values of the importance of each factor and then classified into categories through factor analysis.

Step 5: Exploration of the relationships between CSFs and KPIs

A questionnaire survey is also conducted to collect data. The dataset is initially analysed using descriptive statistics and factor analyses to delineate the associations between the CSFs and KPIs. Then, PLS-SEM is applied to examine of the significances of the KPI-related CSFs.

Step 6: Development of a CMs evaluation model

A dynamic model for evaluating CMS, which contains the identified KPIs and CSFs, is established using Vensim software on the basis of the SD theory.

Step 7: Scenario analysis for enhancing the CMS

Using the dynamic model established in Step 6, several scenarios are designed and simulated in the Vensim software to identify the effective strategies for enhancing CMS.

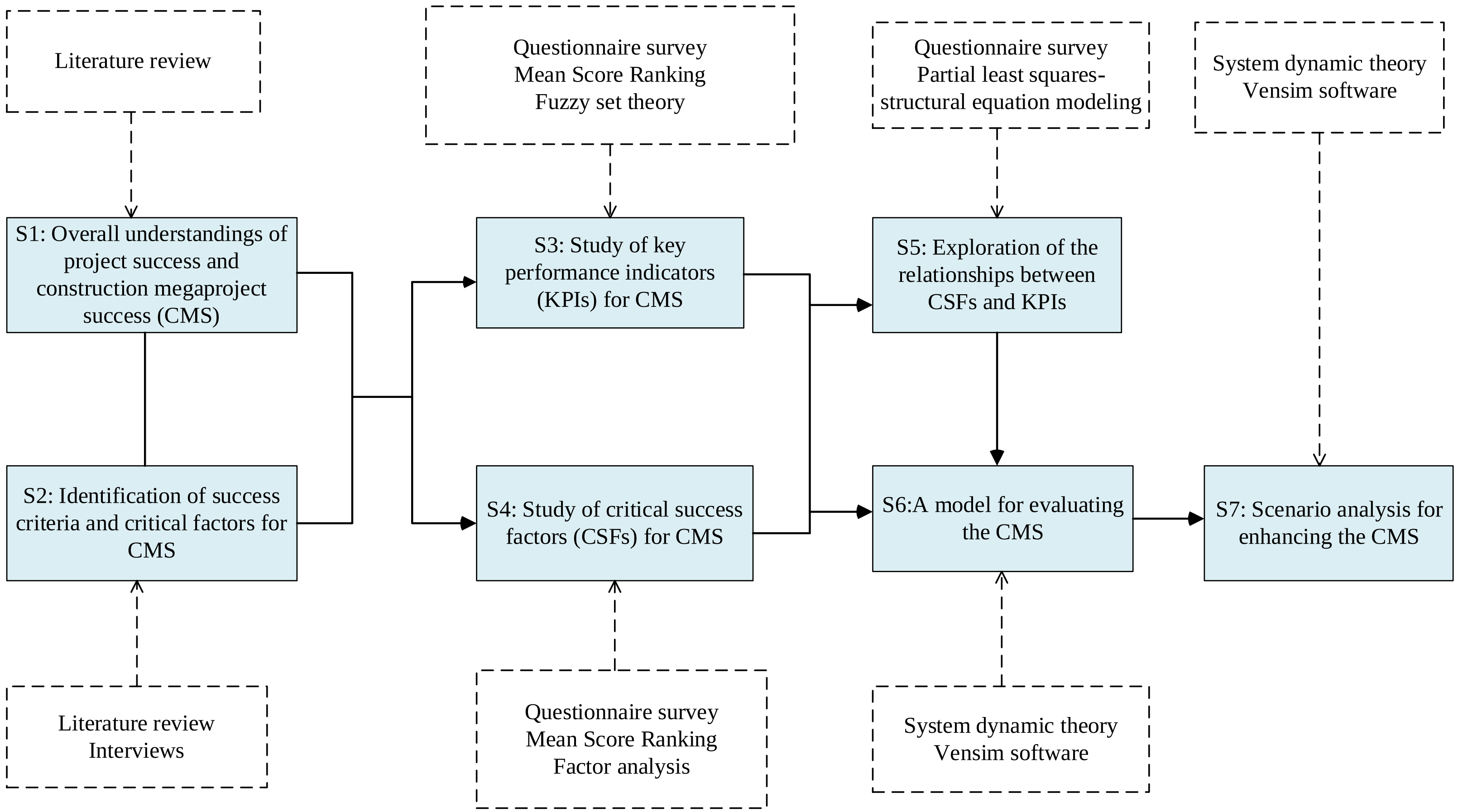

Figure 4.1 The research process and research methodology

4.3 Overview of the research methods for this study

The selection of the research methods is determined by the research objectives, questions and settings. No best rules for selecting research methods and no best research methods are available (Fellows and Liu, 2015). The research methods that can effectively fulfil the proposed research objectives are selected. The adoption of well-known and widely used research methods does not only help obtain meaningful results but also supports the reproducibility of the results (Alwaer and Clements-Croome, 2010). Literature review, expert interviews and questionnaire survey are used in this study mainly for data collection, whereas mean score ranking, factor analysis, fuzzy set theory, PLS-SEM and SD are utilised for the data analysis (**Table 4.1**).

Table 4.1 Corresponding methods for achieving the research objectives

Research objectives	Research methods							
	Data collection methods			Data analysis methods				
	Literature review	Expert interviews	Questionnaire survey	Mean score raking	Factor analysis	Fuzzy set	PLS-SEM	System dynamic
To identify a set of key performance indicators (KPIs) for measuring the CMS	✓	✓	✓	✓	✓	✓		
To identify Critical Success Factors (CSFs) that have strong effects on the CMS	✓	✓	✓	✓	✓			
To explore the relationships between identified CSFs and KPIs			✓	✓	✓		✓	
To establish a model for dynamically evaluating the success level of a construction megaproject	✓							✓
To conduct scenario analysis to identify the effective managerial strategies for enhancing the success level of construction megaproject management	✓							✓

4.4 Data collection techniques

4.4.1 Literature review

The literature review provides a solid foundation for developing the knowledge base in a particular research area. The review in this study is not only just about reviewing the relevant publications but is also used to identify critiques and research gaps of the existing works in a particular research area (Yeung, 2007). The objectives of the literature review are as follows: (1) to determine the research gaps in the research on project success and CMS to identify the research problems, (2) to develop an overall research framework for the research problems, (3) to identify the potential success criteria for CMS, (4) to identify the potential critical factors for CMS, (5) to provide a basis for conducting interviews and questionnaire survey and (6) to provide a theoretical foundation for establishing the SD model. The literature reviews are summarised, analysed and reported in Chapters 2 and 3. The former summarised the gaps, whereas the latter identified the imitative success criteria and critical factors for CMS.

4.4.2 Semi-structured interviews

An interview is a qualitative method that aims to identify the core themes of the real world of the subjects by recording and analysing the underlying meanings from the interviewees' statements (Kvale and Brinkmann, 2009). This approach has been widely used in construction engineering and management research (Yang *et al.* (2018), Hu *et al.* (2015a). Interviews can be divided into three different forms, namely, structured, (Yeung, 2007), semi-structured (Hu, 2013) and unstructured interviews (Rooke *et al.*, 2004). In this study, a semi-structured interview method was adopted to conduct prior research on the success criteria and critical factors for CMS, which aims to provide a solid foundation for the questionnaire design and survey. **APPENDIX B** provides the outline of the expert interview.

4.4.2.1 Process and criteria for the experts' selection

The interview experts should be carefully and objectively selected to ensure the validity of the study and the quality of the results, which are directly related to the selection process (Hsu and Sandford, 2007, Dorussen *et al.*, 2005). The experts' selection is generally determined by the disciplinary areas of expertise required by the topic under study. In this study, a two-step approach was adopted to select the experts. Official invitation letters requesting support from the members of the Research Institute of Complex Engineering Management (website: http://ricem.tongji.edu.cn/#/Home), which includes one academician in China, more than 30 industry researchers and more than 50 postgraduates and Ph.D. students in the area of complex project and megaproject management, were sent. The members were asked to nominate qualified practitioners (within and outside the institute) based on the predefined criteria in the letter. The predefined criteria are listed below.

1. Possess an extensive working experience (at least 5 years) and a good knowledge of construction megaproject management in China;
2. Have recent hands-on experience in at least one construction megaproject in China; and
3. Possess expertise and good knowledge of the concept of project and megaproject successes.

This step produced a pool of potential candidates for the interviews. These target interviewees were then contacted and asked if they were willing to participate in the study and what time they would be available for the interviews. Ten such practitioners agreed to participate in the study.

4.4.2.2 Background information of the respondents

In this study, an interview was conducted to establish prior research on the success criteria and critical factors for assessing the success of construction megaprojects after the literature review. The interview aims to validate the results obtained from the review and provide a solid foundation for the questionnaire design and survey. A series of semi-structured interviews with ten experts was conducted in Shanghai (June and July 2018) to identify the relevant success criteria and critical factors of the success of construction megaprojects in China. Seven out of the ten interviewees possess more than 10 years of working experience in construction megaproject engineering and management, and three are academic experts working on large-scale and complex megaproject research. **Table 4.2** lists the background information of the experts.

Table 4.2 Background information of the experts

Interviewees	Current Positions	Years working in the project management area	Participated megaprojects
Expert 1	Professors	32	Shanghai EXPO, Shanghai Disneyland Resort
Expert 2	Professors	23	Shanghai EXPO, Changchun West Railway Station
Expert 3	Research assistant	5	Beijing-Xinjiang Expressway
Expert 4	Project manager	16	Guangzhou Baiyun International Airport, Shanghai EXPO
Expert 5	Project manager	17	Shanghai EXPO, Shanghai West Bund Media Harbor
Expert 6	Project manager	23	Hong Kong-Zhuhai-Macau Bridge, Hangzhou Bay Bridge
Expert 7	Deputy project management	15	Shanghai Disneyland Resort, Buddhist Academy of China
Expert 8	Project management consultant	11	Shanghai West Bund Media Harbor, Buddhist Academy of China
Expert 9	Project management consultant	12	Kunming Metro Line 2, Shanghai West Railway Station
Expert 10	Project supervisor	8	Shanghai West Bund Media Harbor

Each interview lasted for 45 minutes to 1 hour and was conducted in a semi-structured manner with rich feedback (Lucko and Rojas, 2010). The interview outline included three major parts: brief introduction of the interviewer (e.g. research interests), several important notes about the interview (e.g. objectives of the interview) and the formal interview questions. The formal interview part is divided into two sections, namely, personal information and opinions regarding the success indicators and critical factors for assessing the success of construction megaprojects. The questions were open, and the interviewees were encouraged to express their opinions and add any details that they deemed necessary.

4.4.3 Questionnaire survey

Questionnaire survey is a systematic method of collecting data from a sample population (Tan, 2011). Some advantages made this method popular in the research field of construction megaproject management (Shen *et al.*, 2010, He *et al.*, 2015, Yan *et al.*, 2019), including quantifiability and objectiveness (Ackroyd and Hughes, 1981). In addition, a questionnaire survey is a cost-effective method for rapidly collecting quantitative data whilst maintaining the anonymity of the respondents (McQueen and Knussen, 2002). As previously mentioned, a questionnaire survey was used as the main data collection method in this study. This method can provide the quantitative descriptions of the perceptions and attitudes of the entire study population studying only a sample of the population (Creswell, 2003). Despite some disadvantages of the questionnaire survey (e.g. risk of bias and low response rate), this method grants researchers a great opportunity to examine a considerable number of factors if appropriate measures are implemented to attain a representative and reasonable sample (Darko, 2018).

The questionnaire was used to solicit professional views. The questionnaire survey in this study was specifically designed to

1. Identify the KPIs for measuring the CMS in China;
2. identify the CSFs for the CMS in China; and
3. Explore the relationships between the identified CSFs and KPIs.

4.4.3.1 Questionnaire development

The adequacy and readability of the designed questionnaire were tested through a pilot study. Five experts were invited in the pilot study, and their comments were incorporated into the final questionnaire. The designed questionnaire included three sections. The first section contained questions regarding project information, such as the name of the megaproject, the commencement year and the city where the megaproject is located. The respondents were required to select one construction megaproject that they are recently involved in to serve as a reference in answering the questionnaire. The second section was developed on the basis of the initially identified 23 success criteria and 35 critical factors. Five-, seven- and nine-point rating scales were considered to gather the professionals' opinions, amongst which the five-point rating scale was selected for this study due to its advantages in the interpretation of unambiguous results (Darko, 2018). In this study, the respondents are required to rate the importance of each success criterion and critical factor on a five-point Likert scale (1 = strongly disagree; 2 = disagree; 3 = neutral; 4 = agree; 5 = strongly agree), which has been widely used in the research on construction project management (Zhang *et al.*, 2011). The final section of the questionnaire includes the background information of the respondents, such as years of experience in megaproject management. The background-related information enriches the quality of the data collected from the second section of the questionnaire (Yan *et al.*, 2019). **Appendix C** presents the questionnaire.

4.4.3.2 Background information of the respondents

The survey was conducted between June and August 2019. (Zheng *et al.*, 2019) only considered the cost of one construction megaproject over one billion RMB (Chinese currency).The selection process of questionnaire respondents was similar to that of selecting interviewees. Briefly speaking, the author sent the questionnaires to the members of the Research Institute of Complex Engineering Management and asked them to help complete or distribute the questionnaire to qualified respondents. A total of 300 questionnaires were sent through email and online linkage in this work; 129 of which were deemed valid and were analysed. The response rate is 43%, which is acceptable and higher than the average response rate for an online survey (10%–15%) (Xu *et al.*, 2012). Forty-seven respondents were owners (e.g. government officials who are directly related to the project or a member of the owner's project team and consultants commissioned by the owner), 69 were contractors and 13 were designers (i.e. commissioned by the owner and design consultants). There are three criteria to exclude invalid questionnaires in this research, including 1) incomplete answers; 2) obviously wrong answers, such as all A choices; 3) too short time for completion of the online questionnaire. **Table 4.3** shows the backgrounds of the respondents, and **APPENDIX D** shows the detailed information of the megaproject. As shown in the table, 51.94% of the respondents with 6 to 10 years' work experience in construction project management, 28.68% with 11 to 20 years' experience and 19.38% with more than 20 years' experience. The results could indicate the respondents in this questionnaire survey had good experience and required knowledge to provide sensible answers. In terms of project size, 36.43% of construction megaprojects with a total investment between 1 billion to 3 billion RMB, 32.56% of projects with a total investment between 3 billion (exclusive) to 5 billion RMB, 13.18% was between 5 billion (exclusive) to 10 billion RMB and 17.83% was more than 10 billion RMB. The results indicated that projects involved in the questionnaire survey meet the criteria of construction megaprojects. In terms of location, approximately 31% (Jiangsu, Shanghai and Zhejiang provinces) of construction megaprojects were in Eastern China, 21.71% (Henan and Hubei provinces) of construction megaprojects were in central China, 17.05% (Guangxi and Sichuan provinces) of projects were in southwest China, 17.05%

(Guangdong and Hainan provinces) were in southeast China and 3.1% (Beijing) were in northern China ('Others' are not counted). This distribution of samples ensures that the findings derived from the survey cover all variations across the country.

Table 4.3 Backgrounds of the respondents

Characteristic	Category	Number of	Percentage (%)
Gender	Male	107	82.94
	Female	22	17.06
Education	High school or below	4	3.1
	College degree	12	9.3
	Bachelor degree	78	60.46
	Master degree or above	35	27.14
Work experience	6-10 years	67	51.94
	11-20 years	37	28.68
	>20 years	25	19.38
Project size	1-3 billion RMB	47	36.43
	3-5 billion RMB	42	32.56
	5-10 billion RMB	17	13.18
	>10 billion RMB	23	17.83
Location of megaprojects	Henan Province	23	17.83
	Guangxi Province	19	14.73
	Jiangsu Province	18	13.95
	Guangdong Province	18	13.95
	Shanghai	19	14.73
	Hainan Province	4	3.10
	Beijing	4	3.10

Hubei Province	5	3.88
Sichuan Province	3	2.32
Zhejiang Province	3	2.32
Others	13	10.09

*Others refer to the provinces which number of questionnaire obtained below 2 (inclusive), including Guizhou Province, Hebei Province, Shanxi Province, Yunnan Province, Neimeng Province, Liaoning Province and Ningxia Province.

4.5 Data analysis techniques

4.5.1 Descriptive statistics

Russo (2003) argued that useful information cannot be extracted unless the raw data obtained from various samples are effectively organised. Descriptive statistics techniques assist in organising, summarising, simplifying and interpreting datasets (Xu, 2012). In this study, a descriptive statistics technique was used to analyse the demographic and attitudinal data to identify the characteristics of particular groups and describe the similarities and differences across variables or groups.

4.5.2 Cronbach's alpha technique

Cronbach's alpha technique measures the average correlation or internal consistency amongst the factors in the survey and estimates the reliability of a questionnaire set (Darko, 2018). The value of Cronbach's alpha ranges from 0 to 1 in accordance with the increase in reliability (Santos, 1999). In general, Cronbach's alpha should be higher than 0.70 of a reliable questionnaire setting. Cronbach's alpha test is typically performed using the Statistical Package for the Social Sciences (SPSS) software (Shen *et al.*, 2010). In this study, the reliability of the five-point questionnaire survey was determined as follows (Darko, 2018)

$$\partial = \frac{k\overline{cov}/\overline{var}}{1+(k-1)\overline{cov}/\overline{var}}, \qquad (4.1)$$

where ∂ is Cronbach's alpha coefficient value, k is the number of scale items, $\overline{var}$ is the average variance of the scale items and $\overline{cov}$ is the average covariance amongst the scale items. When the factors are standardised and have the same variance, the equation above can be simplified as

$$\partial = \frac{\bar{r}}{1+(k-1)\bar{r}}, \qquad (4.2)$$

where $\bar{r}$ is the average correlation amongst the scale items.

4.5.3 Mean score ranking technique

The mean score ranking technique has been widely used in construction project research for calculating and ranking the relative importance of the factors (Shen *et al.* (2010), Xu *et al.* (2012). In this study, the mean score ranking technique was used to identify the relative rankings of the KPIs and CSFs for CMS. The mean score is determined using Equation (4.3). If two or more factors have the same mean score, the factor with the smaller standard variance will be assigned with the higher rank (Mao *et al.*, 2013). The significance of the mean scores was measured through the one-sample t-test at a 95% confidence level with a p-value of 0.05. The null hypothesis for a factor should be rejected if the p-value is lower than 0.05 (Darko, 2018).

$$B_i = \frac{\sum_{j=1}^{n} \partial_{ij}}{n}, \qquad (4.3)$$

where *n* represents the total number of respondents, ∂_{ij} is the importance/criticality of the factor *i* rated by respondent *j* and B_j is the mean score of the importance/criticality of the factor *i*.

4.5.4 Factor analysis

Factor analyses contain a variety of statistical techniques that represent a set of variables as a small number of hypothetical variables (Kim and Mueller, 1978). Generally, factor analysis contains two major types, namely, Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA). As the title suggests, EFA is exploratory in nature, whereas CFA is used to test a proposed theory (Williams *et al.*, 2010). EFA is a powerful statistical technique that has been widely used to identify the response patterns of the respondents for a set of questions and investigate the underlying structure of such patterns (De-Vaus, 2001) (e.g. which variables are closely linked to one another and how strong the relationships between the observable variables and the extracted latent variables are (Darko, 2018)). EFA can be applied when the underlying structure of the variables is unknown, has not been established in previous research and/or has not been developed with a particular subpopulation (McNeish, 2017). Establishing the underlying structure is necessary to test hypotheses and build theories. EFA has been extensively applied in the research area of construction project management. For example, Xu *et al.* (2011) explored success factors of energy performance contracting for hotel buildings in China. Chau and Long (2016) identified CSFs of Design/Build projects in the implementation phase in Vietnam. In this study, EFA was utilised to analyse the underlying structures of CSFs for measuring CMS to lay the foundation for the subsequent PLS-SEM. Considering exploratory nature of the current study, it is appropriate to adopt EFA approach rather than CFA to identify the underlying structure of the variables. Generally, EFA consists of four typical steps (Chan *et al.*, 2004a):

(1) Identifying the relevant factors;

(2) Calculating the correlation matrix for all factors;

(3) Extracting and rotating the factors and

(4) Interpreting and naming the grouped factors as underlying factors.

Nonetheless, the appropriateness of factor analysis for factor extraction should be evaluated before applying the EFA. The Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity were used to determine the appropriateness of using factor analysis in this research. As the name implies, KMO is a measure of sampling adequacy, which represents the ratio of the squared correlation to the squared partial correlation amongst the variables (Field, 2013). The value of KMO ranges from 0 to 1; a value of more than 0.50 is necessary for satisfactory factor analysis (Kaiser, 1974, Field, 2013). Bartlett's test of sphericity is a statistical test that highlights the presence of correlations amongst variables. EFA comprises factor extraction and rotation. The former is necessary to determine the number of underlying factors in a set of variables, whereas the latter is necessary to improve the interpretability of the underlying factors (Norusis, 2008). Additionally, principal component analysis was used as a tool to extract factors. It is a default method in many statistical programs and is also commonly adopted in EFA (Williams *et al.*, 2010).

4.5.5 Fuzzy set theory

The fuzzy set theory was established to address subjectivity and uncertainties (Zadeh, 1965). Through linguistic variables and membership functions with varying grades, this theory allows the development of strong and significant instruments for the measurement of ambiguities and provides the opportunity to represent meaningfully ambiguous concepts in the natural language (Zimmermann, 2001). This theory addresses complex problems and has been widely used in many research and practical areas, including the area of construction engineering and management (Hu, 2013).

Moreover, this theory facilitates the selection process and can assist in the identification of the KPIs (Hu *et al.*, 2016, Xu, 2012). Since KPIs are usually fuzzy in nature, which involves experts' subjective judgement, thus employing the fuzzy set theory to select the final KPIs for CMS in China is rational and appropriate (Hu, 2013).

A fuzzy set is a set with elements that have varying degrees of membership (Zimmermann, 2001). The degrees of membership of an element are represented by a membership function that can achieve quantitative calculation in fuzzy decision-making (Xia *et al.*, 2011). Baloi and Price (2003), a membership function that maps a universal set of objects X into the unit interval [0, 1], can be used to represent uncertainty. The grades of membership in fuzzy sets may fall anywhere in the interval [0, 1], meaning that an element is not a member of the set if the grade of membership falls on the degree of 0. Conversely, a degree of 1 means that an element belongs to the set (Hadipriono, 1988). Take for example a fuzzy set (A, m), where A is a set and m is the degree of membership of set A $(\mathrm{m}: \mathrm{A} \rightarrow [0,1]\mathrm{m}: \mathrm{A} \rightarrow [0,1])$ (Xu, 2012). For each $\mathrm{x} \in \mathrm{Ax} \in \mathrm{A}$, m(x) is called the grade of membership of x in (A, m). If m(x) = 0, then x is not included in the fuzzy set (A,m), whereas if m(x) = 1, then x is fully included (Xu *et al.*, 2012). If $0 < \mathrm{m}(\mathrm{x}) < 1$, then x is called a fuzzy member. For a finite set $\mathrm{A} = \{x_1, \dots x_n\}$, the fuzzy set (A, m) is denoted as $\left\{\frac{m(x_1)}{x_1}, \dots m x_n / x_n\right\}$, where $\mathrm{m}(x_i)/x_i$ means that the degree of membership of x_i in A is $\mathrm{m}(x_i)$.

4.5.6 PLS-SEM

The PLS-SEM is a multivariate statistical analysis technique used in this study to explore the influences of various types of KPIs and CSFs for CMS. The structural equation model (SEM) comprises two kinds of variables: observable and latent variables. Observable variables can be measured directly, whereas the latent variables are variables that cannot be measured directly using the measurement items. The SEM does not only test hypotheses amongst the measurement items and constructs but also evaluate a structural hypothetical model based on a phenomenon via a confirmatory technique (Byrne, 2013). The SEM can evaluate direct and indirect relationships amongst one or several independent and dependent variables (Darko, 2018). Moreover, the SEM can simultaneously conduct confirmation factor and path analyses, which is significantly different from multivariate regression and factor analyses (Xiong *et al.*, 2015). A typical SEM includes a set of measurement models and a structural model. A measurement model can evaluate the relationships between a construct and the measurement items, whereas a structural one illustrates the relationships amongst the constructs (Hair *et al.*, 2014b). This SEM approach has been widely used in social sciences in recent years, since three significant advantages 1) it can measure errors of observable variables; 2) illustrate ambiguous constructs; 3) estimate causal relationships amongst variables (Xiong *et al.*, 2015).

SEM comprises two approaches, namely, the variance- and co-variance-based SEM (CB-SEM). Compared with the CB-SEM, the PLS-SEM can handle small sample sizes and non-normal data (Hair *et al.*, 2014b). PLS-SEM is less stringent when dealing with non-normal data, but CB-SEM is likely to underestimate standard errors and magnify goodness-of-fit measures when working with such data. Moreover, CB-SEM normally requires a sample size of 200 at least, whereas PLS-SEM can be used with smaller sample sizes (Hair *et al.*, 2014a). These advantages make PLS-SEM popular in construction project management research. For example, Zhao and Singhaputtangkul (2016) used PLS-SEM to explore the influences of the firm characteristics on the enterprise risk management of Chinese construction firms using a sample size of 35. Chan *et al.* (2018) used a sample size of 43 to analyse the critical barriers to green building technology adoption in Ghana. The sample size of this research is 129 and the collected data does not follow multivariate normal distribution. Therefore, this study adopted PLS-SEM to evaluate research hypotheses and validate the hypothetical model.

4.5.7 SD method

4.5.7.1 Overview of SD

The SD theory was first established by Forrester (1961) in the late 1950s. This method first acted as a modelling methodology to solve decision-making problems in industrial management. The SD theory was established to address the inherent complexity, non-linearity and feedback loop structures in physical and non-physical systems (Forrest, 1994). One of the current preventative definitions of this theory is that this method can be applied for qualitative description and analysis of complex systems on their process, information, organisational boundaries and strategies. Meanwhile, it facilitates quantitative simulation and analysis of system structure and control (Wolstenholme (1990)). As mentioned, the indicators and CSFs for CMS are largely interdependent and share complex interactions. Hence, it is reasonable to adopt SD approach to evaluate CMS. Sterman (2002) defined SD by stating the what, why, how and within of this methodology.

What: A rigorous way to think, visualise, share and communicate with the future development of complex organisations and issues.

Why: To solve problems and create powerful designs that will minimise the possibility of unpleasant surprises and unintended consequences.

How: By developing simulation models that will identify organisational boundaries, policies and information and capture the interrelationships of physical and behavioural processes, which will then be used to test the overall results of alternative plans and scenarios.

Within: A framework that fosters the needs and values of awareness, openness, responsibility and equality of individuals and teams.

In summary, SD is a control theory-based methodology. **Figure 4.2** shows the control theory block diagram of a negative feedback system. This theory provides a foundation for the establishment of computer-based models to perform what the human mind cannot do (i.e. interactions and behaviour of complex social systems) and provide a platform where strategies can be simulated and trade-offs can be performed (Bala *et al.*, 2017). **Table 4.4** shows the strengths of the SD method summarised by Winz *et al.* (2009).

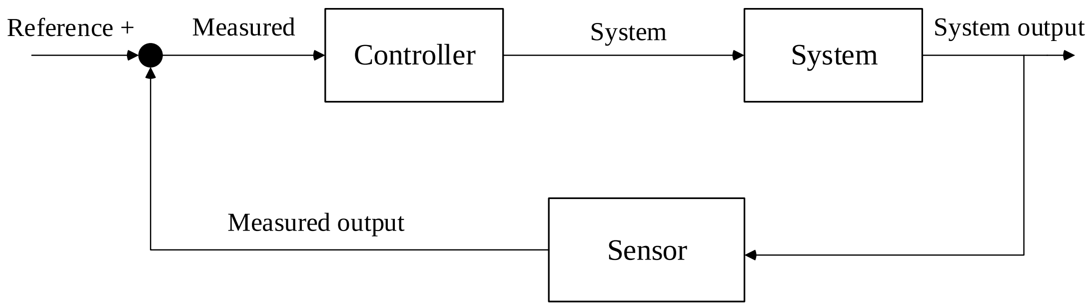

Figure 4.2 An illustration of control theory block diagram of a negative feedback system (Yuan, 2012)

Table 4.4 Overview of the strengths of SD (Yuan, 2012)

Category	Explanations	Characteristics
Flexibility	Used in a variety of applications	*Multi-disciplinary* which refers to allow the use of qualitative and quantitative variables in models, and relationships among variables can be defined on a large range of scale.
		Support a variety of project goals
Ease of uptake and adaptability	Established methodology, ease of uptake, transparency and adaptability	Users easily become familiar with modeling and simulation by changing the structure, parameters and data in the model.
		Transparency can be achieved during the development process and the experimentation with the model output.
		Mature computer software (e.g. i-Think, Vensim, Stella) are available to users and no need to programming. The software supports to various versions of outputs, such as tables, graphs and diagrams.
		Parameter do not need to be fixed before simulation, instead, they can be adjusted.
Ongoing testing and learning	Fore sighting, testing and learning, stakeholder participation	Simulation can be applied for different testing of assumptions and sensitivity analysis of parameters.
		The process of model development can be visualized to facilitate understandings of different stakeholder, thus contributing to building team learning, trust, acceptance among stakeholders.

4.5.7.2 Tools for SD modeling

A causal loop diagram is an essential tool for illustrating the feedback structure of the system. This diagram has three important abilities, including quickly capturing hypotheses about the causes of the dynamics, eliciting and capturing the mental models of individuals or teams and representing the important feedbacks responsible for solving the identified problem (Sterman, 2000). A causal loop diagram also consists of key variables connected by the arrows denoting the causal influences amongst the variables. **Figure 4.3** depicts an example of a causal loop diagram generated using the Vensim software.

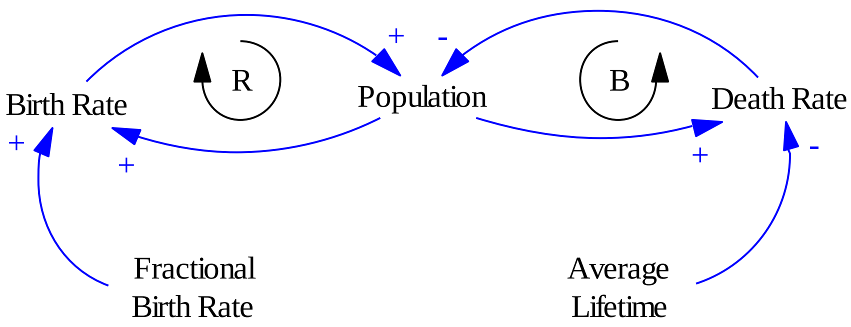

Figure 4.3 Example of a causal loop diagram

Figure 4.3 indicates that the birth rate is determined by two variables: population and fractional birth rate. Each arrow is expressed in terms of polarity(i.e. either positive (+) or negative (−)) to indicate how a dependent variable changes when the independent variable changes (Sterman, 2000). A positive link means that if the cause increases/decreases, then the effect increases/decreases. By contrast, a negative link means that if the cause increases/decreases, then the effect decreases/increases. The important loops are highlighted to show whether the loop is a positive (R, reinforcing) or a negative (B, balancing) one. Seven steps are followed in the development of a causal loop diagram: (1) defining the problem and objectives, (2) identifying the primary variables in the system, (3) identifying the secondary variables in the system, (4) identifying the tertiary variables in the systems, (5) defining the cause–effect relationships, (6) identifying the closed loops and (7) identifying the balancing and reinforcing loops (Bala *et al.*, 2017).

- Stock flow diagram

Despite the ability to represent interrelationships and feedback processes, causal diagrams cannot capture the stock and flow structure of the system (Sterman, 2000). Stocks are critical in generating the dynamics of the system for four reasons (Mass, 1980): (1) stocks describe the state of the system and provide the basis for actions, (2) stocks provide systems with inertia and memory, (3) stocks are the source of delays and (4) stocks decouple the rates of flow and create disequilibrium dynamics.

(1) <u>Stock</u>

The first basic element of an SD model is the stocks, which describe the condition or state of the system at any particular time. **Figure 4.4** displays the stock and flow diagram.

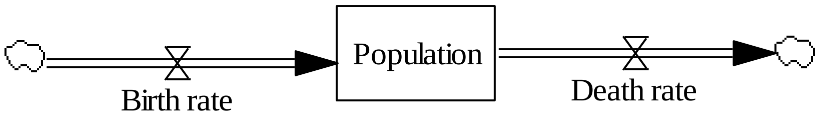

Figure 4.4 Flow diagram of a stock of population

In Figure 4.4, the population is categorised as a stock variable and is represented by the rectangle, resembling a container holding the contents of the stock. The birth rate is an inflow variable depicted as a pipe pointing to the stock, whereas the death rate is an outflow variable represented by a pipe pointing out of the stock (**Figure 4.4**). Stocks integrate the flows in and out of the stock, and the net flow into the stock is the rate of change of the stock. The stock (population) can be defined as follows:

$$\text{Population}(t)=\int_{t_0}^{t}[\text{Birth rate}(s)-\text{Death rate}(s)]ds+\text{Population}(t_0), \quad (4.4)$$

where the birth rate (*s*) represents the value of the birth rate at any time *s* between the initial time t_0 and the current time *t*. The derivative of the birth rate is the net value of the change of the stock, which is the difference between the inflow and outflow values.

$$d(\text{Stock})/dt=\text{Birth rate}(t)-\text{Death rate}(t). \quad (4.5)$$

(2) <u>Flow</u>

The second critical element in SD modelling is the flow, which shows how fast the stocks are changing. **Figure 4.5** shows an example of flow variables, which involve an inflow (birth rate) and an outflow (death rate) of the stock of population. As shown in the figure, the birth rate depends on the population and birth fraction, whereas the death rate depends on the population and death fraction.

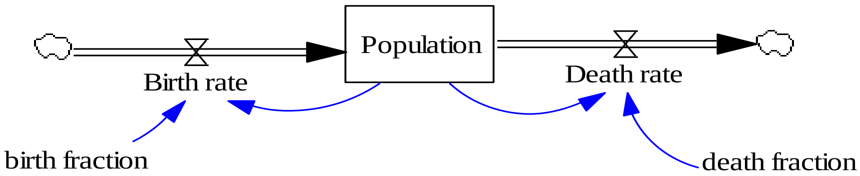

Figure 4.5 Flow diagram showing flows to stock of population

Accordingly, the inflow variable and outflow variable can be described by equation 4.6 and equation 4.7as follow.

Inflow: Birth rate=Population*Birth fraction (4.6)

Outflow: Death rate=Population*Death fraction (4.7)

4.5.7.3 Process for applying SD approach

The general steps of SD modelling include five major phases: problem identification, system description, model development, model validation and scenario analysis (**Figure 4.6)** (Yuan *et al.* (2012) Yuan (2011).

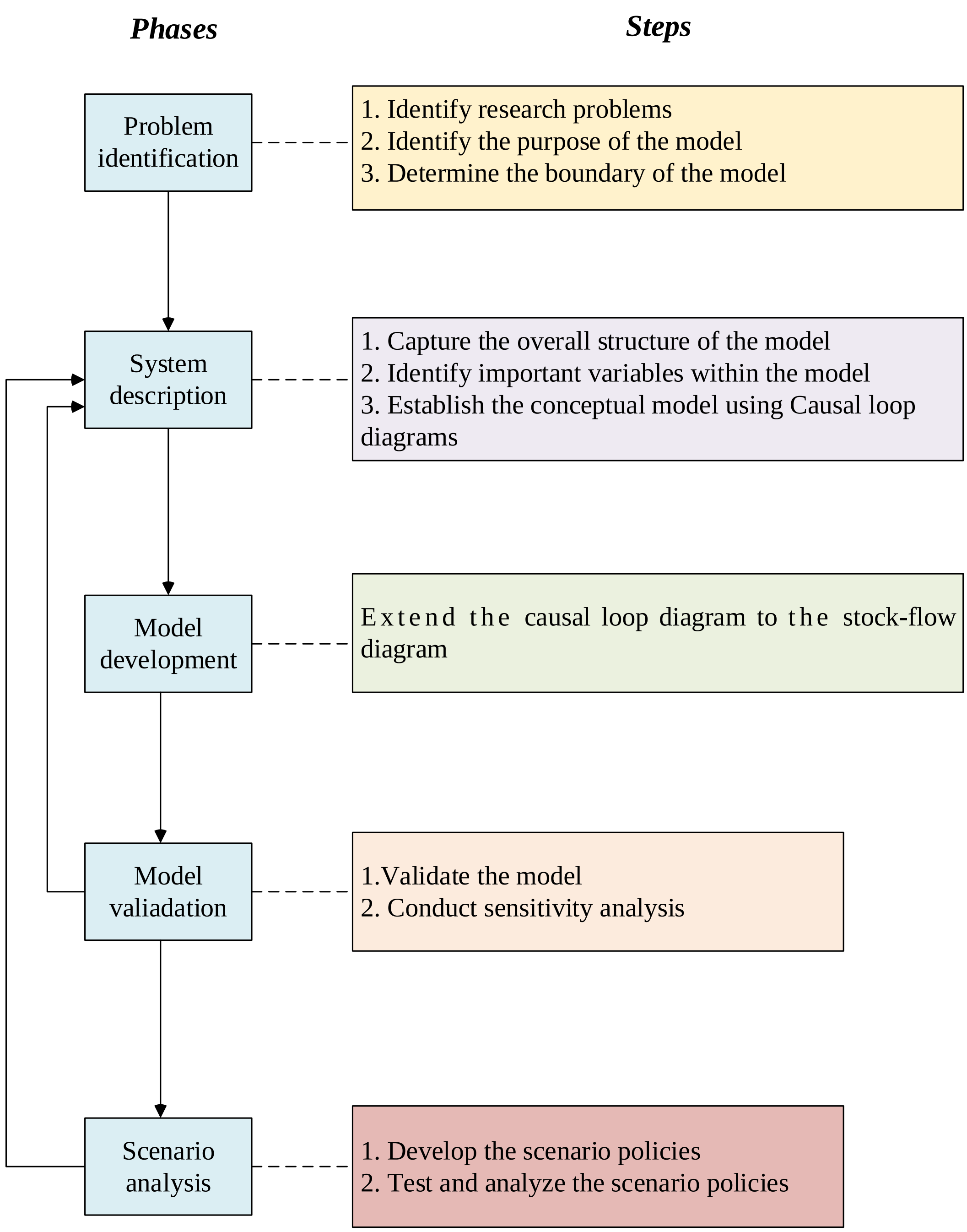

Figure 4.6 Five steps of SD modeling (Yuan, 2011)

Step 1: Problem identification

To establish an SD model, the first step is to identify and define the practical problems in the real world. In this phase, the most important is to figure out “what is the problem and why is a problem” (Sterman, 2000). Three major tasks, including identifying the problem or issue of in the management, stating the purpose of the model and identifying the boundary of the model, should be accomplished in this phase.

Step 2: System description

All key variables should be identified and included in the model. The key variables that can significantly affect the behaviour of the system are captured by researchers to solve the problem. Only the major variables are included in this step to ensure the key behaviours of the system. On the basis of the overall structure of the model and the identified key variables, the system can be described by a causal loop diagram (Coyle, 1996).

Step 3: Model development

A causal loop diagram provides a qualitative insight for decision-makers to solve the problem. A stock-flow diagram, which can facilitate a quantitative analysis, is also established in this step. The causal loop and stock-flow diagrams are two different versions of the same model. One of the distinctions between the two diagrams is that the former is described in arrows and words to develop a conceptual framework that can help the users understand the constructed model (Coyle, 1996).

Step 4: Model validation

Two important notions of building confidence in SD modelling are testing and validation. Testing refers to the evaluation of the feasibility of applying a constructed model to real situations, whereas validation is the process of establishing confidence in the soundness and usefulness of the model (Bala *et al.*, 2017). In this regard, a series of tests should be performed after the model development to assess if the model is suitable and reasonable, thereby building up the confidence in the model (Sterman, 2001). Firstly, the model is tested to ensure that all variables in the model are reasonable and meaningful in the real world. Secondly, the model is tested to assess if it fits reality. Lastly, the behaviour of the model is tested to ensure that the model can behave reasonably under extreme conditions. The tests in SD modelling can be classified into three categories: tests for structure, behaviour and policy implications; the structure and behaviour pattern tests are the essential contents.

Step 5: Scenario analysis

Once the structure and behaviour of the SD modelling have been validated, the constructed model will be implemented to test and develop management policies for improvement.

4.6 Chapter Summary

This chapter illustrates a concise research process and comprehensively describes the proposed research methodologies, including Cronbach's alpha technique, mean score ranking, fuzzy set theory, factor analysis, PLS-SEM and SD model. The research objectives can be achieved through a proper combination and usage of these methods.

CHAPTER 5 KPIs FOR ASSESSING THE SUCCESS OF CONSTRUCTION MEGAPROJECTS[7]

5.1 Introduction

5.2 Identification of the potential list of assessment indicators

5.3 Data analysis

5.4 Discussions of findings

5.5 Chapter summary

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[7] This chapter is largely based upon the following publication (accepted):

Qinghua He, Ting Wang*, Albert P.C Chan and Junyan Xu (2020). Developing a List of Key Performance Indicators for Benchmarking the Success of Construction Megaprojects. ASCE Journal of Construction Engineering and Management.

5.1 Introduction

This chapter identifies the KPIs for evaluating the success of construction megaprojects in China. A questionnaire was developed based on the potential performance indicators identified through a comprehensive literature review and expert interviews. The questionnaires were delivered to three groups of experts, and nine KPIs were subsequently identified through the fuzzy set theory.

5.2 Identification of the potential list of assessment indicators

A list of success indicators for assessing the success of construction megaproject was developed from the comprehensive literature review in Chapter 3 (**Table 5.1**). According to the comprehensive literature review, the authors identified four groups of success indicators, namely, project management success, stakeholders' satisfaction, organisational strategic goals and influence on the society.

Table 5.1 Success indicators summarized in the literature review

Groups	Success indicators	Presentative references
Project management success	"Iron Triangle"; health & safety goal; meeting specifications	Atkinson (1999); Tuman J. (1986); Belassi and Tukel (1996)
Stakeholders' satisfaction	Stakeholders' satisfaction	Atkinson (1999); Shenhar *et al.* (1997); Westerveld (2003)
Organizational strategic goals	Commercial profitability; business strategy	Shenhar *et al.* (2001); Cooke-Davies (2002); Turner and Zolin (2012)
Impact on the society	social-economic benefits; social harmony	Yan *et al.* (2019); Turner and Xue (2018)

On the basis of the literature review and interviews, 23 preliminary indicators for measuring the success of construction megaprojects were established as the foundation of the questionnaire design. These indicators were then grouped into five categories (**Table 5.2**). **Figure 5.1** shows the framework.

Table 5.2 Option List of assessment indicators

Categories	Indicators for CMS	Code	Source
Project efficiency	Meeting time, quality, budget goals	x_1	Literature review
	Meeting health, safety and environment (HSE) goals	x_2	Literature review
	Meeting regulations or specifications	x_3	Literature review
	Meeting designed function and delivering value/services that the public needed	x_4	Literature review
Key stakeholders' satisfaction	Government's satisfaction	x_5	Literature review
	Owner's satisfaction	x_6	Literature review

	Participants' satisfaction (e.g. consultants, designers and contractors)	x_7	Literature review
	The public's satisfaction	x_8	Literature review
	The interests of all participants can be well balanced or satisfied	x_9	Literature review
Organizational strategic goals	Benefits/profits realization	x_{10}	Literature review
	New market or increased market share	x_{11}	Literature review
	Improved brand/reputation	x_{12}	Literature review
	Use of new technologies	x_{13}	Literature review
	New organizational capability and competency	x_{14}	Literature review
	Nurturing experts for organizations	x_{15}	Literature review
Innovation and development of the construction industry	Benchmarking, for example, technical standards can be promoted to similar or similar types of projects	x_{16}	Interview
	Effectively promote innovation and synergy in the construction industry and related industries	x_{17}	Interview
	Improved competitiveness in the international market	x_{18}	Interview
	Significant contributions to theoretical and practical innovation in megaproject filed	x_{19}	Interview
Comprehensive impact on society	Delivering social-economic benefits to the community/local	x_{20}	Literature review
	Sustainability in environment, society, and economy	x_{21}	Literature review
	Maintaining social cohesion/society harmony	x_{22}	Literature review
	Enhancing people's national pride and confidence	x_{23}	Interview

The optional indicators were categorised into five types, namely, project efficiency, key stakeholders' satisfaction, organisational strategic goals, innovation and development of the construction industry and comprehensive influence on the society. Project efficiency is mainly focused on the project level, and the key stakeholders' satisfaction and organisational strategic goals are specific on the organisational level. In addition, the innovation and development of the construction industry are focused on the industrial level, and the comprehensive influence on society is mainly based on the societal level. Moreover, project efficiency is on short-term benefit, whereas the others are on long-term ones.

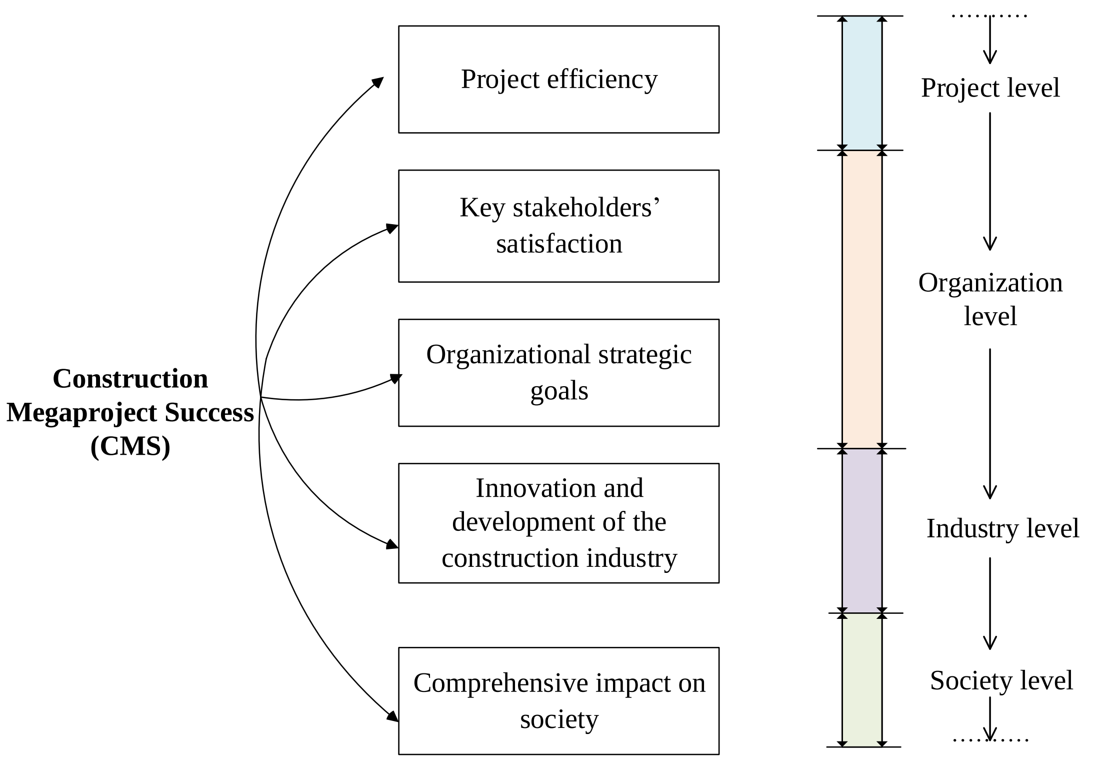

Figure 5.1 CMS framework

5.3 Data analysis

Statistical calculations on the significance of the assessment indicators were conducted using the survey data. **Table 5.3** illustrates the results, where x_1 represents the indicator 'Meeting time, quality, budget goals', which obtained an overall average score of 4.287 and a standard deviation of 0.886. However, the different response groups obtained different scores for each indicator. For example, x_1 has an average score of 4.340 and a standard deviation of 0.939 in the owners' group, whereas according to contractors, the average score and standard deviation are 4.377 and 0.824, respectively (**Table 5.3**). This phenomenon suggests that different groups allocate different weights to each indicator. This situation is acceptable because different groups of experts can have different perceptions about the priorities in assessing megaproject success (Shen *et al.*, 2010).

Table 5.3 Significance score of individual assessment indicators

Group of factor	Indicator code	All (N=129)		Owners (N=47)		Contractors (N=69)		Designers (N=13)	
		Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Project efficiency	x_1	4.287	0.886	4.340	0.939	4.377	0.824	3.615	0.768
	x_2	4.341	0.805	4.319	0.887	4.493	0.633	3.615	0.961
	x_3	4.357	0.737	4.255	0.896	4.493	0.609	4.000	0.577
	x_4	4.302	0.756	4.255	0.846	4.391	0.669	4.000	0.816
Key stakeholders' satisfaction	x_5	4.395	0.765	4.298	0.857	4.565	0.581	3.923	0.987
	x_6	4.388	0.743	4.234	0.813	4.594	0.577	3.846	0.898
	x_7	4.124	0.791	4.021	0.897	4.232	0.730	3.923	0.641
	x_8	4.225	0.803	4.128	0.900	4.348	0.724	3.923	0.759
	x_9	4.248	0.857	4.149	0.932	4.391	0.771	3.846	0.898
Organizational strategic goals	x_{10}	4.008	0.923	3.957	0.883	4.116	0.948	3.615	0.870
	x_{11}	4.217	0.819	4.000	0.978	4.391	0.669	4.077	0.760
	x_{12}	4.295	0.842	4.170	0.940	4.449	0.718	3.923	0.954
	x_{13}	4.093	0.861	4.043	0.884	4.203	0.850	3.692	0.751
	x_{14}	4.109	0.895	4.043	0.908	4.261	0.741	3.538	1.330
	x_{15}	4.186	0.817	4.085	0.830	4.348	0.783	3.846	0.751
Innovation and development of the construction industry	x_{16}	4.226	0.850	4.255	0.820	4.217	0.855	4.154	0.987
	x_{17}	4.062	0.958	4.170	0.916	4.029	0.970	3.846	1.068
	x_{18}	3.721	1.090	3.660	1.089	3.768	1.059	3.692	1.315
	x_{19}	3.992	0.956	4.000	0.933	3.971	0.970	4.077	1.037
Comprehensive impact on the society	x_{20}	4.233	0.843	4.043	0.999	4.348	0.744	4.308	0.630
	x_{21}	4.194	0.781	4.021	0.872	4.304	0.713	4.167	0.725
	x_{22}	4.085	0.848	3.957	0.884	4.217	0.745	3.846	1.143
	x_{23}	4.225	0.841	3.957	0.977	4.406	0.671	4.231	0.926

5.3.1 Reliability analysis

As mentioned, the Cronbach's alpha coefficient was used to test the data reliability in this study. Previous research suggests that if the value of Cronbach's alpha coefficient is 0.7 or above, then the set of items is reliable (Kim and Mueller, 1978). The calculations for Cronbach's alpha coefficient were derived for the aforementioned five factor groups from the information provided by the 95 valid respondents. **Table 5.4** lists the Cronbach's alpha data. The Cronbach's alpha coefficients for the factor groups are 0.823, 0.889, 0.876, 0.911 and 0.908 respectively; all of which exceeded 0.7. In conclusion, the information from the questionnaire survey is reliable.

Table 5.4 Cronbach's alpha of data

Group of factor	Cronbach Alpha	Indicator code	Mean if deleted	Standard deviation if deleted	Alpha if deleted
Project efficiency	0.823	x_1	13.00	3.641	0.773
		x_2	12.95	3.942	0.777
		x_3	12.93	4.081	0.763
		x_4	12.98	4.203	0.795
Key stakeholders' satisfaction	0.889	x_5	16.98	7.156	0.857
		x_6	16.99	7.148	0.850
		x_7	17.26	7.239	0.870
		x_8	17.16	7.460	0.887
		x_9	17.13	6.725	0.856
Organizational strategic goals	0.876	x_{10}	20.90	12.576	0.893
		x_{11}	20.69	11.700	0.847
		x_{12}	20.61	11.411	0.841
		x_{13}	20.81	11.824	0.859
		x_{14}	20.80	11.068	0.839
		x_{15}	20.72	11.578	0.843
Innovation and development of the construction industry	0.911	x_{16}	11.78	7.473	0.894
		x_{17}	11.94	6.840	0.881
		x_{18}	12.28	6.343	0.896
		x_{19}	12.01	6.711	0.868
Comprehensive impact on the society	0.908	x_{20}	12.50	4.939	0.881
		x_{21}	12.54	5.047	0.865
		x_{22}	12.65	5.010	0.893

	x_{23}	12.51	4.986	0.886

5.3.2 Analysis of KPIs with the fuzzy set theory

The data for identifying KPIs are obtained from the previous questionnaire survey. However, the experts' opinions could be subjective and involve fuzziness. Therefore, the fuzzy set theory was used to assist in analysing the KPIs (Xu *et al.*, 2012). This theory is suitable and appropriate to address complex problems due to the imprecise, uncertain or unreliable information that characterise real-world systems (Tah and Carr, 2000). Since the introduction in 1965 by Zadeh (1965), this theory has been applied widely in many research areas, such as engineering, management and social science (Xu *et al.*, 2012). Tah and Carr (2000) used the fuzzy set theory to evaluate the construction project risk in considering the consequences in terms of time, cost, quality and safety performance measures of the project. Shen *et al.* (2010) utilised this theory to identify the key assessment indicators for evaluating the sustainability performance of infrastructures.

Unlike the traditional set theory, the membership value in the fuzzy set theory, which refers to the elements in a set, can be any real value from 0 to 1. This value determines the degree of membership of a given set (Tah and Carr, 2000). In other words, the grades of membership in the fuzzy set may fall anywhere in the interval [0, 1], indicating that an element is not a member of the set if the grade of membership falls on the degree of

0. Conversely, an element belongs to the set if the degree is 1 (Hadipriono, 1988).

In the questionnaire, the importance of each indicator is scored from 1 to 5, with 3 as the neutral level and 4 as an important level. Therefore, if the mean of one indicator's score is higher than 4, then the possibility for this indicator to be one of the KPI set is high. Meanwhile, the value of standard deviation (sd) should be considered when determining whether an indicator belongs to the KPI set (Xu *et al.*, 2012). If the sd is large, then the indicator will be less significant. A parameter Z is introduced to determine whether an indicator should be in the KPI set.

$$Z=(Mean-4)/sd. \quad (1)$$

According to statistics theory, the probability of an indicator's score falling within the range $[4, \infty]$ when Z = 1.65 is 95% (Xu *et al.*, 2012), as shown in **Figure 5.2.** However, the scores from the questionnaire survey are not normally distributed because of the fuzziness involved in the process of subjective judgement by the respondents (Shen *et al.*, 2010). Therefore, a fuzzy distribution was used instead of a normal distribution. According to the fuzzy set theory, the possibility for a variable to belong to a group is called the degree of membership of the variable in the fuzzy set (Zimmermann, 2001), which can be calculated as

$$m(x_i)=\int_4^{\infty} f(x_i)dx=1-P_f, \quad (2)$$

where P_f is the possibility that the indicator does not belong to the group.

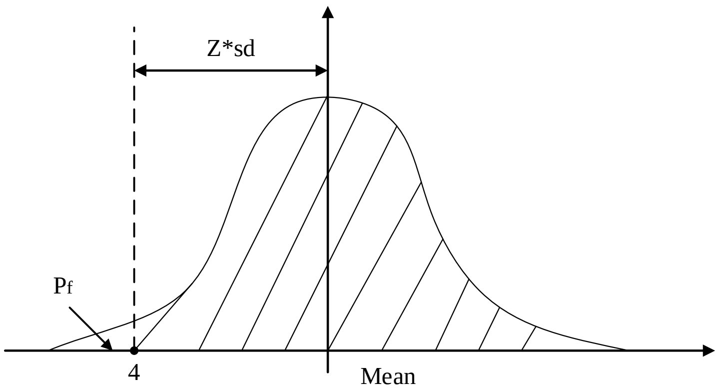

Figure 5.2 Normal distribution of indicator's significance score

A benchmark value is indispensable in identifying whether an indicator is a KPI. That is, $\mathrm{m}_A(x_i)$ should meet a given value (λ) if x_i is considered as a key assessment indicator. In this study, the questionnaire data are gathered from three major groups of experts, namely, owners, contractors and designers; $\widetilde{A_O}$, $\widetilde{A_C}$ and $\widetilde{A_D}$ represent the three different KPI fuzzy set, respectively. Using the calculation results of the significance score of individual assessment indicators and Equations (1) and (2), the value of Z and the degree of membership $\mathrm{m}(x_i)$ can be calculated. **Table 5.5** shows the results of $m_O(x_i)$, $m_C(x_i)$ and $m_D(x_i)$.

The final integrated fuzzy set for each performance indicator should be calculated based on the union of the three fuzzy sets. According to the definition of the union operator on the fuzzy set theory (Yager, 1980), the integrated fuzzy set can be defined as follows:

$$\widetilde{A}=\widetilde{A_O}\cup\widetilde{A_C}\cup\widetilde{A_D}=\left\{x,\ m_{\widetilde{A}_O\cup\widetilde{A}_C\cup\widetilde{A}_D}(x)/x\in X\right\}, \qquad (3)$$

where

$$m_{\widetilde{A}_O\cup\widetilde{A}_C\cup\widetilde{A}_D}=\min\left\{1,\left(m_{\widetilde{A}_O}(x)^n+m_{\widetilde{A}_C}(x)^n+m_{\widetilde{A}_D}(x)^n\right)^{1/n}\right\}. \qquad (4)$$

In this study, n is 23 which refers to the number of indicators. The results of the final integrated fuzzy set $m(x_i)$ according to Equations (3) and (4) are provided in the last column of **Table 5.5**.

Table 5.5 Degree of membership of indicator for KPIs

Indicator set X	Owners		Contractors		Designers		Integrated result
	Z_O	$m_{\tilde{O}}(x_i)$	Z_C	$m_{\tilde{C}}(x_i)$	Z_D	$m_{\tilde{D}}(x_i)$	$m_{\tilde{A}}(x_i)$
x_1	0.363	0.642	0.457	0.676	-0.501	0.308	0.684
x_2	0.360	0.640	0.778	0.782	-0.400	0.344	0.782*
x_3	0.285	0.612	0.809	0.791	0	0.500	0.791*
x_4	0.302	0.619	0.585	0.721	0	0.500	0.722*
x_5	0.347	0.636	0.973	0.835	-0.078	0.469	0.835*
x_6	0.288	0.613	1.030	0.848	-0.171	0.432	0.848*
x_7	0.024	0.509	0.317	0.625	-0.120	0.452	0.625
x_8	0.142	0.556	0.480	0.685	-0.101	0.460	0.685
x_9	0.160	0.563	0.507	0.694	-0.171	0.432	0.694
x_{10}	-0.048	0.481	0.122	0.549	-0.442	0.329	0.550
x_{11}	0	0.500	0.585	0.721	0.101	0.540	0.721*
x_{12}	0.181	0.572	0.626	0.734	-0.081	0.468	0.734*
x_{13}	0.048	0.519	0.239	0.594	-0.410	0.341	0.595
x_{14}	0.047	0.519	0.352	0.638	-0.347	0.364	0.638
x_{15}	0.103	0.541	0.444	0.672	-0.205	0.419	0.672
x_{16}	0.311	0.622	0.254	0.600	0.156	0.562	0.634
x_{17}	0.186	0.574	0.030	0.512	-0.144	0.443	0.575
x_{18}	0.313	0.377	-0.219	0.413	-0.234	0.408	0.425
x_{19}	0	0.500	-0.030	0.488	0.074	0.530	0.538
x_{20}	0.043	0.517	0.467	0.680	0.488	0.687	0.705*
x_{21}	0.024	0.510	0.427	0.665	0.230	0.591	0.667
x_{22}	-0.048	0.481	0.292	0.615	-0.134	0.446	0.615
x_{23}	-0.044	0.483	0.605	0.727	0.249	0.598	0.728*

*The degree of membership is more than 0.7.

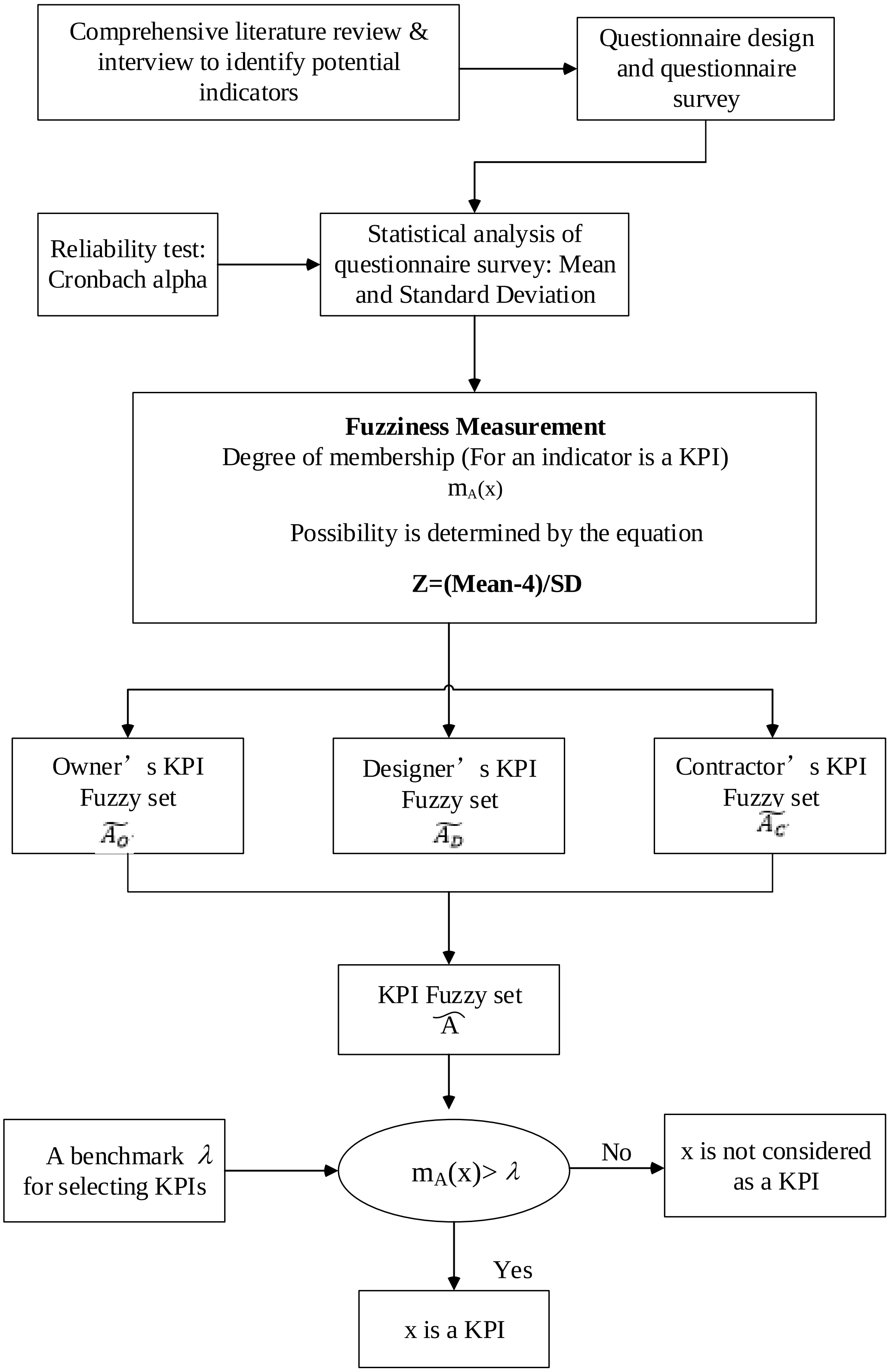

Figure 5.3 KPIs identification process

To identify the final KPIs, the λ-cut set was adopted. This set can transfer a fuzzy set to a classical one. (Tervonen *et al.* (2009))stated that a λ value within the range of 0.5 to 0.8 is effective for analysis. In this study, $\lambda = 0.7$ was adopted as the criterion to select the KPIs.

Figure 5.3 depicts the procedures for identifying the KPIs, which serves as a clear map of how to calculate and identify a KPI. The indicator x_i was selected as a KPI when its integrated $\mathrm{m}_{\tilde{A}}(x_i)$ is equal to or more than 0.7.

5.4 Discussions of findings

This section discusses the research findings shown in **Figures 5.4** and **Table 5.5.** Nine KPIs were identified (**Figure 5.4**), which include the following: 'meeting regulations or specifications', 'meeting health, safety and environment (HSE) goals' and 'meeting the designed function and delivering value/services that the public needed' under project efficiency; 'owner's satisfaction' and 'government's satisfaction' under key stakeholders' satisfaction; 'improved brand/reputation' and new/improved market share' under organisational strategic goals; and 'enhancing people's national pride, confidence and cohesion' and 'delivering social-economic benefits to the community/local' under comprehensive influence on the society.

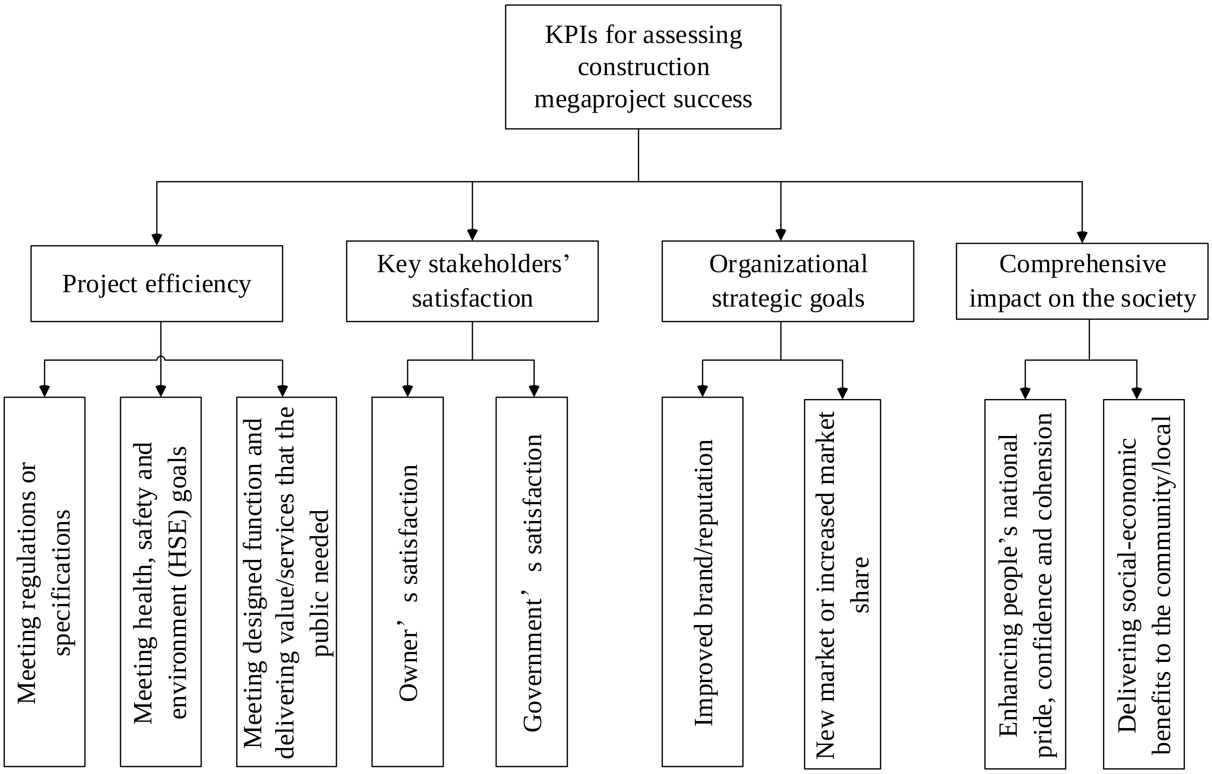

Figure 5.4 KPIs for assessing the success of construction megaprojects

5.4.1 Project efficiency

Three indicators are identified as KPIs in this group, amongst which the indicator meeting regulations or specifications is ranked as the most important, with an $m_{\tilde{A}}(x_3)$ of 0.791. The second most important indicator is meeting HSE goals ($m_{\tilde{A}}(x_2) = 0.782$) and then meeting designed function and delivering value/services that the public needed ($m_{\tilde{A}}(x_4) = 0.722$).

Meeting regulations or specifications is an important prerequisite for the smooth delivery of projects. The client will not accept an unqualified project. Compared with normal-sized projects, megaprojects tend to produce critical facilities that are highly regulated (Greiman, 2013b). This probable reason for this phenomenon is that megaprojects always receive great attention from the government, public and media due to its characteristics, including large-scale investment, political importance and far-reaching effects on the environment, society and welfare. In China, many megaprojects are government-funded, which means that the funds are from taxes (Le *et al.*, 2016b). Consequently, the public would pay more concerns on the news of megaprojects than other types of projects. Moreover, governmental sectors implement strict regulations to ensure the smooth delivery of projects. For example, the audit sector can implement an extremely thorough audit process to improve transparency and achieve comprehensive oversight (Greiman, 2013b). Participants in megaprojects can also establish high-standard regulations or specifications. For example, the participants in the Beijing-Shanghai High Speed Railway, put forward the slogan 'climbing the peak to be world-class' (Wang, 2016). Similarly, the project leader of the Three Gorges Dam emphasised that this megaproject must be built with world-class standards (Li, 2011).

The HSE goals are an important criterion in assessing the success of projects because the construction industry is one of the most unsafe industries and has a high fatality rate (Hare *et al.*, 2006). Projects typically pose a significant negative environmental effect, such as the excessive consumption of materials and resources, a considerable amount of energy and generation of solid waste (Yan *et al.*, 2019, Wang *et al.*, 2018b, Chan and Chan, 2004). This indicator should be highly prioritised in assessing megaproject success because an accident during the construction of a megaproject often leads to serious consequences and widespread public opinion.

Safety issues in China's infrastructure projects are common. According to the statistics of the World Health Organisation (WHO), road fatalities in China are some of the highest in the world with 18.8 fatalities per 100,000 inhabitants per year, which is higher than those in UK (2.9 fatalities). The primary reasons for this phenomenon are poor technical design and road quality issues (WHO, 2015). With the increasing importance of safety and environmental issues in China, the HSE problems involved in projects are attracting increasing attention. For example, Kecen Han from the Shanghai Airplane Design and Research Institute, who is the administrative commander of the C919 airliner project, stated that '*Time is not the most important element; the top priority is to guarantee the safety of the plane'… Words that would not have been heard a decade ago, when the "old normal" in China was speed, first and foremost'* (Chen, 2014). In the Hong Kong-Zhuhai-Macau Bridge, Xihong Dai, Vice Minister of Safety and Environmental Protection Department of Hong Kong-Zhuhai-Macao Bridge Administration, used to praise this megaproject for achieving the goal of 'zero injury, zero pollution, zero accident' (Gao *et al.*, 2018a).

The last key criterion in this group is meeting the designed function and delivering value/services that the public needed. The primary purpose of construction megaprojects is to improve people's lives and facilitate social development (Sheng, 2018). Without considering the value, the project may be regarded as a failure because the public is generally the client or user of the megaprojects. Hence, the value or services that the public needed should not be ignored. Previous studies reported that some infrastructures have been used inefficiently because they cannot meet the value or provide the services that the public actually needed (Shen *et al.*, 2010).

5.4.2 Key stakeholders' satisfaction

Only two indicators are identified as KPIs in this group, namely, owner's and government's satisfaction ($\mathrm{m}_{\tilde{A}}(x_6)$ = 0.848 and $\mathrm{m}_{\tilde{A}}(x_5)$ = 0.835, respectively). Stakeholders are the receivers and implementers of the success indicators; thus, their needs should be satisfied. Many studies have shown that project stakeholders' satisfaction plays a crucial role in sustaining success (Hu *et al.*, 2015a). Normally, the owner is at the core of all stakeholders in a construction project (Yan *et al.*, 2019) and plays a critical role in ensuring the project success (Winch and Leiringer, 2016). Therefore, the owner's satisfaction should be a priority in this factor group.

The project owner is the owner of the project's assets, whereas the project sponsor provides the financial resources for the project. Sometimes, the owner or the sponsor can serve a dual role as a developer or management consultant and as an investor or funder (Greiman, 2013b). In general, owners and sponsors are separate in private-funded projects. However, in construction megaprojects, the government usually play diverse roles, such as decision-maker, funder, project manager and operator. Taking the Hong Kong-Zhuhai-Macau Bridge as an example, in view of the particularity of the co-construction and management of Guangdong, Hong Kong and Macau and based on the existing laws and regulations, the innovative decision-making mechanism for the co-construction and management of the three local governments is established for the construction of this super bridge (Gao *et al.*, 2018b). **Figure 5.5** shows the organisational structure of the HZMB. governments including central government, local government (GDP government, HKSAR government, MSAR government) and related governmental sectors (e.g. National Development and Reform Commission) are involved in this megaproject. Despite the different roles in the project, all play an important role in the successful project delivery. Therefore, government's satisfaction should be considered as a KPI in the group of key stakeholders' satisfaction.

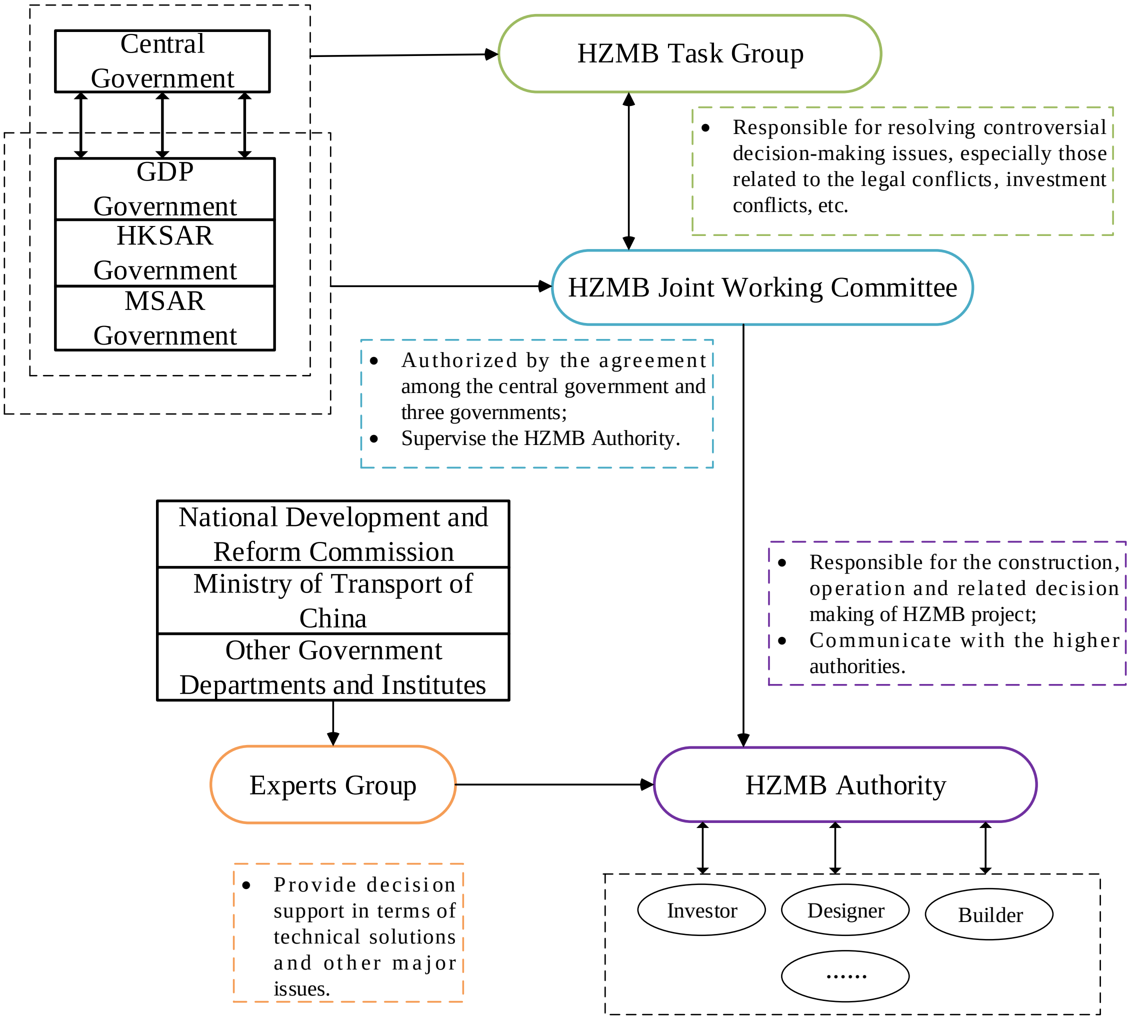

Figure 5.5 Organization structure of the Hong Kong-Zhuhai-Macau Bridge

*Source: the figure is partly cited from the work done by Qiu *et al.* (2019). HZMB=the Hong Kong-Zhuhai-Macau Bridge; GDP Government=the People's Government of Guangdong Province; HKSAR Government=the Government of Hong Kong Special Administrative Region; MSAR Government=the Government of Macau Special Administrative Region.

5.4.3 Organizational strategic goals

Two KPIs are identified in the group of organisational strategic goals, including the improved brand/reputation ($m_{\tilde{A}}(x_{12}) = 0.734$) and new market or improved market share ($m_{\tilde{A}}(x_{11})$ = 0.721). Improving the company's brand or reputation is viewed as an important success criterion in organisational goals (Shenhar *et al.*, 2001). Companies that participate in megaprojects usually have already achieved great success in a certain area and would value the enterprise's development or other long-term interests instead of only focusing on maximising economic benefits (Li and Liang, 2014, Yang *et al.*, 2018). A good brand or reputation can improve the company's competitiveness, thereby contributing to the goal of obtaining additional long-term potential interests (Tao and Guo, 2013).

The project participants in megaprojects in China are mostly state-owned enterprises or successful enterprises that are highly associated with the government (Hu *et al.*, 2015a). Thus, many project managers or leaders hold part-time positions in semi-official industry associations, which is referred to as participating entities' government connection (Le *et al.*, 2016a). **Figure 5.6** shows the overall organisational structure of the Beijing-Shanghai High-speed Railway. In this megaproject, Peiyan Zeng, who is the former vice-premier of the State Council of the People's Republic of China, serves as the group leader in the construction leading group of the BSHSR. The vice groups leaders are Ping Zhang, director of the Development and Reform Commission, Guangzu Sheng, Minister of Railways and Jiwei Lou, deputy sectary of the State Council. A similar phenomenon occurred in the construction leading group office of

BSHSR, BSHSR Co., Ltd. and construction headquarter of BSHSR.

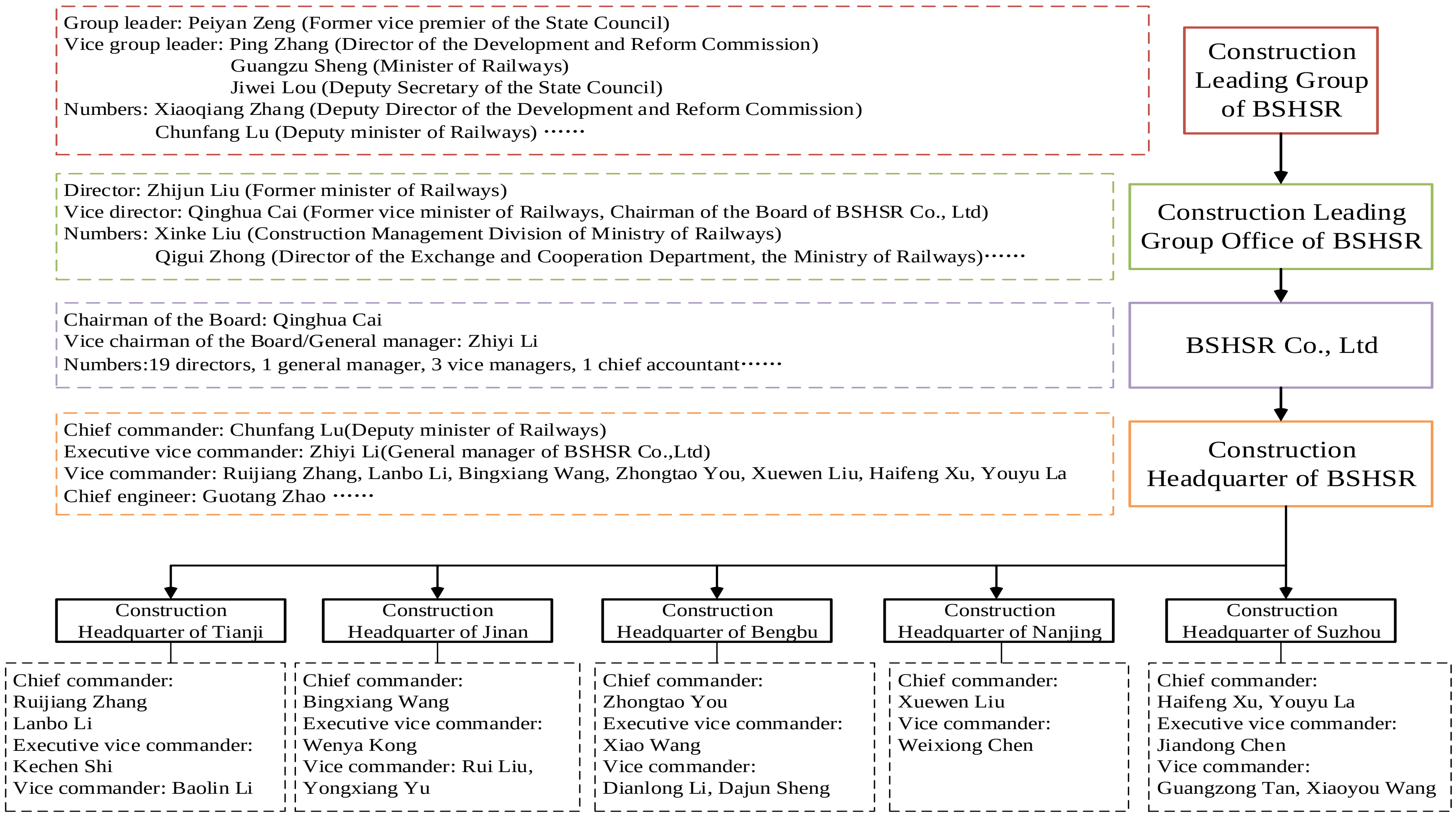

Figure 5.6 Overall organization structure of the Beijing-Shanghai High-speed Railway (BSHSR)

*Source： The data is collected from the Beijing-Shanghai High-speed Railway Co. (2012), translated and illustrated by the author.

Participating in the construction of megaprojects is one of the ways for companies to maintain or strengthen their ties with the government of China (Li *et al.*, 2011). Companies with a good brand or reputation likely garner the favour of the government and thus obtain additional resources, such as higher legitimacy and market assess rights (Li and Liang, 2014). Meanwhile, managers or leaders from companies with a good reputation, specifically state-owned enterprises, also likely obtain political promotion. The pursuit of political promotion may also motivate managers to deliver satisfactory performances in megaprojects, thereby contributing to the enhancement of the company's brand or reputation.

Similar to improved brand or reputation, the new or improved market share also belongs to a long-term organisational goal. This success criterion is identified as a KPI in the group of organisational strategic goals, which is in line with other previous studies (e.g. Yan *et al.* (2019) and Shenhar *et al.* (2001)). As previously mentioned, participating in the construction of megaprojects is a good opportunity to show the strength and good brand image of the participants. Brand effects and experience in megaproject construction can help companies gain project opportunities and market share (Chi *et al.*, 2011, Xing and Chalip, 2009). Compared with short-term benefits, long-term goals, such as new or improved market share, are highly valued by the participants (Turner and Muller, 2003).

5.4.4 Comprehensive impact on the society

Two KPIs are identified in the group of comprehensive influence on the society, including the indicator enhancing people's national pride, confidence and cohesion ($m_{\tilde{A}}(x_{23})$ = 0.728) and delivering social-economic benefits to the communities/local ($m_{\tilde{A}}(x_{20})$ = 0.705). As previously stated, megaprojects often cause wide public concern. When the project is successfully delivered, the public will feel proud of the project; such feeling is important to help maintain social harmony and stability, specifically for China with a population of 1.4 billion (Wang and Cui, 1993). Moreover, megaprojects are usually associated with political importance (Flyvbjerg, 2014). For example, the Qinghai–Tibet Railway is the highest and longest plateau railway in the world, with a total length of 1,142 km. According to the requirements of the Ministry of Railways, the Qinghai–Tibet Railway Company, which is in charge of the construction of this megaproject, should promote national unity and cohesion as a political task. Through the 5-year construction of this railway, the economy of Qinghai and Tibet has developed, and the social cohesion has improved (Wang, 2008).

Megaprojects also produce significant socioeconomic influences. The World Cup on June and July 2014 and the Summer Olympic Games in 2016 in Brazil can deliver approximately $100 billion and create 120 thousand new jobs (Ernst and Terco, 2011). (Graham, 2007) used the data of the London metropolitan region to show how a new rail line, Crossrail, can increase the social–economic benefits. **Table 5.6** shows the benefits of the Crossrail project.

Table 5.6 Benefits from Crossrail project, London, U.K. (Graham, 2007)

Benefits	Welfare (£million)	GDP(£million)
Business time saving	4487	4487
Commuting time saving	4152	
Leisure time saving	3833	
Total transport user benefits	12832	_
Increase in labor force participation	3094	872
People working longer	0	0
Move to more productive jobs	485	10772
Agglomeration benefits	3580	3094
Increased competition		0
Imperfect competition		485
Exchequer consequences of increased GDP		
Addition to conventional appraisal	7159	
Total	19991	20069

5.5 **Chapter summary**

The focal point of this chapter is to identify what constitutes a construction megaproject success. Firstly, comprehensive literature review and expert interviews were performed to explore the list of potential assessment indicators. Secondly, the survey was conducted to analyse the significance of each assessment indicator. A total of 129 construction industry practitioners responded. Five categories of crucial assessment indicators were revealed, namely, project efficiency, key stakeholders' satisfaction, organisational strategic goals, innovation and development of the construction industry and comprehensive influence on the society. Thirdly, the fuzzy set theory was utilised to identify the nine KPIs for evaluating the success of construction megaprojects, which include meeting regulations or specifications, meeting HSE goals, meeting the designed function and delivering value/services that the public needed, owner's satisfaction, government's satisfaction, improved brand/reputation, enhancing people's national pride and confidence and delivering social–economic benefits to the community/local.

CHAPTER 6 CSFs FOR THE SUCCESS OF CONSTRUCTION MEGA PROJECTS IN CHINA

6.1 Introduction

This chapter aims to analyse the data collected from the questionnaire survey to identify the CSFs for the success of construction megaprojects in China. Factor analysis was adopted to structure and explain the findings.

6.2 Identification of CSFs

6.2.1 Option List of CSFs for the success of construction megaprojects

Similar to the identification of the potential success indicators for assessing the success of construction megaprojects, comprehensive literature review and expert interviews were also conducted to identify the potential CSFs. **Table 6.1** lists the identified potential CSFs. The success factors were divided into five categories, namely, project-related, project participant-related, economic and management-related, innovation-related and external environmental factors.

Table 6.1 Option list of CSFs

No.	Categories	Success factors	Source
1	Project-related factors	Clear strategic vision	Literature review
2		Aligned perceptions of project goals and success	Literature review
3		Clear goals and project definition to make sure the project goes smoothly	Literature review
4		Effective strategic planning	Literature review
5		Good governance	Literature review
6		Project organization structure	Literature review
7	Project participants-related	Partnering/relationships with key stakeholders	Literature review
8		Adequate communication and coordination among related parties	Literature review

9	factors	Mutual trust among project stakeholders	Literature review
10		Capabilities and leadership of the owner	Literature review
11		Capabilities and leadership of project managers	Literature review
12		Capabilities and leadership of contractors	Literature review
13		Positive behavior of project participants that could collectively facilitate the effective achievement of construction goals	Interview
14		Great organizational support	Literature review
15		Positive organizational culture for effective project management	Literature review
16	Economic and management related factors	Adequate resource availability	Literature review
17		Establish effective incentive and punishment mechanisms	Interview
18		Systematic control and integration mechanisms	Literature review
19		Effective risk management	Literature review
20		Effectively address complexities	Literature review
21		Scope management	Literature review
22		Well-formulated and detailed contracts	Literature review
23		Select the appropriate contracting and delivery model	Literature review
24		Adopt competitive and transparent procurement process to effectively control corruption	Interview
25	Innovation related factors	Owners need to clarify the innovation orientation and strategic choice, and also need to guiding the innovation management of participating enterprises	Interview
26		Owners need to provide the necessary innovation resources and innovative environment, such as provide subsidies to promote innovative behavior	Interview
27		Focus on pre-stage research and necessary talents training	Interview
28		Experience and talents accumulated from previous similar projects	Literature review
29		Adopt up to date or innovatively improve technologies and methods	Literature review
30	External environment factors	Direct or strong support of the state (central government)	Literature review
31		Cooperation and strong support from local governments	Interview
32		Public support or acceptance	Literature review

33	Effective external supervision and audit	Interview
34	Full understanding of cultural, financial and legislative requirements	Literature review
35	Economic and political stability	Literature review

6.2.2 Ranking of CSFs

Research data were collected through a questionnaire survey to analyse the significance of the list of **Table 6.1**. The detailed information about the questionnaire development and data collection was already discussed in Section 4.4.3.

SPSS V 25.0 was used to analyse the data collected for the CSFs. The value of Cronbach's coefficient alpha was 0.955, and the Cronbach's coefficients of the five categories were 0.861, 0.870, 0.881, 0.728 and 0.751, respectively. All Cronbach's coefficients were more than 0.7, indicating that the five-point scale measurement was reliable. **Table 6.2** lists the results of Cronbach's alpha data. Scale ranking and factor analysis were applied to analyse the data. The procedure, findings and relevant discussion will be provided in the following sections.

Table 6.2 Cronbach's alpha of data

No.	Categories	Cronbach alpha	Mean if deleted	Standard deviation if deleted	Alpha if deleted
1	Project-related factors	0.861	21.21	10.198	0.858
2			21.32	9.281	0.832
3			21.22	9.999	0.846
4			21.29	9.381	0.828
5			21.32	9.140	0.834
6			21.36	9.341	0.828
7	Project participants-related factors	0.870	34.24	19.325	0.848
8			34.22	19.113	0.847
9			34.36	19.827	0.857
10			34.35	18.713	0.849
11			34.32	18.219	0.842
12			34.36	18.497	0.845
13			34.29	22.769	0.891
14			34.30	19.838	0.858
15			34.40	19.335	0.858
16	Economic and management related factors	0.881	33.37	23.595	0.871
17			33.73	27.137	0.907
18			33.53	21.829	0.847
19			33.47	22.157	0.851
20			33.52	22.548	0.857
21			33.53	22.173	0.850
22			33.45	22.359	0.852
23			33.47	23.485	0.868
24			33.59	25.400	0.898
25	Innovation related factors	0.728	16.38	5.394	0.622
26			16.34	5.695	0.629
27			16.22	5.874	0.633
28			16.20	6.834	0.767
29			16.19	6.657	0.731
30	External environment factors	0.751	21.12	6.328	0.693
31			21.09	7.360	0.736
32			21.22	6.531	0.696
33			21.47	7.204	0.772
34			21.19	6.043	0.667
35			21.16	6.715	0.719

Table 6.3 lists the ranking or CSFs for the success of construction megaprojects. If two or more factors have the same mean value, then the one with the lowest standard deviation will be ranked as the factor with the highest importance. Xu *et al.* (2011) suggested that in the five-point questionnaire, the factors with means of more than or equal to 4 can be viewed as CSFs. This criterion is adopted in this study. A total of 32 factors were identified as CSFs that significantly influence the success of construction megaprojects. The factors ‘effective external supervision and audit’, ‘establish effective incentive and punishment mechanisms’, ‘owner’s clarification of the innovation orientation and strategic choice’ and ‘guiding the innovation management of participating enterprises’ were excluded from the list of CSFs. Table 6.3 summarises the ranking of the factors according to the mean values.

Table 6.3 Ranking of CSFs

	Success factors	Mean	Standard deviation
CSF1	Adequate communication and coordination among related parties	4.38	0.752
CSF2	Cooperation and strong support from local governments	4.36	0.637
CSF3	Partnering/relationships with key stakeholders	4.36	0.728
CSF4	Clear goals and project definition to make sure the project goes smoothly	4.33	0.741
CSF5	Clear strategic vision	4.33	0.764
CSF6	Direct or strong support of the state (central government)	4.33	0.782
CSF7	Adequate resource availability	4.33	0.842
CSF8	Positive behavior of project participants that could collectively facilitate the effective achievement of construction goals	4.32	0.696
CSF9	Great organizational support	4.3	0.756
CSF10	Economic and political stability	4.29	0.762

CSF11	Capabilities and leadership of project managers	4.29	0.85
CSF12	Full understanding of cultural, financial and legislative requirements	4.26	0.786
CSF13	Well-formulated and detailed contracts	4.26	0.803
CSF14	Capabilities and leadership of the owner	4.26	0.832
CSF15	Effective strategic planning	4.25	0.781
CSF16	Capabilities and leadership of contractors	4.25	0.829
CSF17	Mutual trust among project stakeholders	4.24	0.748
CSF18	Effective risk management	4.24	0.818
CSF19	Select the appropriate contracting and delivery model	4.24	0.827
CSF20	Public support or acceptance	4.23	0.734
CSF21	Aligned perceptions of project goals and success	4.22	0.822
CSF22	Good governance	4.22	0.859
CSF23	Positive organizational culture for effective project management	4.21	0.835
CSF24	Project organization structure	4.19	0.788
CSF25	Effectively address complexities	4.19	0.827
CSF26	Scope management	4.18	0.805
CSF27	Systematic control and integration mechanisms	4.18	0.824
CSF28	Adopt up to date or innovatively improve technologies and methods	4.14	0.845
CSF29	Experience and talents accumulated from previous similar projects	4.13	0.905
CSF30	Focus on pre-stage research and necessary talents training	4.12	0.797
CSF31	Adopt competitive and transparent procurement process to effectively control corruption	4.12	0.941
CSF32	Owners need to provide the necessary innovation resources and innovative environment, such as provide subsidies to promote innovative behavior	4.00	0.843
CSF33	Effective external supervision and audit	3.98	0.824
CSF34	Establish effective incentive and punishment mechanisms	3.98	0.852
CSF35	Owners need to clarify the innovation orientation and strategic choice, and also need to guiding the innovation management of participating enterprises	3.95	0.917

6.3 Factor analysis

Thirty-two CSFs are not sufficient to explain the success of a project. Thus, factor analysis was adopted to explore and identify the underlying relationships amongst the identified CSFs. This statistical technique can analyse the structure of interrelationships of a considerable number of variables by defining a set of common underlying factors (Hair *et al.*, 1998). The factor analysis was conducted through a two-step process: factor extraction and rotation. The former aims to determine the factors through principal component analysis (PCA). PCA is a common factor analysis method that can mathematically represent the derived linear combinations to avoid the need for questionable causal models (Johnson, 1998). By contrast, factor rotation was conducted to enhance the interpretability of the factors. The Varimax rotation technique was used in this step because this technique can produce rotated component matrixes that are easy to interpret (Akintoye, 2000). This approach is widely used in construction management research (Chan *et al.*, 2004a). **Table 6.4** shows the results of the factor analysis of the 32 CSFs.

Table 6.4 Variance explained by the success factor variables

Component	Eigenvalue	Percent of variance explained	Cumulative percent of variance explained
1	14.335	44.797	44.797
2	2.986	9.331	54.128
3	1.507	4.709	58.837
4	1.308	4.087	62.924
5	1.252	3.914	66.838
6	1.168	3.651	70.489
7	0.916	2.861	73.350
8	0.784	2.449	75.799
9	0.763	2.385	78.183
10	0.710	2.218	80.401
11	0.657	2.053	82.454
12	0.531	1.659	84.113
13	0.494	1.543	85.655
14	0.453	1.417	87.072
15	0.440	1.376	88.448
16	0.403	1.260	89.708
17	0.364	1.137	90.844
18	0.359	1.121	91.966
19	0.330	1.031	92.996
20	0.294	0.918	93.915
21	0.244	0.764	94.678
22	0.241	0.753	95.432
23	0.217	0.678	96.110
24	0.210	0.656	96.766
25	0.191	0.598	97.363
26	0.160	0.500	97.863
27	0.152	0.474	98.338
28	0.136	0.425	98.763
29	0.116	0.362	99.125
30	0.110	0.345	99.470
31	0.092	0.288	99.758
32	0.077	0.242	100.000

The eigenvalue represents the total variance explained by each factor. For example, as the linear combination formed by the combination of component 1 has a variance of

14.335, which accounts for 44.797% of the total variance of the 32 factor variables (Table 6.3). As stated in a previous section, the KMO test is a measure of sampling adequacy, which compares the magnitudes of the partial correlation coefficients (Lam *et al.*, 2008). The value of KMO in this study is 0.910, which is greater than 0.5. In addition, the Bartlett test of sphericity is 3,188.353, and the associated significance level is 0.000. These results indicate that the sample data are acceptable and appropriate for factor analysis.

After factor extraction and rotation, the extracted factors should be renamed as a cluster in the interpretation of the results of the analysis. Six clusters with eigenvalues more than 1 are extracted. **Table 6.5** shows the cluster matrix after the Varimax rotation, and **Table 6.6** presents the final statistics of the PCA; the extracted clusters account for 70.489 of the variances.

Table 6.5 Cluster matrix after varimax rotation

	Component					
	1	2	3	4	5	6
CSF25	0.823					
CSF26	0.735					
CSF13	0.693					
CSF4	0.693					
CSF27	0.691					
CSF18	0.688					
CSF17	0.589					
CSF21	0.587					
CSF7	0.572					
CSF15	0.491					

CSF11	0.791					
CSF14	0.764					
CSF22	0.740					
CSF16	0.629					
CSF24	0.560					
CSF3	0.539					
CSF1	0.524					
CSF5	0.500					
CSF29	0.471					
CSF30		0.870				
CSF2		0.823				
CSF32		0.812				
CSF31		0.628				
CSF20			0.794			
CSF12			0.693			
CSF6			0.571			
CSF19				0.792		
CSF10				0.724		
CSF28				0.523		
CSF8					0.829	
CSF9					0.728	

Table 6.6 Final statistic of PCA

Clusters	Eigenvalues	Percentage of variance	Cumulative percentage of variance
1	5.629	17.592	17.592
2	5.138	16.057	33.649
3	3.118	9.744	43.393
4	3.034	9.480	52.873
5	2.853	8.917	61.790
6	2.784	8.699	70.489

6.4 Discussions of findings[8]

Based on the examination of the inherent relationships amongst the 32 CSFs under each of the clusters, six clusters were extracted using factor analysis (**Table 6.7)**. The clusters include project management action, project participant-related factors, application of innovation management approaches, external factors, economic factors and organisational factors.

Table 6.7 Six clusters extracted by factor analysis

	Clusters	CSFs
Cluster 1	Effectiveness of project management action	• CSF25 Effectively address complexities • CSF26 Scope management • CSF13 Well-formulated and detailed contracts • CSF4 Clear goals and project definition to make sure the project goes smoothly • CSF27 Systematic control and integration mechanisms • CSF18 Effective risk management • CSF17 Mutual trust among project stakeholders

[8] Some content of discussions is from the following publication: He Q.H, Xu J.Y, Wang T and Chan Albert P.C. (2019) "Identifying the driving factors of successful megaproject construction management: Findings from three Chinese cases." Frontiers of Engineering Management, 1-12, Doi: 10.1007/s42524-019-0058-8.

		• CSF21 Aligned perceptions of project goals and success • CSF7 Adequate resource availability • CSF15 Effective strategic planning
Cluster 2	Project participants-related factors	• CSF11 Capabilities and leadership of project managers • CSF14 Capabilities and leadership of the owner • CSF22 Good governance • CSF16 Capabilities and leadership of contractors • CSF24 Project organization structure • CSF3 Partnering/relationships with key stakeholders • CSF1 Adequate communication and coordination among related parties • CSF5 Clear strategic vision • CSF29 Experience and talents accumulated from previous similar projects
Cluster 3	Application of innovation management approaches	• CSF30 Focus on pre-stage research and necessary talents training • CSF2 Cooperation and strong support from local governments • CSF32 Owners need to provide the necessary innovation resources and innovative environment, such as provide subsidies to promote innovative behavior • CSF31 Adopt up to date or innovatively improve technologies and methods
Cluster 4	External factors	• CSF20 Public support or acceptance • CSF12 Full understanding of cultural, financial and legislative requirements

		• CSF6 Direct or strong support of the state (central government)
Cluster 5	Economic factors	• CSF19 Select the appropriate contracting and delivery model • CSF10 Economic and political stability • CSF28 Adopt competitive and transparent procurement process to effectively control corruption
Cluster 6	Organizational factors	• CSF8 Positive behavior of project participants that could collectively facilitate the effective achievement of construction goals • CSF9 Great organizational support • CSF23 Positive organizational culture for effective project management

6.4.1 Cluster 1: Effectiveness of project management action

This cluster comprises ten CSFs, including 'effectively addressing complexities', 'scope management', 'well-formulated and detailed contracts', 'clear goals and project definition to make ensure the smooth delivery of the project', 'systematic control and integration mechanisms', 'effective risk management', 'mutual trust amongst project stakeholders', 'aligned perceptions of project goals and success', 'adequate resource availability', and 'effective strategic planning'.

Project management is critical for the success of a project. Some factors, such as scope management and well-formulated and detailed contracts, are identified CSFs whether the project is a normal construction or a large-scale project (Chan *et al.*, 2001, Chan *et al.*, 2004a, Cooke-Davies, 2002). However, some CSFs are extremely crucial to the success of construction megaprojects. For example, complex megaprojects can face emergent risks that are not usually present in traditional construction projects, including political risks, catastrophic loss, sophisticated engineering and design risk and substantial unknowns, which can affect the budget and schedule (Greiman, 2013b). Therefore, effective risk management is important to achieve project goals and success. In addition, effectively addressing complexities and systematic control and integration mechanisms should be emphasised in megaproject management to ensure project success (Qiu and Zhang, 2018, Hu *et al.*, 2015b, Davies and Mackenzie, 2014). The complexity of a system depends on the number and variety of components, including the interdependencies amongst them (Shenhar *et al.*, 2001, Belassi and Tukel, 1996). Components produced by different organisations must be integrated into a functioning system. Previous studies revealed that system integration as the core organisational capability refers to dealing with the interdependency, uncertainty and change in complex projects (Davies and Mackenzie, 2014). Megaprojects must devote considerable resources to systems integration to address the highly distinct cross-functional structures (Morris, 2013).

6.4.2 Cluster 2: Project participant-related factors

This cluster includes nine CSFs, namely, 'capabilities and leadership of project managers', 'capabilities and leadership of the owner', 'good governance', 'capabilities and leadership of contractors', 'project organisation structure', ‘partnering/relationships with key stakeholders’, ‘adequate communication and coordination amongst related parties’, ‘clear strategic vision’ and ‘experience and talents accumulated from previous similar projects’.

Capabilities and leadership have been mentioned as essential success factors in several previous studies (Nguyen *et al.*, 2004b). The capabilities and leadership of project managers refer to technical, communication and coordination skills. The capabilities and leadership of owners involve strategic, financial and governance aspects. The capabilities and leadership of contractors refer to the robust construction and delivery capabilities. The governance of megaprojects has become an emerging issue in the expansion of globalisation and plays an important role in project success. Nowadays, multiple governance structures that coexist within an organisation are common in large projects (Greiman, 2013b).

The importance of organizational mode and structure in the megaproject performance has been indicated in many previous studies (Hu *et al.*, 2015a). In China, the mode and structure of organisations in megaprojects are closely related to the administration, which refers to the following: (1) top management groups and construction committees usually organised by the central or local governments and (2) top project leaders often play dual roles in governmental sectors and project management systems (Hu *et al.*, 2015a). This kind of organisation mode has been proved to contribute to the achievement of the project goals (Le *et al.*, 2014b).

Existing studies suggest that good partnering and relationships, which may extend beyond contracts, play important roles in improving project governance and project efficiency and contribute to project success (Zhai *et al.*, 2017, Ning and Ling, 2014). The lack of cross-functional communication is one of the main obstacles in maintaining the effectiveness of the organisation (Shehu and Akintoye, 2010). Considering the construction of megaprojects, which involves numerous participants, communication and coordination are of important factors in achieving successful outcomes during the project execution.

The clear strategic vision is another crucial factor of megaprojects. A strategic vision of the construction megaprojects is always presented in a visual and emotional way and can act as a strong link to deliver exceptional leadership (Shenhar and Holzmann, 2017). Good leaders know how to use the strategic vision to effectively motivate the people involved in the construction projects, including how to combine the vision with the right strategy (Patanakul and Shenhar, 2012). Moreover, technological and managerial experiences accumulated and cultivated from previous project practices or relevant academic programs can provide valuable contributions to the success of similar megaprojects (He *et al.* 2019).

6.4.3 Cluster 3: Application of innovation management approaches

The third cluster comprises four CSFs, namely 'focus on pre-stage research and necessary talents training', 'cooperation and strong support from local governments', 'provision of the necessary innovation resources and innovative environment, such as subsidies, from the owners to promote innovative behaviour' and 'adoption of up-to-date or innovative technologies and methods'.

For mega-sized projects, mature technologies and professionals are not always available. Therefore, relevant academic research and talents training are necessary for the pre-project stage. The adoption of up-to-date or innovative technologies and methods is essential. Technological challenges have been recognised as a crucial issue in megaprojects (Kipp *et al.*, 2008). New technologies and operating procedures were explored, identified, selected and experimented by project organisations to elevate megaproject processes (Davies *et al.*, 2009). In addition, innovations of management systems in megaprojects are an important aspect of innovations. The innovation and application of management systems refer to the establishment or promotion of managerial systems to guide, standardise and control the work according to the characteristics of megaprojects to guarantee a successful megaproject delivery (He *et al.*, 2019b). Traditional management systems could not enough to meet the requirements in megaprojects, such as schedule, cost, quality and safety goals. Meanwhile, these systems are not enough to deal with emergencies or severe accidents in megaprojects because they are high in complexity, risks and number of stakeholders. In the Hong Kong-Zhuhai-Macao Bridge, a three-level of organizational structure was innovatively established to ensure a decision-making mechanism of co-construction and management (Qiu *et al.*, 2019). These innovative project construction systems guaranteed the effective implementation of project goals and project success.

Megaprojects are engines for technological innovations. Important technological innovations can exceed the needs of the project itself and further expand to enhance the competitiveness of the industry and even the country. Owners often represent the country or the government to organise and arrange related technological innovation activities on a strategic level (Zhu *et al.*, 2015). For example, owners need to provide the necessary innovation resources and innovative environment, such as subsidies, to promote innovative behaviours amongst participants. Lastly, the cooperation and strong support from local governments belong to this cluster. Local governments usually coordinate in major construction issues to provide convenience to project teams and help solve the problems.

6.4.4 Cluster 4: External factors

The cluster of external factors includes 'public support or acceptance', 'full understanding of cultural, financial and legislative requirements' and 'direct or strong support of the state (central government)'. Belassi and Tukel (1996) stated that some external organisational factors still exert influence on project success or failure.

Megaprojects usually attract a high public attention because public entities and public spending are involved in the construction process (Feldmann, 1985). Therefore, public support plays an critical role of establishing a harmonious and stable social environment for the smooth implementation of megaproject construction, specifically when some works may negatively affect people's living surroundings (e.g. demolition works) (Yan *et al.*, 2019). On such occasions, support from the public, such as active cooperation and support in migration can reduce the conflicts and help the project teams achieve the project objectives and guarantee project success. The full understanding of cultural, financial and legislative requirements ensures that the megaproject construction is legal. If the project is stopped due to non-compliance with the cultural, financial and legislative requirements, then substantial cost and schedule losses will be incurred.

Central and local governments always attach great importance to the construction of these projects because they are normally symbols. The role of the government, specifically central governments, cannot be replaced in the decision-making and construction of megaprojects (Li *et al.*, 2018). Although some scholars argued that 'projects and politics do not mix', these two are combined in China (Zhai *et al.*, 2017). The setting that participants are either state-owned companies or are closely connected with the government contributes to the successful project outcomes in China (Chi *et al.*, 2011).

6.4.5 Cluster 5: Economic factors

This cluster includes 'selecting the appropriate contracting and delivery model', 'economic and political stability' and 'adoption of the competitive and transparent procurement process to effectively control corruption'. Many previous studies have reported that economic factors can affect project success (Belassi and Tukel, 1996, Chan *et al.*, 2004a). Economic environmental factors can influence the function and decisions of businesses in terms of inflation, economic policy, interest rates and unemployment rates.

Selecting the appropriate contracting and delivery model is a critical factor of project success. An appropriate contracting and delivery mode can reduce risks, complexities and costs. Taking the Hong Kong-Zhuhai-Macao bridge as an example, it has high complexities, such as deep and complex seabed, high technical standards and high risk in sea construction. Consequently, an improved prerequisite general contracting mode of Design/Build has been adopted to the island-tunnel project. In this mode, the owner provided preliminary design and possessed the right to manage the construction consortium. This mode helps to creatively and effectively degrade the special complexities that arise from the multiple dimensions of the project (Qiu and Zhang, 2018). Economic and political stability, which is a critical issue in projects, is also one of the CSFs in this cluster. This factor is highly important in the construction of megaprojects due to the considerable investment and political importance involved.

Moreover, a competitive and transparent procurement process, which can effectively reduce corruption in megaprojects, also plays a vital role in ensuring project success (Locatelli *et al.*, 2017b).

6.4.6 Cluster 6: Organizational factors

The last cluster is the organisational factor, which comprises 'positive behaviour of project participants and can collectively facilitate the effective achievement of construction goals', 'great organisational support' and 'positive organisational culture for effective project management'.

In academia, the positive behaviour of project participants, which can collectively facilitate the effective achievement of construction goals, is referred to as the OCB. In megaprojects, megaproject citizenship behaviour can be defined as the discretionary positive behaviour of project participants, which are not required by formal contracts or regulations, but facilitates the achievement of project goals (Yang *et al.*, 2018). This kind of behaviour can benefit the improvement of labour productivity and organisational efficiency and further benefit the megaproject as a whole (He *et al.*, 2019b). In China's megaproject practice, labour contests launched by the public sectors are common methods to motivate megaproject citizenship behaviour (Yang *et al.*, 2018). The winners will not garner economic awards, but they will receive medals and praises from the media and the government (Tang *et al.*, 2013).

Great support from organisations is also a contributor to the success of construction megaprojects. Megaprojects are commonly managed by the top management team, which plays a vital role in monitoring and managing the projects (Lundrigan *et al.*, 2015). Crosby (2012b) highlighted that support from the top level is necessary for project success. This kind of team plays an important role in coping with complex circumstances and systems and ensuring the implementation and successful delivery of construction projects (Wang *et al.*, 2018a).

Culture can affect the behaviour of the participating entities and employees and thus promotes project performance (Zuo and Zillante, 2011). Research outcomes have demonstrated that positive culture in organizations can effectively enhance employees' work enthusiasm, reduces conflicts, and even maintains harmonious atmosphere within or amongst organisations in megaprojects (Jia *et al.*, 2011, Yang *et al.*, 2018).

6.5 **Chapter summary**

This chapter identified and ranked the CSFs of the success of megaprojects according to importance. A total of 35 optional factors were generated from the literature review and expert interviews. The list was trimmed down to 32 CSFs according to the result of the survey, in which they were then ranked based on importance. Then, the identified CSFs were grouped into six clusters using factor analysis, namely, the effectiveness of project management action, project participant-related factors, application of innovation management approaches, external factors, economic factors and organisational factors.

CHAPTER 7: RELATIONSHIP BETWEEN CSFs AND THE SUCCESS OF CONSTRUCTION MEGAPROJECTS

7.1 Introduction

This chapter investigates the relationship by testing the hypothesis that the identified CSFs in Chapter 6 are positively correlated with the KPIs in Chapter 5 using PLS-SEM method. The principal cluster of CSFs with significant contribution to the success of construction megaprojects is also identified in this chapter.

7.2 A hypothesized model of CSFs and the success of construction megaprojects

On the basis of the findings in Sections 5.5 and 6.4, a hypothesised SEM was developed (**Figure 7.1**). This hypothesised structural model of the CSFs and the success of construction megaprojects comprise two second-order hierarchical models. The former includes six constructs of CSFs, namely, the effectiveness of project management action (PM), project participant-related factors (PP), application of innovation management approaches (IM), external factors (EF), economic factors (ECF) and organisational factors (OF). Meanwhile, the nine identified KPIs comprise meeting regulations or specifications, meeting HSE goals, meeting the designed function and delivering value/services that the public need, owner's satisfaction, government's satisfaction, improved brand/reputation, enhancing people's national pride, confidence and cohesion and delivering social–economic benefits to the community/local. The second-order hierarchical model follows the approach suggested by (Wetzels *et al.*, 2009), which maximises the interpretability of the measurement and the hierarchical models. Moreover, this hypothesised model contains one structural model that measures the causal relationships between the CSFs and KPIs for the evaluation of the success of construction megaprojects. The hypothesis that CSFs are positively correlated with KPIs is to be tested using the hypothesised SEM.

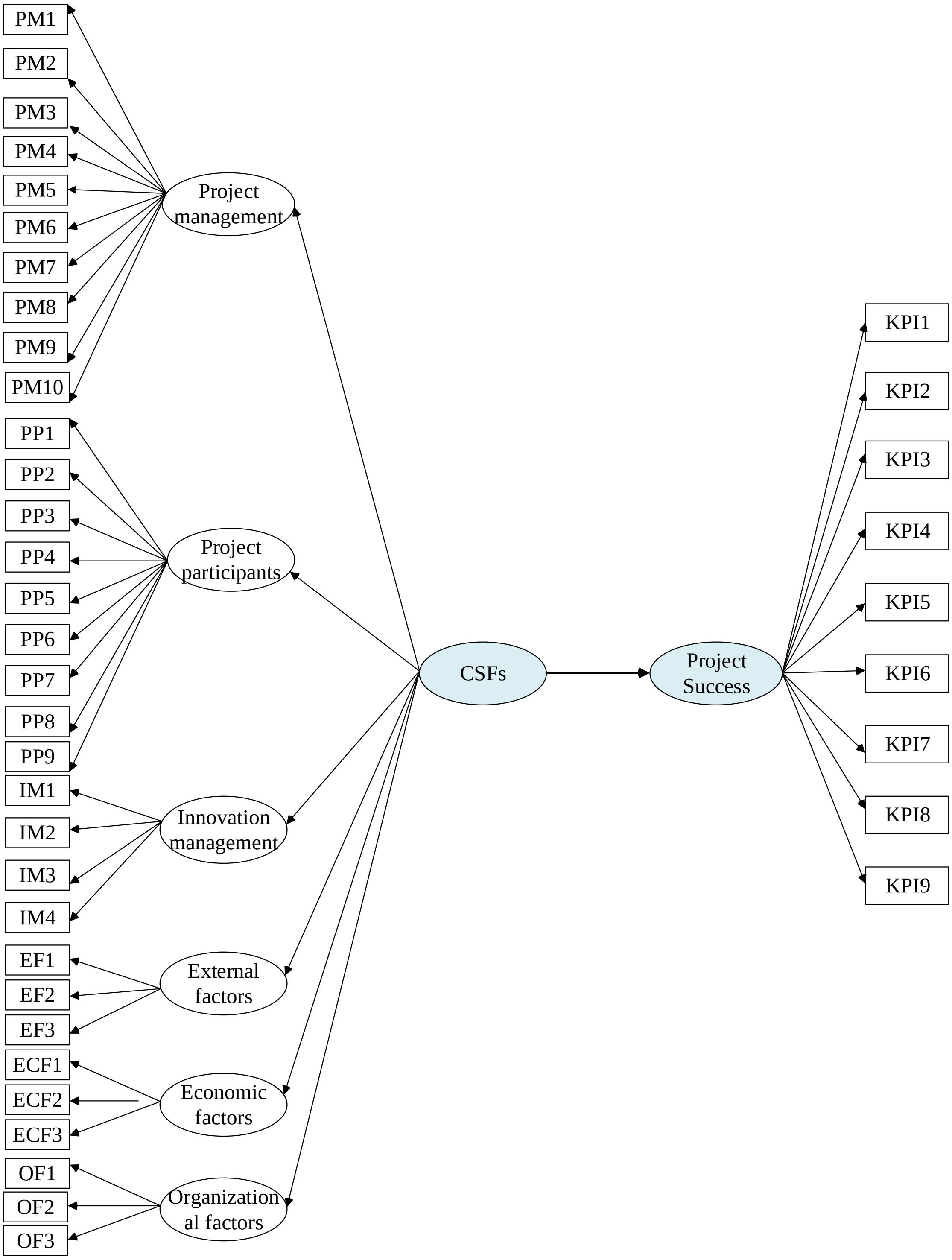

Figure 7.1 A hypothesized SEM of CSFs and the success of construction megaprojects

7.3 Model evaluation

The CSFs and KPIs for evaluating the success of construction megaprojects were collected from the survey results and then inputted into the Smart PLS V3.2.7 software to test the hypothesised SEM. The model contains three types of components, namely, measurement, hierarchical and structural models.

The composite reliability (CR) and average variance extracted (AVE) were determined to evaluate the construction reliability and validity of the hypothesised structural model. **Table 7.1** shows that the CR value of each matrix exceeds 0.7, thereby suggesting the satisfactory level of the reliability of the internal measurement indicators with each construct. The AVE values are higher than 0.5, which similarly indicates the satisfactory level of the convergent validity of the constructs (Hair *et al.*, 2014b).

Table 7.1 Results of construction reliability and validity

Matrix	Cronbach's Alpha	CR	AVE
Effectiveness of project management action	0.943	0.952	0.689
Project participants-related factors	0.919	0.927	0.566
Application of innovation management approaches	0.867	0.906	0.707
External factors	0.798	0.881	0.712
Economic factors	0.845	0.906	0.764
Organizational factors	0.742	0.851	0.655
Project success	0.916	0.930	0.598

*CR=Composite Reliability; AVE=Average Variance Extracted

The t-value is the key evaluation criterion for hierarchical models that lie in the internal paths. **Table 7.2** and **Figure 7.2** show the path coefficients and t-values within the hypothesised structural model. Hair *et al.* (2014b) found that t-values greater than 2.58 suggest the statistical significance at the 0.01 level and satisfactory reliability of the hierarchical models. The path coefficients between the economic factors and success indicators, including the organisational factors and success indicators, have t-values higher than 2.58. This finding shows that only the economic and organisational factors are positively correlated with the KPIs in the hypothesised model.

7.4 Results and discussions

According to the PLS-SEM results, only the economic and organisational factors are positively correlated with the KPIs for evaluating the success of construction megaprojects. Moreover, the economic factors emerged as the principal CSFs that affect the success of construction megaprojects (path coefficient of 0.389), followed by the organisational factors (path coefficient of 0.353).

Table 7.2 Paths and t-values in the PLS-SEM analysis

Paths	Path coefficient	t-value	Paths	Path coefficient	t-value
PM1←Project management	0.872	27.987	IM3←Innovation management	0.790	3.896
PM2←Project management	0.814	21.569	IM4←Innovation management	0.799	3.434
PM3←Project management	0.803	18.992	EF1←External factors	0.875	6.997
PM4←Project management	0.806	15.626	EF2←External factors	0.857	8.737
PM5←Project management	0.733	11.703	EF3←External factors	0.797	8.273
PM6←Project management	0.758	11.809	ECF1←Economic factors	0.891	34.064
PM7←Project management	0.760	11.081	ECF2←Economic factors	0.885	27.671
PM8←Project management	0.705	9.233	ECF3←Economic factors	0.845	19.663
PM9←Project management	0.747	11.511	OF1←Organizational factors	0.790	12.800
PM10←Project management	0.441	2.951	OF2←Organizational factors	0.834	15.015
PP1←Project participants	0.857	22.027	OF3←Organizational factors	0.803	14.760
PP2←Project participants	0.897	40.309	KPI1←Project success	0.802	16.980
PP3←Project participants	0.865	25.762	KPI2←Project success	0.793	18.153

PP4←Project participants	0.877	29.794	KPI3←Project success	0.744	12.779
PP5←Project participants	0.883	22.986	KPI4←Project success	0.696	10.602
PP6←Project participants	0.852	23.674	KPI5←Project success	0.863	25.407
PP7←Project participants	0.677	8.518	KPI6←Project success	0.796	15.943
PP8←Project participants	0.764	12.508	KPI7←Project success	0.761	13.696
PP9←Project participants	0.775	12.650	KPI8←Project success	0.765	12.523
IM1←Innovation management	0.897	4.873	KPI9←Project success	0.729	10.219
IM2←Innovation management	0.872	4.032			

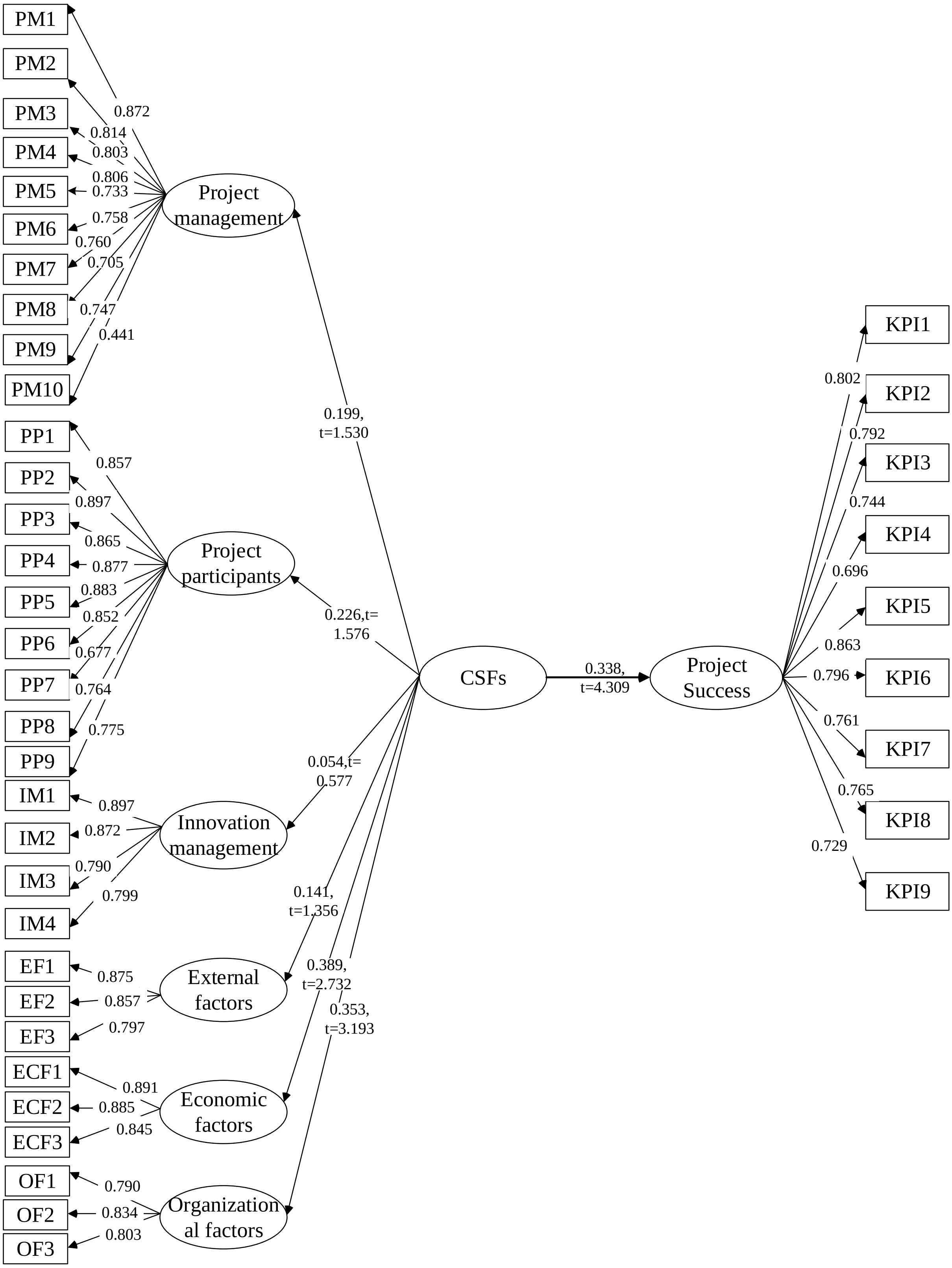

Figure 7.2 Test results of the hypothesized structural equation model

*Project management=Effectiveness of project management action; Project participants=Project participants-related factors; Innovation management=Application of innovation management approaches;

7.4.1 Economic factors

Selecting the appropriate contracting and delivery model ranks first in the group of economic factors, with a path coefficient of 0.891. A project delivery model can refer to the process by which the finance, design, construction, operation and maintenance activities of a project are executed. This model also stipulates the responsibilities and roles of the parties involved in a project (Love *et al.*, 1998). The adoption of an appropriate contracting and delivery model can effectively enhance the efficiency and success rate of a construction project (Rwelamila and Meyer, 1999). The economic and political stability ranks second in this group, with a path coefficient of 0.885, followed by the application of the competitive and transparent procurement process to effectively control corruption (0.845). As previously mentioned, 15,010 cases of corruption were recorded in the public construction section between 2009 and 2011, which caused an estimated loss of 3 billion RMB (approximately US$ 0.42 billion). Existing studies showed the vulnerability of project to corruption increased, which can ruin the construction sector at multiple levels and result in the underperformance of construction projects (e.g. quality defects, cost overruns and delay) (Kenny, 2009).

7.4.2 Organizational factors

Great organisational support ranks first in the group of organisational factors, with a path coefficient of 0.834. In megaprojects, projects are commonly managed by the top management team (Lundrigan *et al.*, 2015). Crosby (2012a) stated that support from the top level is necessary for project success. The positive organisational culture for effective project management is second in the ranking, with a path coefficient of 0.803. In the organisational theory, culture is viewed as an undefined, immanent characteristic of any society (Allaire and Firsirotu, 1984). Deal and Kennedy (1983) stated that weak and strong cultures have a powerful influence on organisational behaviour; strong and powerful culture, however, is the key to improve performance. Strong culture has always been the driving force behind the continued success in organisations (Deal and Kennedy, 1982). The 'positive behaviour of project participants, which can collectively facilitate the effective achievement of construction goals' is the third place, with a path coefficient of 0.790. This kind of behaviour benefits labour productivity and organisational efficiency, including the entire megaproject (Wang *et al.*, 2018a). For example, in the South-to-North Water Transfer project of China, when the prestressed concrete cylinder pipeline (PCCP) installation in the Beijing–Shijiazhuang section encountered an obstacle that led to a high possibility of delay, the PCCP department asked the Hydropower Fifth Division installation department for help. After struggling for almost 40 hours in frigid weather, the problem was solved through the assistance of the latter (Yang *et al.*, 2018).

7.5 Chapter summary

This chapter analyses the principal CSFs by investigating the causal relationships between the identified CSFs and KPIs for evaluating the success of construction megaprojects using PLS-SEM. The results revealed that only economic and organisational factors are positively correlated with the KPIs in the hypothesised model. Moreover, economic factors emerged as the principal CSFs that affect the success of construction megaprojects, followed by organisational factors. The results of this chapter will lay a foundation in establishing a dynamic model for evaluating the success of construction megaprojects in Chapter 8.

CHAPTER 8: ESTABLISHING A DYNAMIC MODEL FOR EVALUATING THE SUCCESS OF CONSTRUCTION MEGA PROJECTS IN CHINA[9]

8.1 Introduction

8.2 Description of the model

8.3 Identification of major variables in the model

8.4 Causal loop diagrams

8.5 Stock-flow diagram

8.6 Chapter summary

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[9] This chapter is largely based upon the following publication:

Ting Wang, Qinghua He*, Yujie Lu, Delei Yang (2018). How Does Organizational Citizenship Behavior (OCB) Affect the performance of megaprojects? Insights from a System Dynamic Simulation. *Sustainability*, 1-18. Doi: 10.3390/su10061708.

8.1 Introduction

8.1.1 Overview of this chapter

A simulation model stemmed from the System Dynamics theory (SD) is able to illustrate the dynamic interrelationships among activities involved in evaluation system of megaproject success. This Chapter presents a dynamic model for evaluating the success of construction megaproject by using SD based on the research findings of Chapter five, six and seven. It is worth noting that as identified in the Chapter 7, the cluster of organizational factors can have a significant effect on the success of construction megaprojects. Thus, the author selects one factor in this group, "positive behavior of project participants that could collectively facilitate the effective achievement of construction goals" to examine its effects on the success of construction megaprojects (explanations in the following section 8.1.2). This chapter starts with a schematic diagram illustrating the steps of developing the model in this study to provide a brief understanding of the model's development (shown in **Figure 8.1**). It is first a brief description of the model, in which its purpose and overall structure are explained. The second step introduces how to identify major variables in the established model. The third step develops a conceptual model based on the causal loop diagram and the final step transforms the causal loop diagram into a stock-flow diagram by using the Vensim PLE software which enables the model to be effectively simulated on a computer.

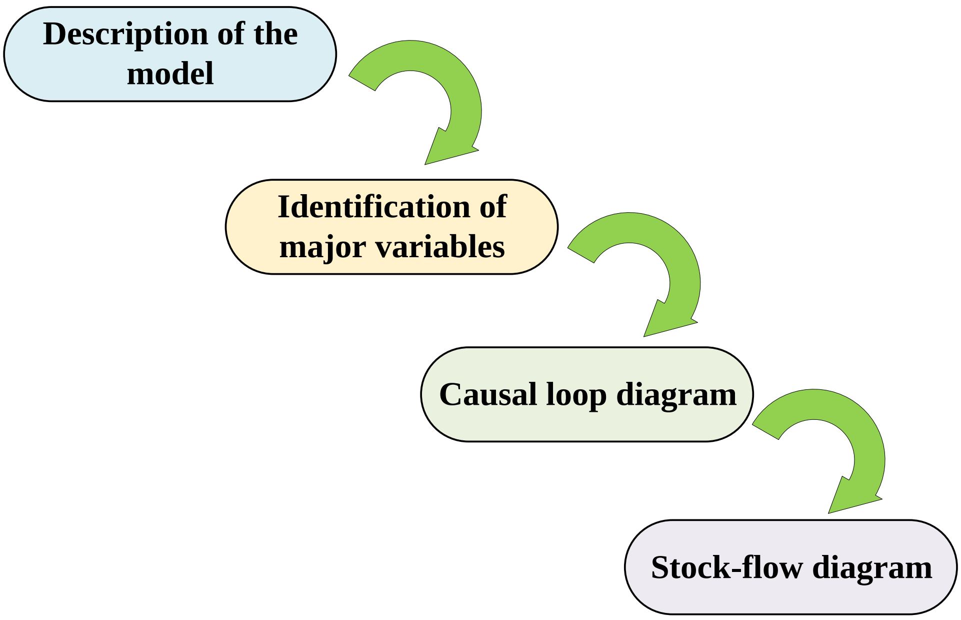

Figure 8.1 Schematic diagram of the procedure for developing the dynamic model (Yuan, 2012)

8.1.2 Reasons for considering OCBs in the model

Megaproject is a highly decentralized multi-organization system (Vries *et al.*, 2016). Seventy percent of the project complexity and management dilemma are caused by the project organization (Vidal and Marle, 2008). Thus, 'organization' is one of the key determinants for the success of mega-size projects (Baiden *et al.*, 2006). Moreover, compared with managerial and economic factors which are emphasized traditionally in project management, organizational factors should be highlighted to contribute to reduce complexity and enhance the level of project success (Yang *et al.*, 2018, Luo *et al.*, 2017). Therefore, although the cluster of 'economic factors' is also identified as a key cluster in the Chapter 7, this study only selects 'organizational factors' to study in detail.

As identified in the Chapter 7, the cluster of ’organizational factors’ contains three key factors. However, the factor of ‘positive behavior of project participants that could collectively facilitate the effective achievement of construction goals’ was chosen to further examine its effects on the success of construction megaprojects in Chapter 8 and Chapter 9. Yang et al., (Yang *et al.*, 2018) advocated that rational economic benefits may not be the only or the most important objective for megaprojects. They do not mind investing more time and resources to benefit the greater megaproject community, rather than just taking the most cost-effective route (Zhai *et al.*, 2017). These types of actions are commonly known as OCB in organizational theory, which could collectively improve the effective functioning of organizations (Organ, 1988). In the megaproject area, this kind of behavior was demonstrated to be vital for achieving management effectiveness especially during the project implementation stage (Patanakul *et al.*, 2016). Despite its significant impact, there is limited research on OCB in megaprojects. The lack of understanding highlights the need for a thorough assessment of OCB in megaproject and its impact on project success (Yang *et al.*, 2018). Therefore, OCB was chosen for an in-depth analysis in this study.

8.2 Description of the model

8.2.1 Purpose of the model

There are three purposes of the established model in this research. Firstly, the purpose is to allow researchers and decision-makers to understand the dynamics of the evaluation system of CMS, particularly to consider the effects of OCBs. The model is developed as an experimental platform for exploring the effects of implementing different OCB measures on the enhancement of success level of construction megaprojects. Secondly, this model aims to provide a solid basis for understanding how major variables in the system affect the success of construction megaprojects. Thirdly, the purpose is to provide a useful tool for presenting potential effects or changes of OCB measures. Once researchers and decision-makers experimented for improving the success of construction megaprojects, then they will be able to provide their findings to others by using the established model to simulate different policy scenarios. One example of this might be examining with cultural effect to see whether it will lead to a significant improvement in the overall success of construction megaprojects.

8.2.2 Overview structure of the model

Determining a boundary for the SD model at the beginning is really important (Sterman, 2000). Only in this way, can the variables that should be excluded or included from the model be determined (Yuan, 2012). As identified in the Chapter 7, the cluster of organizational factors can have a significant effect on the success of construction megaprojects. Thus, in this research, the author selects one factor in this group, 'positive behavior of project participants that could collectively facilitate the effective achievement of construction goals' to examine its effects on the success of construction megaprojects. In line with the model boundary, two main subsystems comprise the model, namely evaluation system of construction megaproject success, and system of OCB adoption. Meanwhile, the author only considers two major parts in the system of OCB adoption, including incentives to adopt OCB and collected OCB. The illustration of interrelationships between these subsystems is shown in **Figure 8.2**.

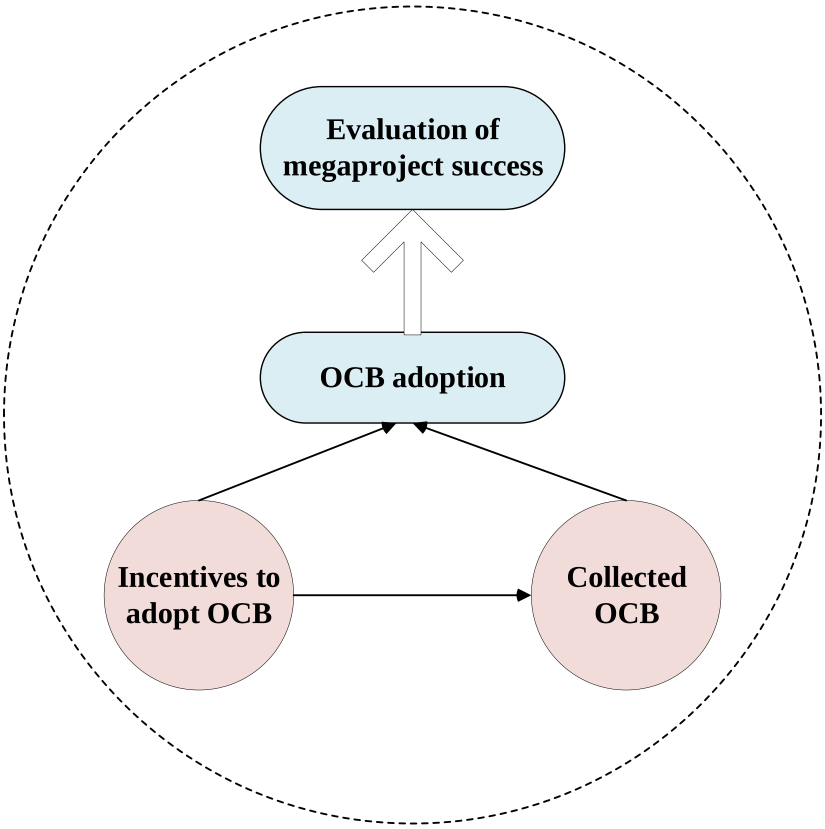

Figure 8.2 Overview structure of the model

8.3 Identification of major variables in the model

The concept of the OCB was firstly introduced in the 1980s, which was defined as "individual behavior that is discretionary, not directly or explicitly recognized by the formal reward system, and that, in the aggregate, promotes the effective functioning of the organization" (Organ, 1988). Although many studies were performed afterwards, literature review on OCB were limited, especially in the field of construction megaprojects. Likewise to the definition of OCB in organizational areas, OCB within the context of construction megaprojects could refer to the positive behaviors of participants not being required in formal contracts, but would contribute to the effective achievement of the project goals (Yang *et al.*, 2018). Studies have already demonstrated that OCB can effectively contribute to the effectiveness of management and benefit the achievement of project success eventually (Patanakul *et al.*, 2016).

The dimensions and driving factors of OCB are two popular subtopics in relevant studies. Most of studies on OCB are conducted in the field of permanent organizations; and they are different from the temporary organizations like project-based organizations (Nielsen, 2009, Braun *et al.*, 2012). Hence, OCBs in construction megaprojects would be featured with distinct dimensions and motivations. Braun *et al.* (2012) indicated that project compliance should be viewed as an important OCB behavior in project-based organizations. Organizational loyalty and sportsmanship are behaviors describing the extents to which individual staff dedicated to their work. Thus, these two behaviors were also characterized as conscientiousness (Nielsen, 2009, Farh *et al.*, 2004). Civic virtue can be interpreted as agreeable relationships in organizations, where the core is considered as harmony maintaining their inter-group relationships (Braun *et al.*, 2012). In the context of permanent organizations, self-development and individual initiative were equivalent to creativity and improvement on working skills (George and Jones, 1997). As such, the innovation behavior streamlined behaviors providing direct helps for colleagues in the megaproject (Farh *et al.*, 2004, Podsakoff *et al.*, 2014). Luo *et al.* (2015) reckoned that these behaviors could be classified as collaboration behavior. In this study, a total of five dimensions of OCB including the 1) project compliance behavior, 2) innovation behavior, 3) collaboration behavior, 4) conscientiousness, and 5) harmonious relationship maintenance behavior are encompassed in the model.

Different from permanent organizations, in construction megaprojects, behavioral motivations of participants are critically important for the in sociality and long-term interests (Braun *et al.*, 2013, Turner and Muller, 2003, Li and Liang, 2014). In China, as mentioned, participants are mostly state-owned enterprises, thus by joining in the megaprojects, participants are also able to fulfill the political appeal (He and Luo, 2014). Those are performed will in the construction of megaprojects are more likely to get promotion opportunities (Flyvbjerg, 2014). Additionally, the external environment also was reported to shape the OCB. The external environment affects substantially on participants' behaviors in the following ways like regulations, project culture, corporate reputation (Cao, 2014, Müller *et al.*, 2014, Wang *et al.*, 2010). Therefore, the driving factors included in established model covered the project culture, potential promotion, corporate reputation, and public satisfaction. As to the evaluation system of construction megaproject success, the major variables are based on the research findings of Chapter 5 which will not be discussed again here.

8.4 Causal loop diagrams

The causal loop diagram is used to illustrate a dynamic process, in which the chain effects in a cause were identified via a series of related variables and then were traced back to the original cause (Yuan, 2012). In this research, two subsystems of evaluation of megaproject success and OCB adoption are integrated in causal loop diagrams that will be discussed in the following section in detailed.

8.4.1 Subsystem of OCB adoption

As stated in the Section 8.3, the subsystem of OCB adoption mainly includes two parts of variables, including the dimensions of OCB and the relevant driving factors. As summarized, the dimensions of OCB contain five kind of behaviors and its driving factors include four factors. In this model, OCB is the driving factor that significantly affected the success of megaprojects. A qualitative analysis was conducted to delineate the interrelationships across the variables after identifying the major variables within the proposed subsystem. A causal loop diagram with four feedback loops is illustrated in **Figure 8.3** as the conceptual model.

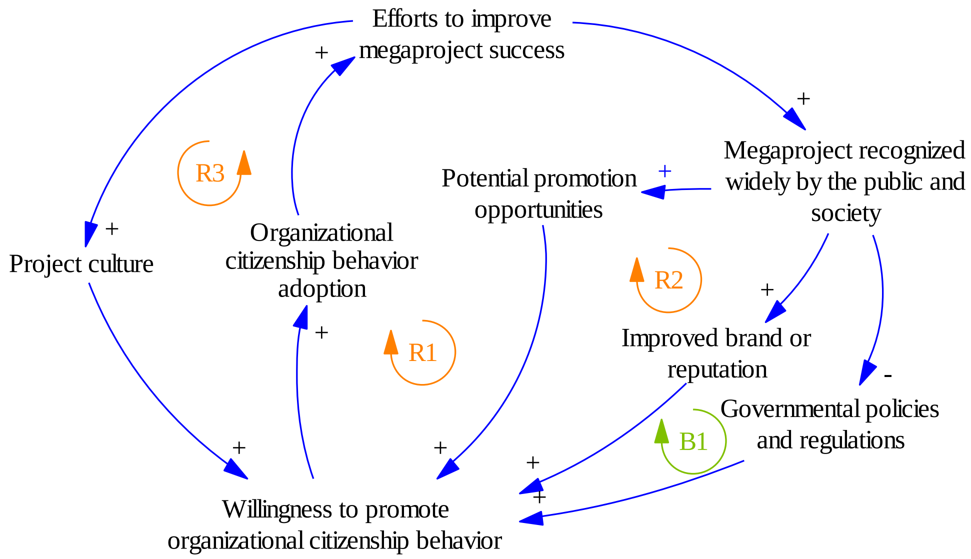

Figure 8.3 Causal loop diagram of subsystem of incentives to adopt OCB

Positive feedback loop R1:

As shown in **Figure 8.4**, the OCB adoption through the positive chain can reinforce itself. After that, megaproject is supposed to be improved and to accelerate the success through the adoption of OCB during the construction phase. The close relationship between enterprises and the relevant governing authorities are close in the construction megaprojects, and meantime the project leaders with good performance could be more likely promoted (Müller *et al.*, 2014). As a result, the involved participants from different sides in megaprojects could become more willing to enhance OCB, which further affected project success again (Yen *et al.*, 2008).

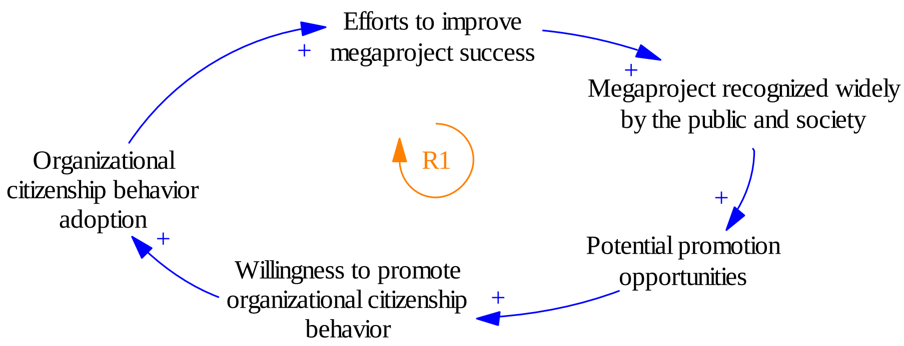

Figure 8.4 Positive feedback loop R1 in the subsystem of OCB adoption

<u>Positive feedback loop R2:</u>

As shown in **Figure 8.5**, the success of the megaproject is positively related to the acceleration of project success, which also influenced the satisfaction of the public and society with the project (Flyvbjerg, 2014). In addition, this result further contributes to the corporate reputation and motives the increase of OCB by all participating sides (Wang *et al.*, 2010).

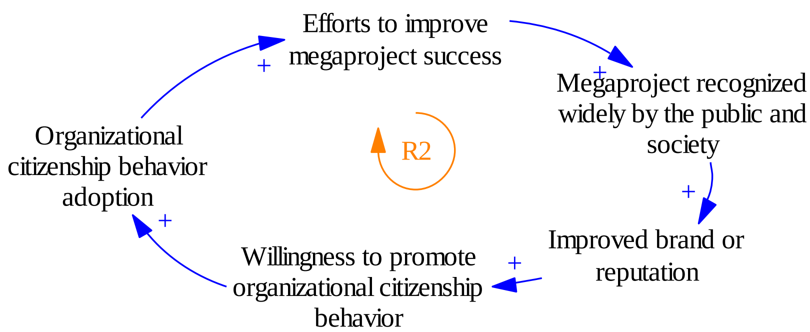

Figure 8.5 Positive feedback loop R2 in the subsystem of OCB adoption

<u>Positive feedback loop R3:</u>

Figure 8.6 clearly shows a feedback loop, where the only difference of R3 to R1 is the magnification of adoption of OCB directly lead to the betterment of the project culture (Wang *et al.*, 2010).

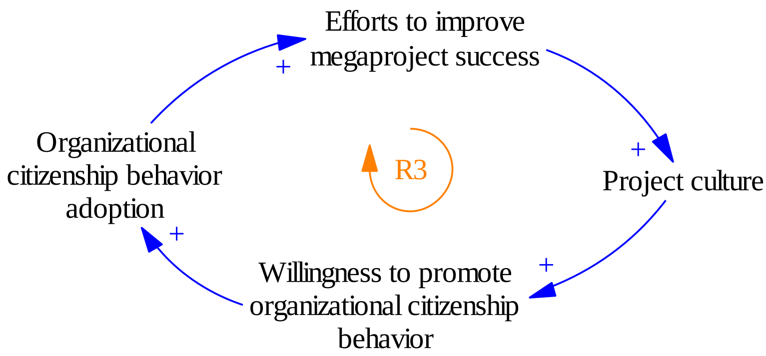

Figure 8.6 Positive feedback loop R3 in the system of OCB adoption

<u>*Negative feedback loop B1:*</u>

In the loop presented in **Figure 8.7**, changes of involved variables could all lead to the negative feedbacks. In case there were an increase in the adoption of OCB, the project success is expected to be accelerated. Consequently, the feeling of satisfaction would be elevated for the social and public sectors, which were followed by the decline regarding the costs from governmental regulations or policies (Müller *et al.*, 2014). As such, the adoption of OCB will decrease accordingly.

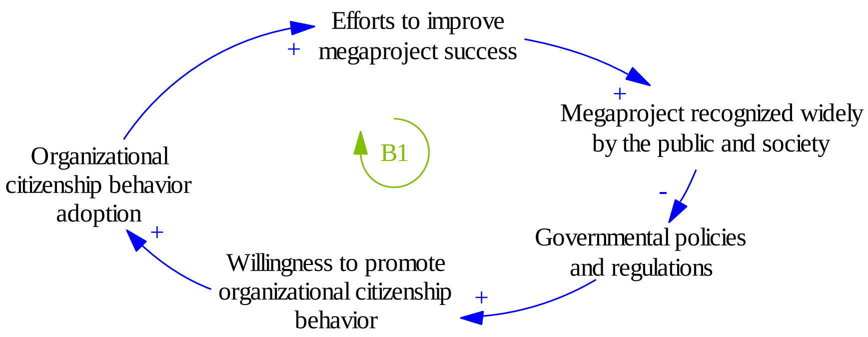

Figure 8.7 Negative feedback loop B1

8.4.2 Subsystem of evaluation of megaproject success

It has been discussed in Chapter 5 that there are nine major variables in the subsystem of evaluation of megaproject success, including ‘meeting regulations or specifications’, ‘meeting HSE goals’, ‘meeting designed function and delivering value/services that the public needed’, ‘owner’s satisfaction’, ‘government’s satisfaction’, ‘improved brand/reputation’, ‘enhancing people’s national pride’, ‘confidence and cohesion’, and ‘delivering social-economic benefits to the community/local’. By connecting these major variables based on their interrelationships, the causal loop diagram of the subsystem of evaluation of megaproject success which contains four feedback loops in total is shown in **Figure 8.8**. Among the feedback loops, there are one negative and three positive loops.

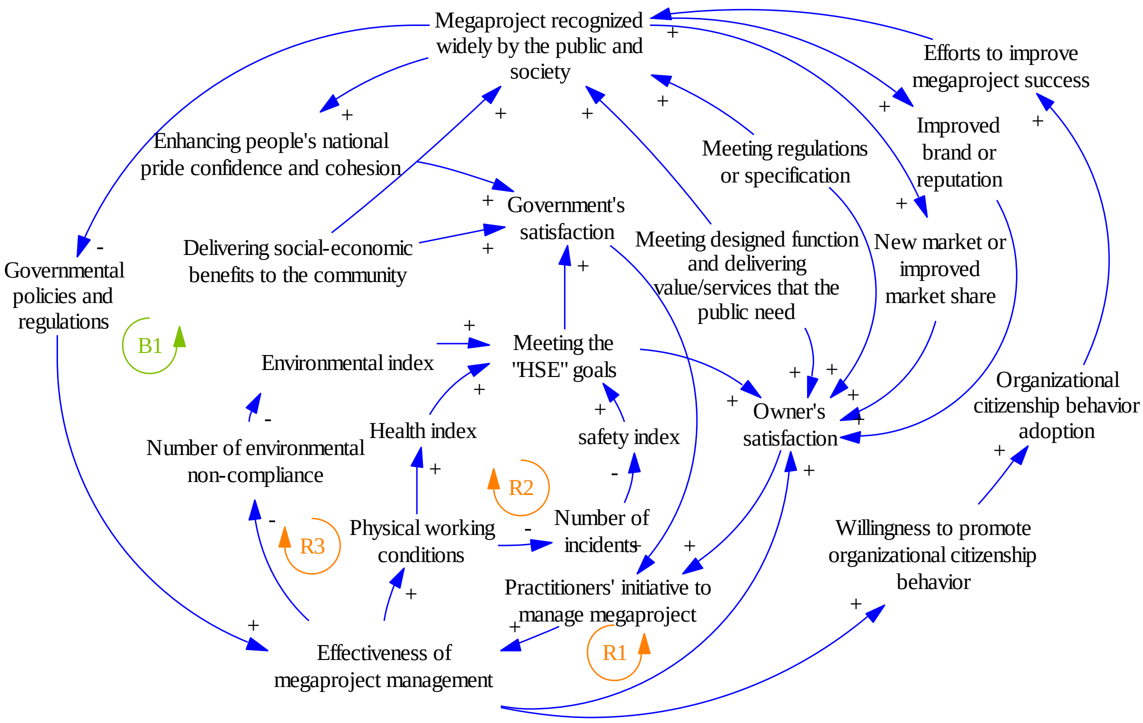

Figure 8.8 Causal loop diagram of subsystem of evaluation of megaproject success

<u>Negative feedback loop B1:</u>

As shown in **Figure 8.9**, this feedback loop is the same with one in **Figure 8.7**, which would connect the two subsystems in the established model.

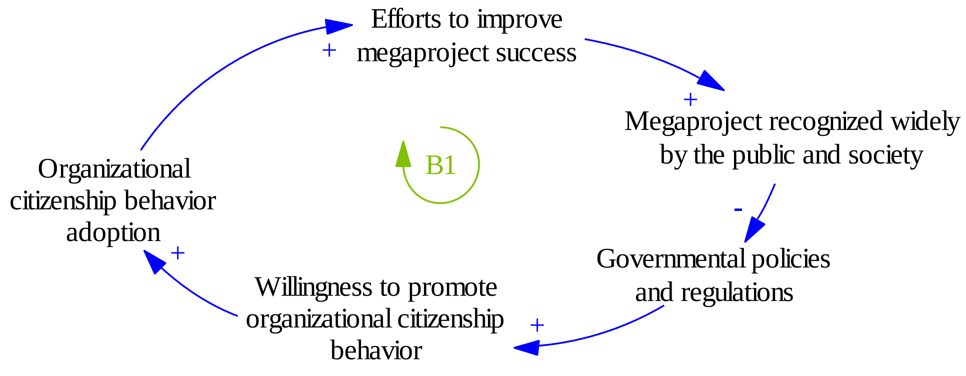

Figure 8.9 Negative feedback loop B1

Positive feedback loop R1:

It can be seen from **Figure 8.10** that the owner's satisfaction is on a self-motivated chain. Suppose that the owner's satisfaction accelerates the practitioners' initiative to manage megaproject, and then further improve the effectiveness of megaproject management (Winch and Leiringer, 2016). Consequently, the effectiveness of megaproject management would affect owner's satisfaction positively again.

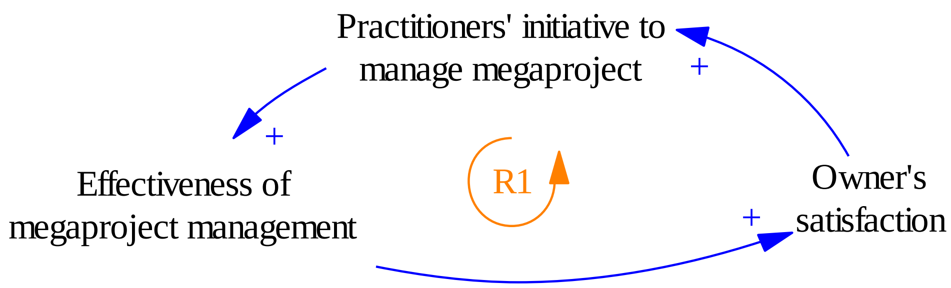

Figure 8.10 Positive feedback loop R1 in the subsystem of evaluation of megaproject success

Positive feedback loop R2:

Figure 8.11 illustrates that the owner's satisfaction is positively relied on previous performance. Suppose that the owner's satisfaction accelerates the practitioners' initiative to manage megaproject, and then further improve the effectiveness of megaproject management (Winch and Leiringer, 2016). Effective megaproject management would enhance working conditions in construction site and improve healthy performance, which would positively contribute to meeting the HSE goals (Leon *et al.*, 2018). Consequently, the owner's satisfaction will be affected again (Maloney, 2002).

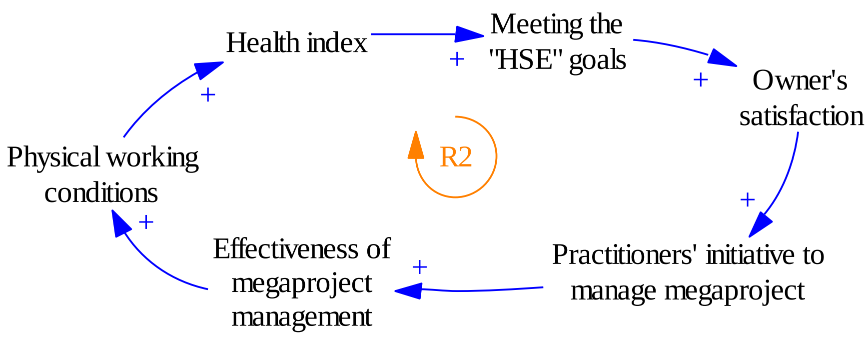

Figure 8.11 Positive feedback loop R2 in the subsystem of evaluation of megaproject success

Positive feedback loop R3:

Figure 8.12 particularly pointed out that improvements in effectiveness of megaproject management was expected to directly cost a reduction on the number of environmental noncompliance and further contributes negatively to environmental index (Tam *et al.*, 2006).

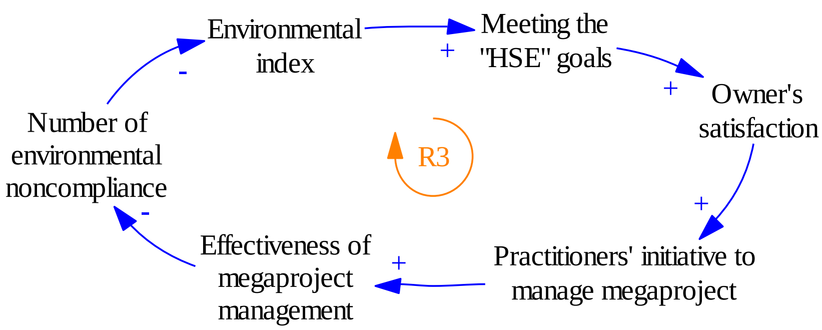

Figure 8.12 Positive feedback loop R3 in the subsystem of evaluation of megaproject success

8.5 Stock-flow diagram

Subsequent to identifying the relationships among the major variables, which were defined within the causal-loop diagram, a stock-flow diagram was carried out to quantify their impacts by using the Vensim PLE software. A casual loop diagram is always developed as a conceptual model of system in our study. Meantime, a stock-flow diagram is constructed from a casual loop that utilized computing simulations. The major difference between them is that the stock-flow diagram is a detailed one and enables a quantitative study. The stock-flow diagram and key definitions of the variables were provided in **Figure 8.13**. And the descriptions on the variables are shown in the **Appendix E**.

8.6 Chapter summary

This chapter provided a stepwise process during the development of the dynamic model, which was expected to assess the success of megaproject constructions. This chapter also explained how the major variables were identified and in which way these factors were related in the subsystems through a causal loop diagram with the assistance of the Vensim PLE software. The next chapter will apply this SD model to simulating the success of construction megaprojects in China.

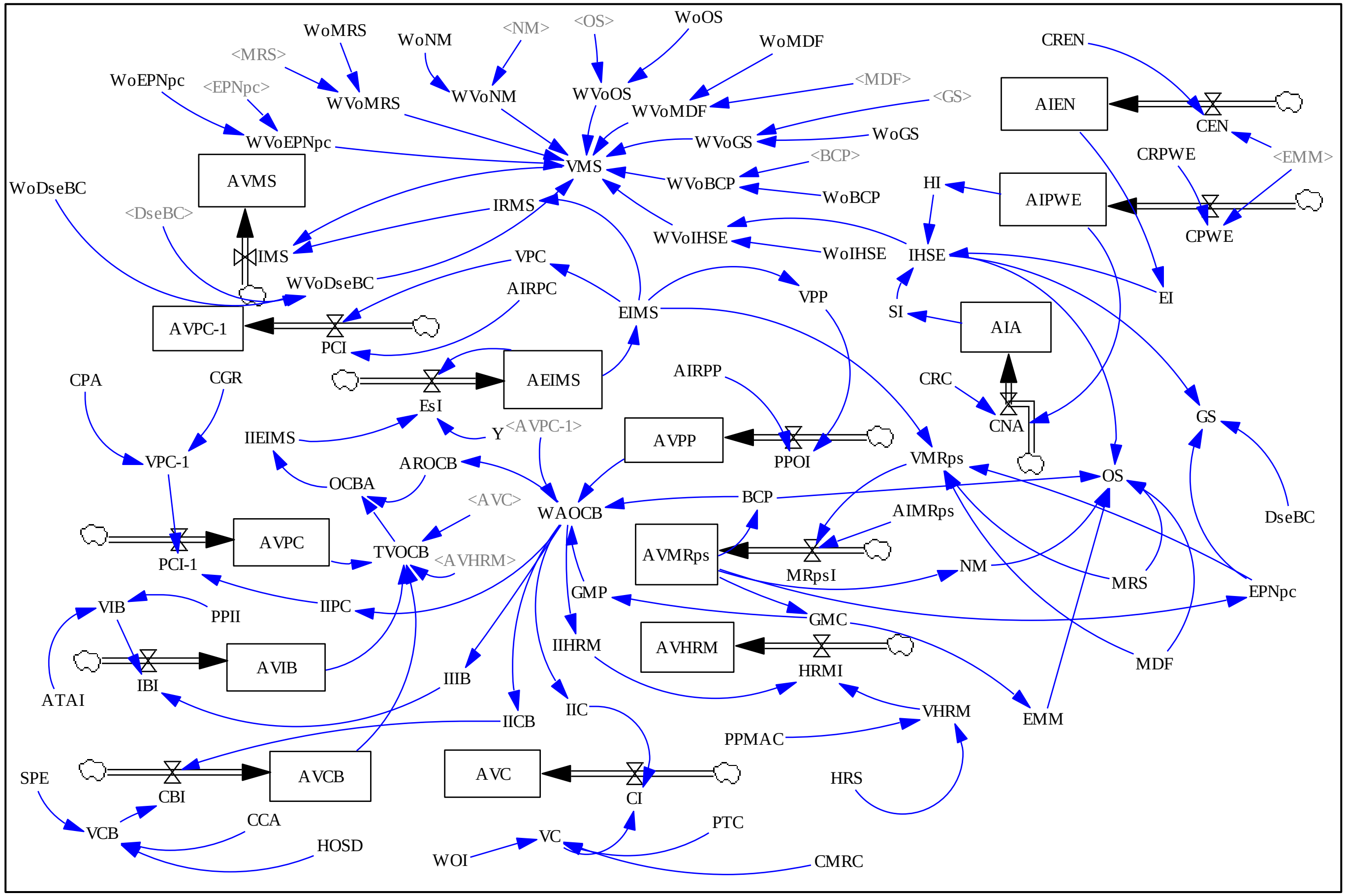

Figure 8.13 The stock-flow diagram of the established model

CHAPTER 9: APPLICATION OF THE SD-BASED MODEL FOR EVALUATING THE SUCCESS OF CONSTRUCTION MEGA PROJECTS[10]

9.1 Introduction

9.2 Methods for quantification of variables

9.3 Model validation

9.4 Policy analysis

9.5Chapter summary

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[10] This chapter is largely based upon the following publication:

Ting Wang, Qinghua He*, Yujie Lu, Delei Yang (2018). How Does Organizational Citizenship Behavior (OCB) Affect the performance of megaprojects? Insights from a System Dynamic Simulation. *Sustainability*, 1-18. Doi: 10.3390/su10061708.

9.1 Introduction

The Chapter 8 provided an exhaustive description of how a dynamic model for evaluating the success of construction mega projects was established by using causal loop diagrams and stock-flow diagrams. This chapter focuses on the application of constructed models. Firstly, this chapter introduces how to quantify variables in the model. Secondly, this study validates the model from different typical tests through the SD approach. Finally, this chapter shows the simulation results of base run of the developed model and analyzes the results within different policy scenarios.

9.2 Methods for quantification of variables

Before performing the computer-based simulation, variables input in the model should be quantified. The selected variables were grouped into three categories, including constant, dependent, and qualitative variables. Each group has been assigned with data from corresponding sources. At first, variables belonging to the constant group refer to these that remain unchanged during the computations and they are not influenced. Generally, their empirical values were obtained from the published materials, such as literature and the data of questionnaire survey in this research. Secondly, dependent variables functioned as matter of other factors and their values were quantified by the judgement of experts who joined a 15-minutes' long session in Shanghai. Again, the selection process of the experts is similar to that adopted for selecting the interview experts and questionnaire respondents discussed in section 4.4.2.1 and 4.4.3.2

respectively. The final values were computed by the Vensim PLE software (Li *et al.*, 2014). The background information of experts can be seen in **Table 9.1**. Supplementary data related to the model are provided in **Appendix F**.

Table 9.1 Profile of the experts consulted in the part

Interviewees	Current Positions	Affiliation	Years working in the project management area	Participated megaprojects
A	Professors	Tongji	23	Shanghai EXPO
B	Project manager	Contractor	11	Shanghai West Bund Media Harbor
C	Project manager	Contractor	12	Shanghai West Railway Station
D	Project supervisor	Consultant compony	8	Shanghai West Bund Media Harbor
E	Project supervisor	Consultant compony	17	Shanghai EXPO

9.3 Model Validation

Prior to quantitative simulation and analysis, the SD model tests were taken to validate the accuracy of the constructed model and ensure that it can well reflect the real conditions (Qudrat-Ullah and Seong, 2010). The tests in this research included three parts including a structure verification test (test 1), a dimensional consistency test (test 2), and a sensitivity test (test 3).

Test 1: structure verification test

This test is to ensure that the structure of established model function logically and in consistence with the existing literature. As shown in **Figure 8.8**, the causal loop diagram is constructed on the existing studies and acknowledged knowledge.

Test 2: dimensional consistency test

Test 2 is to make sure that each equation in the model is dimensionally consistent with the use of the parameters (Ding *et al.*, 2016, Sterman, 2001). Fortunately, with the aid of the Vensim software provides, users can conduct this test function automatically after all the units of the variables have been determined. If the dimensional consistency test fails, the subsequent simulations would not be processed by the system in the Vensim software.

Test 3: sensitivity test

The purpose of the sensitivity test is to understand the functioning ranges of the constructed model, which is expected to exhibit a reliability within a reasonable range. Here, the typical example was taken to demonstrate whether the modelling behaviors reflect the real-world situation. **Figure 9.1** included the dominant variables in the OCBA (organizational citizenship behavior adoption). They vary in accordance with the variables of AIRPP (actual increasing rate of potential promotion). In this sensitivity test, five scenarios were assumed and tested. In the scenario 1, the value of the AIRPP was set as 0.8 (shown in Line 1); in the scenario 2, the value of the AIRPP was set as 0.5 (shown in Line 2); in the scenario 3, the value of the AIRPP was 0.3 (illustrated in

Line 3); in the scenario 4, the value of the AIRPP was set as 0, (illustrated in Line 4); and in the scenario 5, the value of the AIRPP was 0.05 which is also the base scenario in the model (shown Line 5). As shown in **Figure 9.1**, all curves that were generated from five different scenarios varied in a similar pattern. This means the size of AIRPP is proportional to the betterment of OCB. Our sensitivity testing results are in accordance with previous studies. The promotion opportunities became an effective incentive to enhance the OCB within organizations (Li and Liang, 2014) . Therefore, it can be concluded from the established model was sensitive to the changes in variables in a reasonable range, which can be applied to the real simulation and policy analysis.

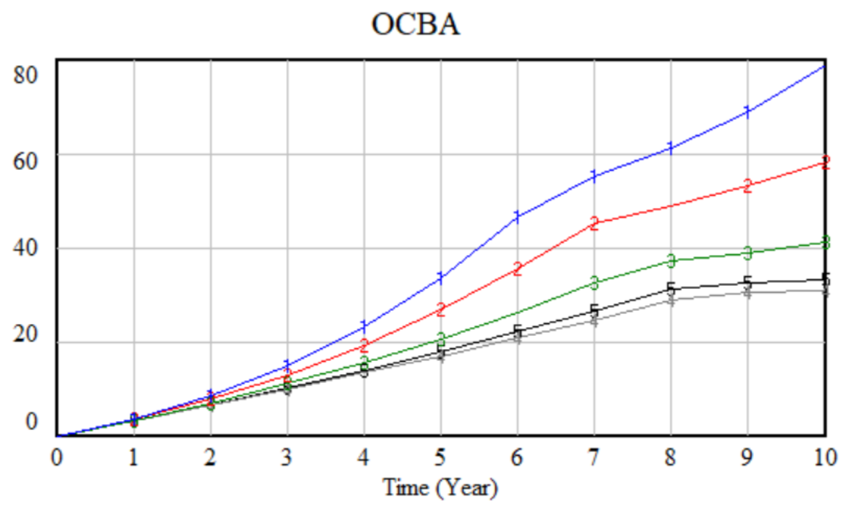

Figure 9.1 An example of a sensitivity test

(Line 1 for scenario 1; Line 2 for scenario 2; Line 3 for scenario 3; Line 4 for scenario 4; Line 5 for scenario 5).

9.4 Policy analysis

In this model, the author initially set a 10 years long period for the simulated megaproject, which is a reasonable de facto duration setting. **Figure 9.2** shows the impacts on the final success of megaprojects. The selected outputs included OCBA, the AVMS (accumulated value of megaproject success), the AVPC-1 (accumulated value of the project culture), the AVPP (accumulated value of the potential promotion), and the AVMRps (accumulated value of megaproject recognized widely by the public and society). **Figure 9.3** further shows the simulated varying trends of AVPC, AVIB, AVHRM (accumulated value of the maintenance of harmonious relationships), the AVCB (accumulated value of the collaboration behavior), the AVC (accumulated value of conscientiousness). The variables were listed in **Table 9.2**.

9.4.1 Results of base scenarios

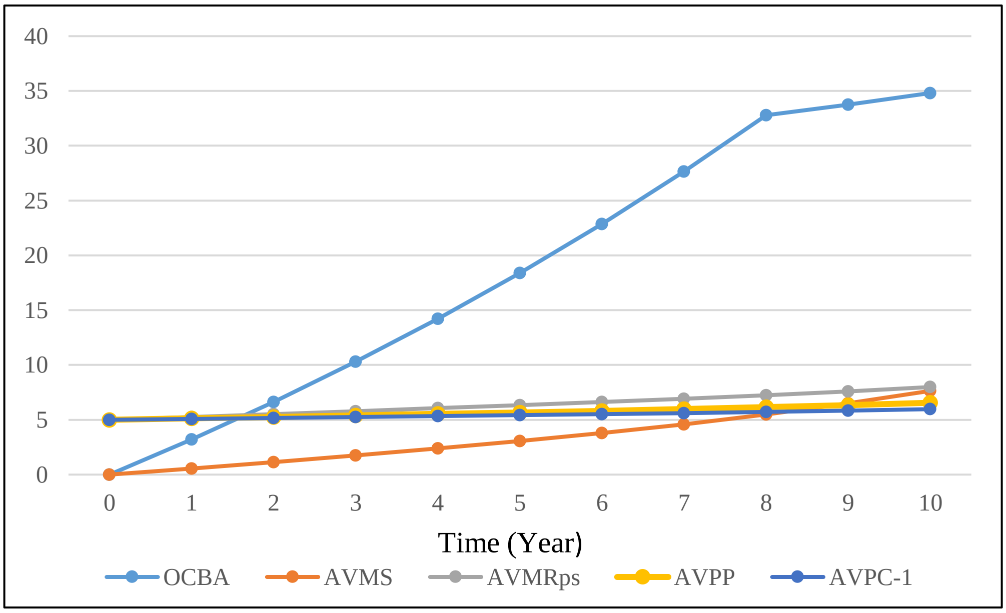

Figure 9.2 The simulation results of the five selected outputs in the base scenario (OCBA, AVMS, AVMRps, AVPP, AVPC-1)

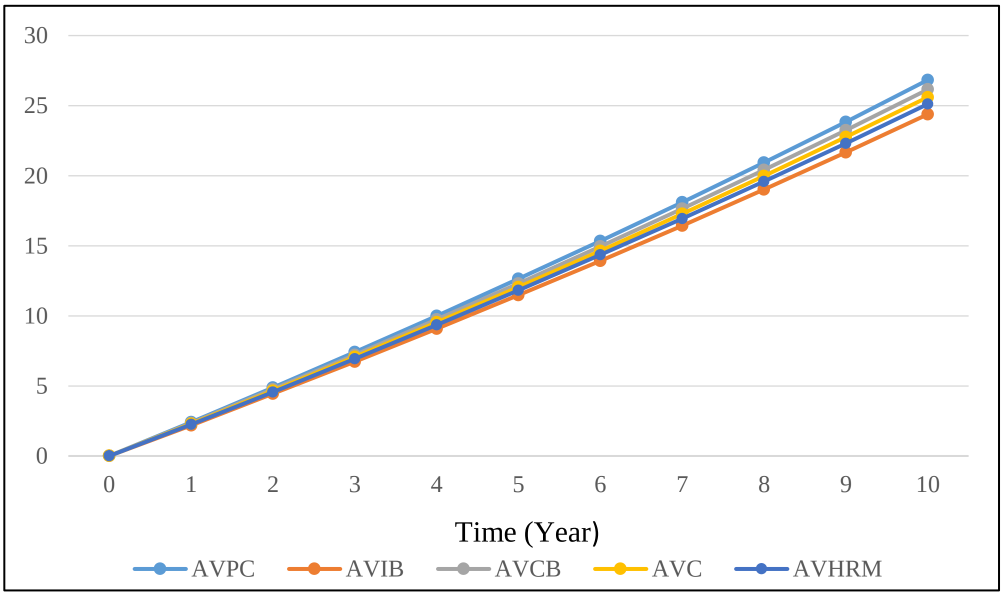

Figure 9.3 The simulation results of the five selected outputs in the base scenario (AVPC, AVIB, AVCB, AVC, AVHRM)

The AVMS is designed to index the success level of construction megaproject. This factor was set to a range from 0 (lowest) to 100 (highest) level. The OCBA examines OCB of participants from the set AVMS ranges. As shown in **Figure 9.2**, although the modeling output increased as a function of time, the main difference can still be observed upon the OCBA. Its value is generally on an increased trend in the first eight years; however, the increment became less and less in the end of the period (**Table 9.2**). It is probably because that the delay in the OCB brought about the increase in AVMS along with the progress of project. As such, a noticeable rise occurred in project success at last. Regarding the the AVMRps, it increased from 5.261 to 7.987. At the same time, the value of AVPP was elevated to 6.554 in the last few years and the AVPC-1 was the slowest growing factor and it reached the maximum point of 5.971 in the end.

Notably, the simulating results of the AVMS appeared to be enhanced during the set period of time. This is in accordance with previous studies (Nielsen, 2009). As shown in **Figure 9.3**, the value of the AVPC is the observed to be the highest among all factors. It was simulated as 26.83 in the end. The maximum values of AVCB, AVC, AVHRM, and AVIB were 26.15, 25.15, 25.11, and 24.38, respectively. This further proved that the project compliance is the most importance OCB for megaprojects, which echoes the research findings stated by Yang *et al.* (2018).

Table 9.2 The simulation results of the selected outputs in the base scenario.

Year	Selected outputs									
	OCBA	AVMRps	AVPP	AVPC-1	AVMS	AVPC	AVIB	AVCB	AVC	AVHRM
1	3.201	5.261	5.133	5.083	0.564	2.409	2.189	2.347	2.298	2.254
2	6.632	5.524	5.267	5.167	1.148	4.876	4.43	4.751	4.652	4.562
3	10.3	5.79	5.401	5.251	1.756	7.401	6.724	7.211	7.061	6.925
4	14.22	6.061	5.537	5.336	2.393	9.985	9.072	9.729	9.526	9.342
5	18.39	6.337	5.676	5.422	3.065	12.63	11.47	12.3	12.05	11.82
6	22.85	6.624	5.821	5.513	3.787	15.33	13.93	14.94	14.63	14.35
7	27.64	6.926	5.976	5.61	4.581	18.10	16.44	17.64	17.27	16.93
8	32.8	7.249	6.147	5.717	5.48	20.93	19.02	20.4	19.97	19.59
9	33.76	7.599	6.337	5.835	6.511	23.84	21.66	23.23	22.75	22.31
10	34.81	7.987	6.554	5.971	7.638	26.83	24.38	26.15	25.6	25.11

9.4.2 Results of policy scenarios

(1) Single-Policy Scenario

Due to the importance of OCB to the improved performance of megaprojects, researchers explored how to promote and what specifically influenced OCB in effect. Among the existing factors, political motivations and project culture background are unanimously reckoned as the typical influencing factors in previous field studies (Li and Liang, 2014, Wang *et al.*, 2010). Therefore, they were selected in our model to simulate the policy analysis. Here, the author implemented two policies in separate ways but analyzed them in parallel, where various scenarios were created for simulation.

On one hand, Policy scenario A and B are designed as single-policy scenarios. They had only one variable changed during the computation. One the other hand, Policy C is used to simulate the multi-policy scenario where we created two independent variables.

- Scenario A: Promotion Effect

This section aims to analyze how the variations of AIRPP can impose effects on AVMS, OCBA, AVC, AVCB, AVHRM, AVIB, and AVPC. Initially, AIRPC was set to a value of 0.05 for the run of base. After that, this value was gradually tuned up to 0.2 and 0.4 for PSA-1 and PSA-2, respectively. As shown in **Table 9.3**, the increase in the value of AIRPP co-occurred with the improvement in the OCBA. This is key to the success of construction projects. The OCBA increased by 22.40% and 55.10% in conditions of PSA-1 and PSA-2 and they reached to levels of 42.606 and 53.989, respectively. Similarly, the AVMS also increased by 2.03% and 4.08% in PSA-1 and PSA-2, in comparison with the baseline scenario. With respect to other five selected variables (AVPC, AVIB, AVCB, AVC, and AVHRM), we also observed increases in their values in end stage of simulation (Table 9.3). And among them, the AVPC is the mostly increased variable, which exhibited an increase of 9.94% in PSA-1 and 23.51% in PSA-2. A plausible to this result is that the increased promotion encouraged participants to be more actively involved in the construction. As a result, the author observed improved special skills and initiatives to fulfill a project. These are key elements to enhance OCB and to magnify the potentials of megaproject success.

- Scenario B: Cultural Effect

Likewise, to Scenario A, this B scenario is also policy-single and it is designed to reify the impacts of the AIRPC (actual increasing rate of project culture) on other variables in simulation as a function of time. In this scenario, two devised environments were simulated (PSB-1 and PSB-2). They are used to compare to the baseline results. The AIRPC was set as 0.05 in the baseline run, whereas they were increased to 0.2 and 0.4 in PSB-1 and PSB-2, respectively. **Table 9.4** shows that the AIRPC was positively relate to the OCBA and AVMS. These two factors increased from 41.003 and 7.762 in run PSB-1, to 52.194 and 7.930 in run PSB-2. Regarding the OCBA, its value was predicted increase by 17.79% (PSB-1) and by 49.94% (PSB-2). At the same time, the AVMS also increased by 1-5 % at the end of simulated period.

It is notable that the enhancements were observed upon another five variables included in the simulation. The values of the AVPC, the AVIB, the AVCB, the AVC, and the AVHRM were 28.961, 26.313, 28.220, 27.631 and 27.097 in PSB-1, and 32.586, 29.607, 31.752, 31.090 and 30.489 in PSB-2. Among them, AVPC is the mostly increased variable, which had 7.94% and 21.45% increase with respective in the PSB-1 and PSB-2. The observed improvement of all variables is often directly linked to the participants of the construction. They are prone to be influenced by project culture, which further affected the quality of their daily work in a positive way. This is indeed leading to an increasing level of success of project.

However, albeit with the improvement in both PSA and PSB by comparison to baseline run, results from these two simulated scenarios were different to each other. Generally, results in PSB are more moderate than those in PSA. This indicates that, compared to the culture issues, opportunities of promotion is more influential to the betterment of OCB and project success, which is particularly true to the top management personnel (Le *et al.*, 2016a).

Table 9.3 The simulation results of policy scenario A

Year	PSA-1							PSA-2						
	OCBA	AVMS	AVPC	AVIB	AVCB	AVC	AVHRM	OCBA	AVMS	AVPC	AVIB	AVCB	AVC	AVHRM
1	3.273	0.564	2.409	2.188	2.347	2.298	2.254	3.369	0.564	2.409	2.188	2.347	2.298	2.254
2	7.002	1.148	4.931	4.480	4.805	4.705	4.614	7.505	1.148	5.005	4.547	4.877	4.775	4.683
3	11.210	1.756	7.567	6.875	7.373	7.220	7.080	12.470	1.756	7.788	7.076	7.589	7.431	7.287
4	15.929	2.393	10.317	9.374	10.053	9.844	9.653	18.339	2.394	10.761	9.777	10.485	10.267	10.068
5	21.201	3.069	13.183	11.978	12.846	12.578	12.335	25.218	3.075	13.925	12.651	13.568	13.285	13.029
6	27.096	3.802	16.169	14.690	15.755	15.427	15.129	33.280	3.822	17.287	15.706	16.844	16.493	16.174
7	33.724	4.618	19.280	17.517	18.786	18.395	18.039	42.790	4.674	20.860	18.953	20.327	19.903	19.518
8	38.360	5.564	22.527	20.467	21.950	21.493	21.078	46.001	5.673	24.668	22.413	24.037	23.536	23.081
9	40.318	6.629	25.926	23.555	25.262	24.736	24.258	49.610	6.780	28.744	26.116	28.009	27.425	25.895
10	42.606	7.793	29.498	26.801	28.743	28.144	27.600	53.989	7.950	33.139	30.110	32.292	31.618	31.007

Table 9.4 The simulation results of policy scenario B

Year	PSB-1							PSB-2						
	OCBA	AVMS	AVPC	AVIB	AVCB	AVC	AVHRM	OCBA	AVMS	AVPC	AVIB	AVCB	AVC	AVHRM
1	3.258	0.564	2.409	2.188	2.347	2.298	2.254	3.354	0.564	2.409	2.189	2.347	2.298	2.254
2	6.927	1.148	4.920	4.470	4.794	4.694	4.604	7.428	1.148	4.994	4.537	4.866	4.765	4.673
3	11.026	1.756	7.534	6.845	7.341	7.188	7.049	12.278	1.756	7.755	7.046	7.557	7.399	7.256
4	15.580	2.393	10.251	9.313	9.988	9.780	9.591	17.969	2.394	10.694	9.716	10.421	10.203	10.006
5	20.625	3.068	13.072	11.877	12.738	12.472	12.231	24.596	3.074	13.813	12.550	13.460	13.179	12.925
6	26.221	3.799	16.001	14.538	15.592	15.267	14.972	32.313	3.819	17.119	15.554	16.681	16.333	16.017
7	32.459	4.611	19.043	17.302	18.556	18.169	17.818	41.359	4.665	20.623	18.737	20.095	19.676	19.296
8	37.241	5.547	22.207	20.177	21.639	21.188	20.779	44.834	5.660	24.346	22.120	23.723	23.228	22.779
9	38.981	6.605	25.507	23.175	24.854	24.336	23.866	48.169	6.761	28.318	25.729	27.594	27.018	26.496
10	41.003	7.762	28.961	26.313	28.220	27.631	27.097	52.194	7.930	32.586	29.607	31.752	31.090	30.489

4 Scenario C: Dual Effects

In this scenario, the author developed a multi-policy approach to simulate the combined changes in the AIRPP and the AIRPC, which is expected to generate a comprehensive understanding of their influences on other factors like OCBA and AVMS. As such, the author designed five settings with different AIRPC and AIRPP values.

As shown in **Table 9.5**, significant improvements were observed upon OCBA and AVMS and they reached at 49.275 and 7.896 in PSC-1, respectively. Similar results were also confirmed in other cases .This implies that the value of AIRPP was positively associated with OCBA and AVMS; and this general trend in our prediction is consistent with previous studies and further validated that dominating effects (same as the single-policy run) of promotion over other issues in OCB and project performance (Le *et al.*, 2016a). Interestingly. in either PSC-1 or PSC-5 (having 0 values), the predicted OCBA and PP were not equal to 0. This could be nature of our modelling methods, which is highly iterative and the multiple inputting manners made the simulation system become less dependent on the selected variables of promotion and project culture. Therefore, the 0-setting of AIRPC/PP is not supposed to generate null values of OCBA and AVMS.

Table 9.5 The simulation results of scenario C

Year	PSC-1		PSC-2		PSC-3		PSC-4		PSC-5	
AIRPC/PP	0/0.4		0.1/0.3		0.2/0.2		0.3/0.1		0.4/0	
	OCBA	AVMS	OCBA	AVMS	OCBA	AVMS	OCBA	AVMS	OCBA	AVMS
1	3.330	0.564	3.321	0.564	3.316	0.564	3.316	0.564	3.311	0.564
2	7.302	1.148	7.252	1.148	7.226	1.148	7.214	1.148	7.201	1.148
3	11.960	1.756	11.834	1.756	11.77	1.756	11.739	1.756	11.708	1.756
4	17.358	2.394	17.115	2.394	16.996	2.394	16.936	2.394	16.876	2.394
5	23.574	3.072	23.171	3.072	22.970	3.071	22.870	3.071	22.770	3.071
6	30.733	3.814	30.112	3.812	29.803	3.811	29.650	3.810	29.497	3.810
7	39.030	4.651	38.118	4.646	37.666	4.643	37.441	4.641	37.217	4.640
8	42.905	5.637	42.140	5.625	41.758	5.619	41.567	5.616	41.377	5.612
9	45.808	6.728	44.877	6.712	44.414	6.704	44.183	6.700	43.952	6.696
10	49.275	7.896	48.133	7.879	47.567	7.871	47.285	7.867	47.004	7.863

9.5 Chapter summary

In this chapter, various methods were utilized to test the quantitative variables in the constructed model, which is validate as robust to use. In the designed three policy scenarios, the success level of megaprojects was tested, and our predictions pointed out that AIRPP is more influential than other factors (AIRPC) regarding the outcomes of OCB. The multi-policy scenarios simulations validated a proportional relationship between the value of the AIRPP and that of OCBA, which prioritized the importance of AIRPC for the project success.

CHAPTER 10: CONCLUSIONS

10.1 Introduction

This chapter summarises major research findings and presents recommendations for future research. The research objectives were reviewed, followed by the summarisation of the general conclusions, which elaborates how the research objectives were met. Then, the study was concluded by highlighting the research limitations and proposing recommendations for future research.

10.2 Contributions

- Theoretical contributions

(1) Identified 23 success indicators can be used by construction practitioners to understand success indicators and effectively manage construction megaprojects.

(2) Application of 9 KPIs can help decision-makers identify an optimal solution amongst several alternatives.

(3) 32 CSFs can help industrial professionals understand the crucial success factors behind successful megaprojects to further improve project management.

(4) Developed SD model helps to explain the interactions amongst variables from a quantitative perspective.

(5) Established SD model can serve as a platform to accurately simulate the potential advantages and disadvantages of managerial strategies.

- Practical contributions

This research can guide the process of assessing the performance of construction megaprojects and enhance the success of construction megaproject management in practice.

10.3 Major conclusions

By accomplishing the five research objectives, several conclusions have been drawn:

(1) Five categories of crucial assessment indicators (23 indicators) for evaluating the success of construction megaprojects were revealed, including project efficiency, key stakeholders' satisfaction, organisational strategic goals, innovation and development of the construction industry and comprehensive influence on the society. In addition, the fuzzy set theory was utilised to identify nine KPIs for evaluating the success of construction megaprojects, which include meeting regulations or specifications, meeting HSE goals, meeting the designed function and delivering value/services that the public needed, owner's satisfaction, government's satisfaction, improved brand/reputation, enhancing people's national pride and confidence and delivering social-economic benefits to the community/local in the Chapter 5.

(2) Thirty-two CSFs were identified and subsequently grouped into six clusters by using factor analysis. These clusters include the effectiveness of project management action, project participant-related factors, application of innovation management

approaches, external factors, economic factors and organisational factors in the Chapter 6.

(3) Chapter 7 explored the principal CSFs by investigating the causal relationships between the identified CSFs and KPIs for evaluating the success of construction megaprojects using PLS-SEM analysis. The results indicated that only economic and organisational factors are positively correlated with the KPIs in the hypothesised model. Moreover, the economic factors emerged as the principal CSFs that affect the success of construction megaprojects.

(4) Chapter 8 provided a detailed explanation of the relationships amongst the key variables obtained in the subsystems through a series of causal loop diagrams. Then, a dynamic model in the form of the stock-flow diagram was established using the Vensim PLE software.

(5) The results of Chapter 9 pointed out that an increase in the AIRPP has more significantly affects the enhancement of OCB and in megaproject success than that in the AIRPC. Moreover, the simulation results of the multi-policy scenarios show that if the value of the AIRPP in combinations is high (the total value has been restricted), then the value of OCBA and the success of the project would also be high. This finding suggests the importance of improving AIRPC first, specifically when the resources are limited.

This study contributed to the body of knowledge in four ways. Firstly, the identified 23 key success indicators can be used by construction practitioners to understand success indicators and effectively manage construction megaprojects. In addition, the application of KPIs can help decision-makers identify an optimal solution amongst several alternatives, which presents the maximum success score of a construction megaproject. Secondly, the 32 CSFs and the corresponding priority ranking can help industrial professionals understand the crucial success factors behind successful megaprojects to further improve project management. Thirdly, the developed SD model not only helps to explain the interactions amongst variables from a quantitative perspective, but also can deepen the stakeholders' understanding of the entire system. Lastly, the established model can serve as a platform to accurately simulate the potential advantages and disadvantages of OCB measures on the success level of megaprojects and to investigate different future scenarios with the aid of computer-based tool, which are relatively rarely studied. In summary, this research can guide the process of assessing the performance of construction megaprojects and enhance the success of construction megaproject management in practice.

10.4 Limitations and future research

This study has two limitations.

(1) The first limitation is the small sample size for the survey. In this study, only 129 validate responses were obtained in the questionnaire survey. Although the author

devoted great effort to deliver questionnaires and collect feedback from various regions in China, and the obtained empirical data supported the developed hypothesis. However, further improvement could be achieved by collecting additional empirical data to strengthen the evidence for model validation especially in the chapter 7.

(2) Another limitation of this study lies in the established SD model. Considering the size and complexity of the model, the author only considered one CSF's effect on the success of construction megaprojects in the chapter 8 and chapter 9. A substantial number of CSFs in the economic cluster and organizational cluster can comprehensively design, simulate and examine the possible dynamic interactions by using the established model in the chapter 8.

Nevertheless, this study not only opened a new window for the dynamic evaluation of the success of construction megaprojects but has also provided a basis for further research.

(1) Future research should include additional CSFs of economic factors and organizational factors to increase credibility and prediction accuracy.

(2) Designing and simulating all policy scenarios are not practical. In this study, only three policy scenarios have been simulated and analysed through the comparison of the results with the base scenarios. In future studies, similar simulations composed of

different designed policies can be conducted and analysed under different scenarios using the proposed method.

10.5 Chapter summary

This chapter reviewed the research objectives, summarised the major findings and limitations and proposed future research directions.

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APPENDICES

Appendix A. List of success criteria and CSFs paper for CMS in construction journals

Appendix B-1. Semi-structured outline of the study (Chinese version)

Appendix B-2. Semi-structured outline of the study (English version)

Appendix C-1. Questionnaire outline of this study (Chinese version)

Appendix C-2. Questionnaire outline of this study (English version)

Appendix D. List of megaproject information in the questionnaire survey

Appendix E. A list of descriptions on variables

Appendix F. List of equations in the SD model

Appendix A. List of success criteria and CSFs papers for CMS in construction journals

No.	Authors	Year	Journal
1	Hu. Y., Chan, Albert P.C., Le, Y.	2015	Journal of Management in Engineering
2	Asgari, M., Kheyroddin, A., Naderpour, H.	2017	Civil Engineering Journal
3	Winch, G., Leiringer, R.	2016	International Journal of Project Management
4	Ning, Y., Ling, F.Y.Y.	2014	Journal of Construction Engineering and Management
5	Kardes, I., Ozturk, A., Cavusgil, S.T., Cavusgil, E.	2013	International Business Review
6	Toor, S.R., Ogunlana, S.O.	2009	Construction Innovation
7	Caldas, C., Gupta, A.	2017	Engineering, Construction and Architectural Management
8	Davies, A., Gann, D., Douglas, T.	2009	California Management Review
9	Puerto, C.L., Shane, J.S.	2014	Journal of Construction Engineering and Management
10	Klakegg, O.J., Williams, T., Shiferaw, A.T.	2016	International Journal of Project Management
11	Dimitriou, H.T., Ward, E.J., Wright, P.G.	2013	Progress in Planning
12	Li, Q., Yin, Z.M., Chong, H.Y., Shi, Q.Q.	2018	Journal of Management in Engineering
13	Verweij, S.	2015	International Journal of Project Management
14	Ng, S.T., Skitmore, M., Tam, K.Y., Li, H.Y.	2014	Proceedings of the Institution of Civil Engineers: Municipal Engineer
15	Mazur, A., Pisarski, A., Chang, A., Ashkanasy, N.M.	2014	International Journal of Project Management

16	Bubshait, A.A., Siddiqui, M.K., Al-Buali, A.M.	2014	Journal of Performance of Constructed Facilities
17	Crosby, P.	2017	Australian Journal of Civil Engineering
18	Sturup, S., Low, N.	2015	Urban Policy and Research
19	Hosseini, M.R., Banihashemi, S., Martek, I., Golizadeh, H., Ghodoosi, F.	2017	Journal of Management in Engineering
20	Locatelli, G., Mikic, M., Brookes, N., Kovacevic, M., Ivanisevic, N.	2017	Project Management Journal
21	Fahri, J., Biesenthal, C., Pollack, J., Sankaran, S.	2015	Construction Economics and Building
22	Cepeda, D.M., Sohail, M., Ogunlowo, O.O.	2018	Management, Procurement and Law
23	Kwak, Y.H., Walewski, J., Sleeper, D., Sadatsafavi, H.	2013	International Journal of Project Management
24	Nguyen, L.D., Ogunlana, S.O., Lan, D.T.X	2004	Engineering, Construction and Architectural Management
25*	Rodríguez-Segura, E., Ortiz-Marcos, I., Romero, J.J., Tafur-Segura, J.	2016	Journal of Business Research
26*	Shenhar, A., Holzmann, V.	2018	Project Management Journal
27*	Al Nahyan, M.T., Sohal, A.S., Fildes, B.N., Hawas, Y.E.	2012	Construction Innovation
28	Lau, C.Y., Lee, W.C.	2016	Environmental Management
29	Tabish, S.Z.S., Jha, K.N.	2018	Journal of Construction Engineering and Management
30	van Niekerk, S.I., Steyn, H.	2011	South African Journal of Industrial Engineering
31	Hu. Y., Chan, Albert P.C., Le, Y., Xu, Y.L., Shan, M.	2016	Journal of Management in Engineering
32	Turner, R., Zolin, R.	2012	Project Management Journal
33	Turner, J.R., Xue, Y.	2018	International Journal of Managing Projects in

			Business
34	Dimitriou, H.T., Ward, E.J., Dean, M.	2016	Research in Transportation Economics
35	Volden, G.H.	2018	Evaluation and Program Planning
36	Chang, A., Chih, Y.Y., Chew, E., Pisarski, A.	2013	International Journal of Project Management
37	Yan, H.Y., Elzarka, H., Gao, C., Zhang, F., Tang, W.B.	2018	Journal of Management in Engineering
38	Toor, S.R., Ogunlana, S.O.	2010	International Journal of Project Management

Appendix B-1: Semi-structured outline of the study (Chinese version)

（一） 采访人自我介绍

问候受访者，并简要介绍自身情况，包括就读专业、学术研究方向等。

（二） 访谈说明

1. 向受访者说明访谈目的：希望通过重大工程建设项目领域专业人士的视角，结合其丰富的实践经验对重大工程项目成功评价指标和成功要素进行识别研究。

2. 向受访者说明，为方便记录会对采访全程进行录音，但仅用于研究活动，对受访者的个人隐私信息也会保密。

3. 告知受访者，在采访中若有疑问或不适可以随时打断，提出意见。

4. 向受访者说明本次访谈不支付报酬，但作为感谢会赠送一份纪念品；倘若对本研究结果感兴趣，则会在研究结束之后将此成果分享给受访者。

联系地址：上海市杨浦区四平路1063号中天大厦20楼05室

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（三） 正式访谈

第一部分：受访者背景资料

1. 您的年龄在什么范围？

☐21-30岁 ☐31-40岁 ☐ 41-50岁 ☐50岁以上

2.您的教育背景：

☐中专以下 ☐中专 ☐ 高中 ☐本科 ☐研究生

3.您在建筑相关行业的工作年限____年，参与重大工程的工作年限是____年。

4.您目前所在的工作单位是：__________；职务：__________

5.您所在单位在重大工程建设过程中承担的角色：

☐业主 ☐承包商 ☐设计方 ☐供应商 ☐工程咨询单位（含监理）☐其他____

6.请您选择曾经参与过的一个重大工程项目案例为参考来回答第二部分问题：

您选择的重大工程的名称：________________

该项目的投资方为：__________；投资额为___________亿元（人民币）。

第二部分：重大工程项目成功的评价指标和成功要素访谈提纲

1. 您认为应该怎样定义重大工程项目的成功？或者您认为当一项重大工程项目产生了怎样的效果（或效益）则可视为成功？与一般建设工程项目相比有何特殊之处（如有，请结合具体的例子进行阐释）？
2. 您认为有哪些关键指标可以用来评价重大工程项目的成功？与一般建设工程项目相比有何特殊之处（如有，请结合具体的例子进行阐释）？

3. 如果对（您刚回答的）重大工程项目成功的关键评价指标进行排序，您认为这个排序应该是怎样的，请谈谈您的看法？

4. 您认为重大工程项目中有哪些有别于一般建设工程项目的成功要素（如有，请结合具体的例子进行阐释）？

5. 如果对（您刚回答的）重大工程项目的成功要素进行排序，您认为这个排序应该是怎样的，请谈谈您的看法？

6. 对于刚才的讨论，您还有需要补充的地方吗？

（四） 访谈结束

再次感谢受访者的积极支持与配合，表达对今后与受访者继续交流的期待。

Appendix B-2: Semi-structured outline of the study (English version)

（一） **Introduction of interviewer**

Greeting the respondents, and briefly introduce myself, including majors and research interests.

（二） Introduction of this interview

1. Explain the purpose of the interview to the interviewee. That is, based on the respondents ’knowledge and practical experience in megaproject management, to identify the success criteria and critical factors for Construction Megaproject Success (CMS).

2. Explain to the interviewee that the interview will be recorded during whole process. But the record will only for this research activity, and the interviewee’s personal information will be kept confidential.

3. Inform the respondent that they can interrupt and give comments at any time if they have any questions or discomfort about questions during the interview.

4. Explain to the respondent that there is no any payment for the interview, but if they are interested in this research results, then we would like to share the results to them.

Contact address：20/F, Zhongtian Plaza, No.1063 Siping Road, Yangpu District, Shanghai, China

Research Institute of Complex Engineering and Management　Post code：200092

Contact：Ting WANG　E-mail：pauline_wt@

（三） Formal interview

Part A：Background of interviewee

1. What's your age range？

☐21-30 years ☐31-40 years ☐ 41-50 years ☐50 years or above

2. What's your highest education degree?

☐ Junior high school or below ☐High school ☐ Bachelor ☐Master or above

3. Your working experience in construction engineering and management:_____years;

   Your working experience in megaproject management_______years.

4. Your current affiliation：__________；Your position：__________

5. What's the role of your organization played in the megaproject?

☐ Owner ☐Contractor ☐Designer ☐Supplier ☐Consultant ☐Others____

6. Please select one megaproject you participated in as a reference to answer the following questions in Part B.

The name of the megaproject：________________

The sponsor of the megaproject：__________；

The amount of investment___________Billion (RMB).

Part B：Identification of success criteria and critical factors for CMS

1. How would you define the success of construction megaprojects? What are the major differences when compared with normal construction projects?
2. What key success criteria should be used to evaluate the CMS? What are the major differences when compared with normal construction projects?
3. How would you rank the success criteria advocated in Question 2?
4. What are the critical factors for CMS?
5. How would you rank the critical factors advocated in Question 4?
6. Do you wish to make further explanations?

（四） End of interview

Once again, thanks for your support.

Appendix C-1: Questionnaire outline of this study (Chinese version)

重大工程项目成功的关键指标及成功要素调查问卷

尊敬的专家：

您好！

非常感谢您拨冗参与本次问卷调研。本调研是同济大学建设管理与房地产系联同香港理工大学建设及房地产学系的博士生研究课题及国家自然科学基金委研究课题“重大工程项目成功要素识别、双元驱动及组织适应性研究”（项目批准号：71971161）的重要组成部分，旨在立足于“政府-市场”二元典型情景下，深入研究我国重大工程实施阶段项目成功的关键评价指标、成功要素及有效提升项目成功的管理策略。

鉴于您在重大工程领域的相关成就及实践经验，我们诚挚地邀请您参与本次问卷调研。问卷中的问题选项无对错之分，**请您选择一个最近主持或参与的重大工程项目为参照，给出您认为最能反映该项目实际情况的选择。**本问卷不记名，我们向您保证，本次调研仅作为学术研究使用，绝不会透露您的个人信息，请放心填写。

填写过程预计需要花费您 10-15 分钟的时间，您的支持对完成本研究非常重要。请您尽量于两周内将填写完毕的问卷发送至 pauline_wt@ 。非常感谢您的重视和支持，特此向您致谢！

博士研究生 王婷

博士生导师 何清华 教授

同济大学 建设管理与房地产系

博士生导师 陈炳泉 讲座教授

香港理工大学 建设及房地产学系

注释：**重大工程**通常指整体投资规模较大，具有较高的建设复杂性和风险性，工期较长，参与人员众多，对所在地区乃至国家的经济、技术、环境和居民生活有

重大及广泛影响的一类建设项目。本研究中的重大工程主要是指基础设施类重大工程项目且总投资额在 10 亿人民币以上，例如大型桥梁、城市地铁、高速公路铁路、大型文化体育场馆设施等等。

第一部分：项目基本信息

【请选择一个您最近主持或参与的重大工程，填写项目基本信息，并以此项目为参照回答本问卷的问题】

1. 您属于该项目的	☐ 业主方（包含与项目直接相关的政府管理部门成员，业主方自身团队成员及业主委托的主要工程咨询团队成员，如全过程工程咨询、项目代建、项目管理、工程监理、造价咨询（QS 咨询）、招标代理等） ☐ 设计方（包含业主委托的设计单位、设计顾问/咨询等） ☐ 施工方（包含工程总承包（EPC/DB）、施工总承包、主要专业分包和供应商等）
2. 该重大项目的名称	单击或点击此处输入文字。
3. 该项目的开工年份	单击或点击此处输入文字。
4. 该项目所在的城市	单击或点击此处输入文字。
5. 该项目的总投资额（人民币）	☐10-30 亿元 ☐30-50 亿元 ☐50-100 亿元 ☐>100 亿元
6. 该项目的属性（可多选）	☐政府投资项目 ☐公私合作项目 ☐社会投资项目
7. 该项目属于（可多选）	☐国家五年规划项目 ☐省五年规划项目 ☐所在地重大/重点项目 ☐其他

第二部分：重大工程项目成功的关键指标调查

【请根据您所参与项目的实际情况进行填写，并在最适当的“☐”处点击勾选】

	分类	指标	评价				
			非常	不认	中立	认同	非常

			不认同	同			认同
1	项目实施效率及效果	项目管理“铁三角”（进度、质量、成本）目标实现	□1	□2	□3	□4	□5
2		职业健康、安全和环境（HSE）目标实现	□1	□2	□3	□4	□5
3		符合设计、技术、环保等的相关规定和要求	□1	□2	□3	□4	□5
4		满足设计使用功能,并能提供公众所需的价值/服务					
5	关键利益相关者满意	政府方满意度	□1	□2	□3	□4	□5
6		业主方满意度	□1	□2	□3	□4	□5
7		参建单位（含咨询单位、设计单位和施工单位等）满意度					
8		社会公众满意度	□1	□2	□3	□4	□5
9		利益相关者之间建立良好的沟通与合作	□1	□2	□3	□4	□5
10	企业（组织）战略目标达成	新发明或新技术的使用	□1	□2	□3	□4	□5
11		收益或利润的实现	□1	□2	□3	□4	□5
12		新市场的开拓，或市场份额/竞争力的提升	□1	□2	□3	□4	□5
13		（企业/组织）培育新的能力或胜任力	□1	□2	□3	□4	□5
14		企业品牌或声誉的提升	□1	□2	□3	□4	□5
15		为企业或项目培养专业人才	□1	□2	□3	□4	□5
16	行业的创新与发展	具有行业标杆或示范效应,某些管理制度或技术标准可向相似或相同类型的项目推广	□1	□2	□3	□4	□5
17		有效促进建筑业及其相关产业的创新与协同发展， 例如树立新的行业标准（规范），推动建筑产业链的发展	□1	□2	□3	□4	□5
		行业在国际市场竞争力的提升	□1	□2	□3	□4	□5

18		具有重大工程技术和管理领域理论和实践创新贡献	□1	□2	□3	□4	□5
20	综合社会影响	为国家或地区发展带来明显的社会经济效益	□1	□2	□3	□4	□5
21		满足社会、经济、环境的可持续性发展要求和目标	□1	□2	□3	□4	□5
22		增强社会的稳定，提升社会和谐度	□1	□2	□3	□4	□5
23		提升公众自信心和自豪感	□1	□2	□3	□4	□5
24		创造新的就业机会	□1	□2	□3	□4	□5

***如果您认为以上对重大工程项目成功的关键评价指标有所遗漏，请在下方表格中的相应空格处填写出您认为还应当添加的评价指标，并对其进行重要性评价（在最适当的“□”处点击勾选）。**

	指标	**评价**				
		非常不认同	不认同	中立	认同	非常认同
1	单击或点击此处输入文字。	□1	□2	□3	□4	□5
2	单击或点击此处输入文字。	□1	□2	□3	□4	□5
3	单击或点击此处输入文字。	□1	□2	□3	□4	□5

第三部分：影响重大工程项目成功的关键要素调查

【请根据您所参与项目的实际情况进行填写，并在最适当的“□”处点击勾选】

	分类	**成功要素**	**评价**				
			非常不认同	不认同	中立	认同	非常认同
1	与项目本身相关的因素	（该项目）清晰的战略愿景	□1	□2	□3	□4	□5
2		项目目标与成功间的一致性	□1	□2	□3	□4	□5
3		清晰的项目目标与项目定义，确保项目能够持续进行；包括目标识别、量化控制指标制	□1	□2	□3	□4	□5

		定和过程监控等					
4		有效的项目战略与目标规划	□1	□2	□3	□4	□5
5		良好的项目治理，例如项目治理顶层系统设计	□1	□2	□3	□4	□5
6		项目的组织设计和结构	□1	□2	□3	□4	□5
1	与项目参建方（组织）相关的因素	关键利益相关者之间的良好伙伴关系，以加强施工过程协作	□1	□2	□3	□4	□5
2		参建方之间充分的沟通与协调	□1	□2	□3	□4	□5
3		利益相关者之间的信任，例如能够在项目过程中坚守道德、履行诺言等	□1	□2	□3	□4	□5
4		业主方的胜任力和领导力，主要包括战略能力、财务能力和治理能力	□1	□2	□3	□4	□5
5		项目管理者的胜任力和领导力，主要包括技术能力、沟通能力等	□1	□2	□3	□4	□5
6		承包商的胜任力，主要指其稳定的建设能力和交付能力	□1	□2	□3	□4	□5
7		参建人员甘于奉献，尽职尽责；能够自觉完成任务甚至做出超越职责要求外的，但对项目有力的积极行为	□1	□2	□3	□4	□5
8		来自组织内部的强有力支持，例如队伍内部的稳定、团结及协作	□1	□2	□3	□4	□5
9		良性的组织和项目文化，例如积极倡导“奉献、奋斗、和谐”的理念和精神，激发参建人员的使命感与责任感	□1	□2	□3	□4	□5
1	经济与管理因素	充足的物资（包括人力、材料、机械以及建设资金）	□1	□2	□3	□4	□5
2		建立有效的激励和约束机制，尤其是精神方面的激励（例如举办劳动竞赛、评优表彰）	□1	□2	□3	□4	□5
3		项目的系统控制、协调和整合机制	□1	□2	□3	□4	□5
4		有效的风险管控，合理的风险共担机制	□1	□2	□3	□4	□5
5		有效的复杂性降解和管控	□1	□2	□3	□4	□5
6		良好的范围管理	□1	□2	□3	□4	□5
7		有效和详尽的合同管理，例如权责对等的合同规范文件	□1	□2	□3	□4	□5

8		选择合适的承发包模式	□1	□2	□3	□4	□5
9		竞争和透明的采购过程，有效控制腐败行为	□1	□2	□3	□4	□5
1	创新因素	引导并注重创新管理，包括体制创新、技术创新、建设管理模式创新、投融资模式创新等	□1	□2	□3	□4	□5
2		注重前期科研及必要的人才培养，例如整合“产、学、研”创新机构，组织科研项目立项	□1	□2	□3	□4	□5
3		以往相似项目的经验积累和人才储备，可以包括参建单位过往实践中的积累，相关科研院所自身开发和掌握的技术，以及从国外引进的技术与经验	□1	□2	□3	□4	□5
4		采用或创新性地吸收改进先进的技术与方法，例如 BIM，自动化建造技术等	□1	□2	□3	□4	□5
1	外部环境因素	国家（政府）的直接或强有力地领导，从而发挥体制优势、进行必要的协调、能够集中力量办大事，	□1	□2	□3	□4	□5
2		政府及相关机构的有力支持，例如政策和方针引导	□1	□2	□3	□4	□5
3		公众对建设项目的接受和支持，例如配合拆迁、移民等	□1	□2	□3	□4	□5
4		有效的外部监督和监管，例如各级监察部门对重大工程建设过程中的合法与合规性进行跟踪监督与审计	□1	□2	□3	□4	□5
5		充分了解外部环境条件（如社会文化、政治等方面）对于项目实施的限制	□1	□2	□3	□4	□5
6		社会、经济、政治环境的稳定	□1	□2	□3	□4	□5
	***如果您认为以上对影响重大工程项目成功的关键要素有所遗漏，请在下方表格中的相应空格处填写出您认为还应当添加的成功要素，并对其进行重要性评价（在最适当的“□”处点击勾选）。**						
	.	**成功要素**	**评价**				
			非常不认同	不认同	中立	认同	非常认同
1		单击或点击此处输入文字。	□1	□2	□3	□4	□5

2		单击或点击此处输入文字。	□1	□2	□3	□4	□5
3		单击或点击此处输入文字。	□1	□2	□3	□4	□5

第四部分：受访者基本信息

【请根据您的实际情况，在适当的“□”处点击勾选】

1. 性别	□男 □女
2. 年龄	□26-35 岁 □36-45 岁 □46-55 岁 □>56 岁
3. 教育背景	□高中 □大专 □本科 □硕士研究生 □博士研究生
4. 您参与工程建设的工作年限	□6-10 年 □11-20 年 □20 年以上
5. 您参与重大工程建设的工作年限	□<5 年 □6-10 年 □11-20 年 □20 年以上
6. 您目前属于	□组织高层 □组织中层 □组织中层以下
7. 您在该项目上属于	□高层管理者 □中层管理者 □中层以下

【问卷到此结束，再次感谢您对本次调研的支持和帮助!】

Appendix C-2: Questionnaire outline of this study (English version)

A survey on the success attributes of construction megaproject management in China

Letter to Participants

Dear Participant,

Thanks a lot in advance for your participation. This questionnaire survey, forming part of a joint Ph.D. study between Tongji University and Hong Kong Polytechnic University, as well as a part of the research project "Research of Feature Identification, Binary drive and Organization Adaptability for Mega Infrastructure Project Success" supported by National Natural Science Foundation of China (Grant No：71971161), is aimed at soliciting experts' views on some success attributes which will help in exploring multi-dimensions, key performance indicators and critical factors for construction megaproject success in Chinese construction sector. Drawing on your knowledge and/or experience in construction megaproject management, please complete the questionnaire by ticking (☒) or selecting (e.g. "Agree") from the given options. It is expected to take about 10 minutes of your valuable time.

Please email this questionnaire back to Ms. Wang Ting via pauline_wt@ , within TWO WEEKS. Be assured that your responses will be kept anonymous and only be used for academic purpose. Thanks once again for your commitment.

Ting Wang, Ph.D. student
Department of Building and Real Estate, Hong Kong Polytechnic University; Research Institute of Complex Engineering and Management, School of Economy and Management, Tongji University.
Ir Prof. Albert P.C. Chan
Chair professor and the head, Department of Building and Real Estate, Hong Kong Polytechnic University.
Prof. Qinghua He
Professor, Research Institute of Complex Engineering and Management, School of Economy and Management, Tongji University.

***Note**: In this research, Megaprojects refer to mega infrastructure projects which typically cost one billion RMB or more, take many years to build, involve many stakeholders, and impact millions of people". Typical examples of megaprojects include airports, seaports, dams, high-speed railways, offshore oil and gas extraction, defense projects, the Olympic, ICT systems, and the development of new aircraft and so on forth.

Section A-Project Information

Please select one construction megaproject that you have recently participated in and fill in the basic information of this projects; and meanwhile, please take this megaproject as a reference to answer the questions in this questionnaire.

1. Please indicate the nature of your current organization:

   ☐Governmental sector ☐Client ☐Contractor ☐Designer ☐Consultant

   ☐Academic institute ☐Others (Please specify 单击或点击此处输入文字。)

2. Please indicate the name of the megaproject

   Please specific 单击或点击此处输入文字。

3. Please indicate the commencement year of the megaproject:
4. Please indicate the city where the megaproject is located

   Please specific 单击或点击此处输入文字。

5. Please indicate the total investment of the megaproject:

   Please specific 单击或点击此处输入文字。

6. Please indicate the importance of the megaproject:

   ☐National Five-year Plan ☐Province or Ministry Five-year Plan ☐Local

   megaprojects ☐Others (Please specific 单击或点击此处输入文字。)

7. Please indicate the nature of the megaproject:

   ☐Government-funded project ☐Public-Private Partnership project ☐Private project

Section B: Evaluation of key performance indicators for construction megaproject success

Please rate the extent to which you consider the following factors as key indicators for evaluating construction megaproject success based on your working experience using a Likert scale from 1-5: **1-Strongly disagree, 2-Disagree, 3-Neutral, 4-Agree, 5-**

Strongly agree.

No.	Dimensions	Indicators	Rating				
			Strongly disagree	Disagree	Neutral	Agree	Strongly agree
1	Project Efficiency	Meeting time, quality, budget goals	□1	□2	□3	□4	□5
2		Meeting health, safety and environment (HSE) goals	□1	□2	□3	□4	□5
3		Meeting regulations or specifications	□1	□2	□3	□4	□5
4		Meeting designed function and delivering value/services that the public needed	□1	□2	□3	□4	□5
5	Key stakeholders' satisfaction	Government's satisfaction	□1	□2	□3	□4	□5
6		Owner's satisfaction	□1	□2	□3	□4	□5
7		Participants' satisfaction (e.g. consultants, designers and contractors)	□1	□2	□3	□4	□5
8		The public's satisfaction	□1	□2	□3	□4	□5
9		The interests of all participants can be well balanced or satisfied	□1	□2	□3	□4	□5
10	Organizational strategic goals	Benefits/profits realization	□1	□2	□3	□4	□5
11		New market or increased market	□1	□2	□3	□4	□5

		share					
12		Improved brand/reputation	☐1	☐2	☐3	☐4	☐5
13		Use of new technologies	☐1	☐2	☐3	☐4	☐5
14		New organizational capability and competency	☐1	☐2	☐3	☐4	☐5
15		Nurturing experts for organizations	☐1	☐2	☐3	☐4	☐5
16	Innovation and development of the construction industry	Benchmarking, for example, technical standards can be promoted to similar or similar types of projects	☐1	☐2	☐3	☐4	☐5
17		Effectively promote innovation and synergy in the construction industry and related industries	☐1	☐2	☐3	☐4	☐5
18		Improved competitiveness in the international market	☐1	☐2	☐3	☐4	☐5
19		Great contributions to theoretical and practical innovation in megaproject filed	☐1	☐2	☐3	☐4	☐5
20	Comprehensive impact on the	Delivering social-economic	☐1	☐2	☐3	☐4	☐5

	society	benefits to the community/local					
21		Sustainability in environment, society and economy	☐1	☐2	☐3	☐4	☐5
22		Maintain social cohesion/society harmony	☐1	☐2	☐3	☐4	☐5
23		Enhancing people's national pride and confidence	☐1	☐2	☐3	☐4	☐5

***If you think there is/are key performance indicators missed in this section, please provide the supplementation and also the evaluation accordingly.**

No.	Indicators	Rating				
		Strongly disagree	Disagree	Neutral	Agree	Strongly agree
1		☐1	☐2	☐3	☐4	☐5
2		☐1	☐2	☐3	☐4	☐5
3		☐1	☐2	☐3	☐4	☐5

Section C: Evaluation of critical factors for construction megaproject success

Please rate the extent to which you consider the following factors as critical factors for construction megaproject success based on your working experience using a Likert scale from 1-5: **1-Strongly disagree, 2-Disagree, 3-Neutral, 4-Agree, 5-Strongly agree.**

No.		Factors	Rating				
1	Project-related factors	Clear strategic vision	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
2		Aligned perceptions of project goals and success	☐1	☐2	☐3	☐4	☐5
3		Clear goals and project definition to make sure the project goes smoothly	☐1	☐2	☐3	☐4	☐5

4		Effective strategic planning	☐1	☐2	☐3	☐4	☐5
5		Good governance	☐1	☐2	☐3	☐4	☐5
6		Project organization structure	☐1	☐2	☐3	☐4	☐5
7	Project participants-related factors	Partnering/relationships with key stakeholders	☐1	☐2	☐3	☐4	☐5
8		Adequate communication and coordination among related parties	☐1	☐2	☐3	☐4	☐5
9		Mutual trust among project stakeholders	☐1	☐2	☐3	☐4	☐5
10		Capabilities and leadership of the owner	☐1	☐2	☐3	☐4	☐5
11		Capabilities and leadership of project managers	☐1	☐2	☐3	☐4	☐5
12		Capabilities and leadership of contractors	☐1	☐2	☐3	☐4	☐5
13		Positive behavior of project participants that could collectively facilitate the effective achievement of construction goals	☐1	☐2	☐3	☐4	☐5
14		Great organizational support	☐1	☐2	☐3	☐4	☐5
15		Positive organizational culture for effective project management	☐1	☐2	☐3	☐4	☐5
16	Economic and management related factors	Adequate resource availability	☐1	☐2	☐3	☐4	☐5
17		Establish effective incentive and punishment mechanisms	☐1	☐2	☐3	☐4	☐5
18		Systematic control and integration mechanisms	☐1	☐2	☐3	☐4	☐5

19		Effective risk management	☐1	☐2	☐3	☐4	☐5
20		Effectively address complexities	☐1	☐2	☐3	☐4	☐5
21		Scope management	☐1	☐2	☐3	☐4	☐5
22		Well-formulated and detailed contracts	☐1	☐2	☐3	☐4	☐5
23		Select the appropriate contracting and delivery model	☐1	☐2	☐3	☐4	☐5
24		Adopt competitive and transparent procurement process to effectively control corruption	☐1	☐2	☐3	☐4	☐5
25	Innovation related factors	Owners need to clarify the innovation orientation and strategic choice, and also need to guiding the innovation management of participating enterprises	☐1	☐2	☐3	☐4	☐5
26		Owners need to provide the necessary innovation resources and innovative environment, such as provide subsidies to promote innovative behavior	☐1	☐2	☐3	☐4	☐5
27		Focus on pre-stage research and necessary talents training	☐1	☐2	☐3	☐4	☐5
28		Experience and talents accumulated from previous similar projects	☐1	☐2	☐3	☐4	☐5
29		Adopt up to date or innovatively improve	☐1	☐2	☐3	☐4	☐5

		technologies and methods					
30	External environment factors	Direct or strong support of the state (central government)	☐1	☐2	☐3	☐4	☐5
31		Cooperation and strong support from local governments	☐1	☐2	☐3	☐4	☐5
32		Public support or acceptance	☐1	☐2	☐3	☐4	☐5
33		Effective external supervision and audit	☐1	☐2	☐3	☐4	☐5
34		Full understanding of cultural, financial and legislative requirements	☐1	☐2	☐3	☐4	☐5
35		Economic and political stability	☐1	☐2	☐3	☐4	☐5
	***If you think there is/are critical factors missed in this section, please provide the supplementation and also the evaluation accordingly.**						
	No.	Factors	Rating				
			Strongly disagree	Disagree	Neutral	Agree	Strongly agree
	1		☐1	☐2	☐3	☐4	☐5
	2		☐1	☐2	☐3	☐4	☐5
	3		☐1	☐2	☐3	☐4	☐5

Section D: Participant Information

1. Please indicate your gender:

   ☐ Male ☐Female

2. Please indicate your age:

   ☐26~35 ☐36~45 ☐46~55 ☐>56

3. Please indicate your highest education degree:

   ☐ High school or below ☐College degree ☐Bachelor ☐Master or above

4. Please indicate your working experience in construction management and

engineering areas:

☐6~10 years ☐11~20 years ☐Above 20 years (Please specific 单击或点击此处输入文字。)

5. Please indicate your working experience in megaproject management:

   ☐ 0~5years ☐6~10 years ☐11~20 years ☐Above 20 years (Please specific 单击或点击此处输入文字。)

6. Please indicate your position in your current organization

   ☐ In the top management team ☐In the middle management class ☐General staff

7. Please indicate your position in the megaproject

   ☐ In the top management team ☐In the middle management class ☐General staff

End of questionnaire
Thanks for your valuable contribution

Appendix D: List of megaproject information in the questionnaire survey

编号	地点		项目名称	问卷数量	编号	地点		项目名称	问卷数量
	省份	城市				省份	城市		
1	河南省	新乡市	延津县城镇一体化建设工程	1	48	江苏省	常州市	常州金融城商务广场	1
2	广西省	北海市	北海银基旅游度假区	1	49	河南省	郑州市	郑州奥林匹克体育中心	1
3	河南省	驻马店	国家储备林基地建设工程	1	50	河南省	郑州市	河南广播电视塔（中原福塔）	1
4	河南省	郑州市	豫兴大道建设工程	1	51	河南省	郑州市	地铁三号线	1
5	江苏省	常州市	常州工学院新校区	3	52	上海		中华艺术宫（中国馆改建工程）	1
6	广西省	崇左市	华润商业综合体项目	2	53	广东省	深圳市	轨道交通十三号线	1
7	广西省	南宁市	华润中心东写字楼项目	1	54	江西省	赣州市	综合文化艺术中心	1
8	广东省	肇庆市	肇庆新区城市地下综合管廊及附属工程	1	55	陕西省	汉中市	汉中兴汉胜境项目	1
9	广西省	南宁市	中国-东盟信息港南宁核心基地五象新区 地理信息小镇工程（一期）	1	56	江苏省	无锡市	江阴“1310 工程”一期（13 五期间政府主导投资建设的 10 大民生类工程）	1
10	四川省	内江市	内江体育中心项目	1	57	湖北省	武汉市	中金数谷武汉大数据中心项目	1
11	江苏省	徐州市	华润商业综合体项目	1	58	湖北省	武汉市	武汉江北快速路工程	1
12	江苏省	常州市	常州工学院产教融合项目实训楼工程（二期）	7	59	陕西省	西安市	西安环球中心	1
13	广西省	南宁市	南宁武鸣管廊项目	1	60	海南省	三亚市	三横路凤凰段项目（二期）	2

14	广西省	南宁市	地铁五号线	2	61	河南省	新乡市	中心医院门急诊儿科综合楼	1
15	广西省	桂林市	桂林机场 T2 航站楼扩建工程	5	62	河南省	郑州市	郑州四环线	2
16	广西省	南宁市	广西国际壮医医院	2	63	辽宁省	大连市	华能大连第二热电厂背压机组新建工程	1
17	广东省	深圳市	深圳新一代信息技术产业园	1	64	北京		亚洲基础设施投资银行总部大楼	1
18	山东省	济南市	山东国际金融中心	1	65	河南省	郑州市	航空港区南四环至郑州南站城郊铁路工程（一期）	1
19	广东省	深圳市	前海综合交通枢纽工程	2	66	河南省	郑州市	渠南路一号隧道工程	1
20	广东省	南宁市	南宁地铁四号线	2	67	江苏省	徐州市	地铁一号线	2
21	广东省	深圳市	深业上城城市综合体	2	68	江苏省	连云港	盛虹炼化一体化项目	1
22	海南省	万宁市	万宁污水处理厂	3	69	北京		2019 年世界园艺博览会国际馆项目	2
23	河南省	焦作市	武陟县城区污水处理厂	1	70	河南省	郑州市	中国（郑州）第十一届国际园林博览会-园博园 B 区暨双鹤湖中央公园	1
24	广东省	深圳市	深圳前海新中心公共基础设施及配套项目集群	1	71	浙江省	杭州市	地铁四号线	1
25	河南省	郑州市	地铁一号线	2	72	浙江省	杭州市	地铁六号线	1
26	河北省	石家庄	元氏县城区集中供热项目管道及配套设施	1	73	宁夏	固原市	S202 省级干线公路工程（西吉至毛家沟）	1
27	广东省	珠海市	珠港澳大桥	1	74	贵州省	贵阳市	贵阳北火车站	1
28	北京		北京轨道交通产业园	1	75	广东省	深圳市	布吉河流域综合治理工程 EPC+0	1

29	浙江省	杭州市	萧山区瓜沥镇小城镇环境综合整治 EPC 项目	1	76	山东省	淄博市	汇金大厦	1
30	广西省	南宁市	高速公路（大塘至浦北段）	1	77	河北省	邢台市	东环城水系工程	1
31	江苏省	苏州市	吴江博览中心	1	78	广东省	深圳市	龙岗龙观两河流域消黑基础设施工程	1
32	广东省	深圳市	罗湖区星园学校新建工程	1	79	上海		西岸传媒港	4
33	广东省	深汕特别合作区	深耕村项目	1	80	上海		上海中环线浦东段	1
34	四川省	成都市	成都天府新区超高层项目	2	81	上海		地铁十号线	1
35	湖北省	武汉市	武汉火车站	2	82	上海		上海交通大学医学院附属仁济医院项目	1
36	广东省	深圳市	平安金融中心	2	83	上海		世博会博物馆	1
37	河南省	安阳市	安阳北区建业城安置房工程	1	84	上海		2010 年上海世博会园区建设	1
38	河南省	郑州市	河南省科技馆（新馆）	1	85	江苏省	南通市	苏通长江公路大桥（苏通大桥）	1
39	广东省	深圳市	医疗器械检测和生物医药安全评价中心建设项目	2	86	河南省	洛阳市	郑州至卢氏高速公路	3
40	广西省	柳州市	柳州文化广场	1	87	上海		地铁十二号线	1
41	河南省	郑州市	金水区聂庄片区改造项目安置区 A 地块	1	88	上海		迪斯尼旅游度假区	3
42	内蒙古	阿拉善盟	北京-乌鲁木齐高速公路（临白段（阿盟境内））	1	89	湖北省	武汉市	地铁二号线	1

43	广东省	深圳市	坪盐通道工程	1	90	上海		地铁十六号线	1
44	上海		上海虹桥国际机场西广场	1	91	上海		国家会展中心	1
45	上海		上海徐家汇中心项目	1	92	河南省	郑州市	南水北调中线一期	1
46	上海		特斯拉上海超级工厂	1	93	云南省	昆明市	昆明南站	1
47	云南省	玉溪市	玉溪-化念天然气长输管道工程 EPC 项目（一期）	1	94	合计：129 份			

Appendix E: A list of descriptions on variables

Acronym	**Descriptions**	**Variable Type**
AEIMS	Accumulated efforts to improve megaproject success	Stock
AIA	Accumulated impact of accidents	Stock
AIEN	Accumulated impact of environmental nonconformance	Stock
AIPWE	Accumulated impact of physical working environment	Stock
AIRMRps	Actual increasing rate of megaproject recognized widely by the public and society	Constant
AIRPC	Actual increasing rate of project culture	Constant
AIRPP	Actual increasing rate of potential promotion	Constant
AROCB	Adoption rate of organizational citizenship behavior	Auxiliary
ATAI	Advanced technology adopted initiatively	Constant
AVC	Accumulated value of conscientiousness	Stock
AVCB	Accumulated value of collaboration behavior	Stock
AVHRM	Accumulated value of harmonious relationship maintenance	Stock
AVIB	Accumulated value of innovation behavior	Stock
AVMRps	Accumulated value of megaproject recognized widely by the public and society	Stock
AVMS	Accumulated value of megaproject success	Stock
AVPC	Accumulated value of project compliance	Stock
AVPC-1	Accumulated value of project culture	Stock
AVPP	Accumulated value of potential promotion	Stock
BCP	Benefits of corporate reputation	Auxiliary
CBI	Collaboration behavior increment	Flow
CCA	Coordination conflicts actively	Constant
CEN	Changing of environmental nonconformance	Flow
CGR	Compliance with governmental requirements on the project	Constant
CI	Conscientiousness increment	Flow
CMRC	Conduct mission requirements consciously	Constant
CNA	Changing of number of accidents	Flow
CPA	Compliance with project arrangements	Constant
CPWE	Changing of physical working environment	Flow
CRC	Changing rate of accidents	Constant
CREN	Changing rate of environmental nonconformance	Constant
CRPWE	Changing rate of physical working environment	Constant

DseBC	Delivering social-economic benefits to the community	Constant
EI	Environmental index	Auxiliary
EIMS	Efforts to improve megaproject success	Auxiliary
EMM	Effectiveness of megaproject management	Auxiliary
EPNpc	Enhancing people's national pride and cohesion	Auxiliary
EsI	Efforts increment	Flow
GMC	Governmental management changing	Auxiliary
GMP	Governmental management performance	Auxiliary
GS	Government's satisfaction	Auxiliary
HI	Health index	Auxiliary
HOSD	Helps others to solve the difficulties	Constant
HRMI	Harmonious relationship maintenance increment	Flow
HRS	Harmonious relationship with stakeholders	Constant
IBI	Innovation behavior increment	Flow
IHSE	Impact of achieving "HSE" goals	Auxiliary
IIC	Increasing index of conscientiousness	Auxiliary
IICB	Increasing index of collaboration behavior	Auxiliary
IIEIMS	Increasing index of efforts to improve megaproject success	Auxiliary
IIHRM	Increasing index of harmonious relationship maintenance	Auxiliary
IIIB	Increasing index of innovation behavior	Auxiliary
IIPC	Increasing index of project compliance	Auxiliary
IMS	Increasing megaproject success	Flow
IRMS	Increasing rate of megaproject success	Auxiliary
MDF	Meeting designed function and delivering value that the public need	Auxiliary
MRpsI	Megaproject recognized widely by the public and society increment	Flow
MRS	Meeting regulations or specifications	Auxiliary
NM	New market or improved market share	Auxiliary
OCBA	Organizational citizenship behavior adoption	Auxiliary
OS	Owner's satisfaction	Auxiliary
PCI	Project culture increment	Flow
PCI-1	Personal compliance increment	Flow
PPII	Project program improved initiatively	Constant
PPMAC	Conscious participation in project meetings and activities	Constant
PPOI	Potential promotion opportunities increment	Flow
PTC	Participation in training consciously	Constant
SI	Safety index	Auxiliary
SPE	Shares with project experience	Constant

TVOCB	Total value of organizational citizenship behavior	Auxiliary
VC	Value of conscientiousness	Auxiliary
VCB	Value of collaboration behavior	Auxiliary
VHRM	Value of harmonious relationship maintenance	Auxiliary
VIB	Value of innovation behavior	Auxiliary
VMRps	Value of megaproject recognized widely by the public and society	VMRps
VMS	Value of megaproject success	Auxiliary
VPC	Value of project culture	Auxiliary
VPC-1	Value of project compliance	Auxiliary
VPP	Value of potential promotion	Auxiliary
WAOCB	Willingness to adopt organizational citizenship behavior	Auxiliary
WoBCP	Weight of BCP	Constant
WoDseBC	Weight of delivering social-economic benefits to the community	Constant
WoEPNpc	Weight of enhancing people's national pride and cohesion	Constant
WoGS	Weight of government satisfaction	Constant
WOI	Work overtime initiatively	Constant
WoIHSE	Weight of impact of achieving "HSE" goals	Constant
WoMDF	Weight of meeting designed function and delivering value that the public need	Constant
WoMRS	Weight of meeting regulations or specifications	Constant
WoNM	Weight of new market or improved market share	Constant
WoOS	Weight of owner's satisfaction	Constant
WVoBCP	Weighted value of BCP	Auxiliary
WVoDseBC	Weighted value of delivering social-economic benefits to the community	Auxiliary
WVoEPNpc	Weighted value of enhancing people's national pride and cohesion	Auxiliary
WVoGS	Weighted value of government's satisfaction	Auxiliary
WVoIHSE	Weighted value of impact achieving "HSE" goals	Auxiliary
WVoMDF	Weighted value of meeting designed function and delivering value that the public need	Auxiliary
WVoMRS	Weighted value of meeting regulations or specifications	Auxiliary
WVoNM	Weighted value of new market or improved market share	Auxiliary
WVoOS	Weighted value of owner's satisfaction	Auxiliary
Y	Yearly	Constant

Appendix F: List of equations in the SD model

1. AEIMS=AEIMS(t-dt)+EsI×dt

   INTI AEIMS=5

2. EsI= IIEIMS×Y×AEIMS
3. IIEIMS=GRAPH(OCBA)

   ([(0,0),(100,1)],(0,0),(10,0.02),(20,0.08),(30,0.13),(40,0.18),(50,0.24),(60,0.31)

   ,(70,0.35),(80,0.39),(90,0.41),(100,0.42))

4. AIA=AIA(t-dt)+CNA×dt

   INTI AIA=0

5. CNA= -CRC×AIPWE
6. AIEN=AIEN(t-dt)+CEN×dt

   INTI AIEN=0

7. CEN= CREN×EMM
8. AIPWE=AIPWE(t-dt)+CPWE×dt

   INTI AIPWE=0

9. CPWE= CRPWE×EMM
10. AIRMRps=0.1
11. AIRPC = 0.05
12. AIRPP = 0.05
13. AROCB=IF THEN ELSE(WAOCB>=100, 0.1 , WAOCB/10)
14. ATAI = 4.07
15. AVC(t) = AVC(t − dt) + (CI) × dt

    INTI AVC = 0

16. AVCB(t) = AVCB(t − dt) + (CBI) × dt

    INTI AVCB = 0

17. AVHRM(t) = AVHRM(t − dt) + (AVHRMI) × dt

INTI AVHRM = 0

18. AVIB(t) = AVIB(t − dt) + (IBI) × dt

19. AVPC(t) = AVPC(t − dt) + (PCI-1) × dt

INTI AVPC = 0

20. AVPP(t) = AVPP(t − dt) + (PPOI) × dt

INTI AVPP = 5

21. AVPC-1(t) = AVPC-1(t − dt) + (PCI) × dt

INTI AVPC-1 = 5

22. HRS = 4.23

23. CCA = 4.17

24. CGR = 4.48

25. CRC=0.1

26. CREN=0.1

27. CRPWE=0.1

28. DseBC=0.705

29. EI=GRAPH(AIEN)

([(0,0),(10,10)],(0,0),(1,0.1),(2,0.25),(3,0.4),(4,0.52),(5,0.6),(6,0.66),(7,0.7),(8,0.7 2),(9,0.74),(10,0.75))

30. EIMS=AEIMS

31. EMM=1/2×GMC

32. EPNpc=1/4×AVMRps

33. MRpsI= AIRMRps×VMRps

34. IICB = 1/5 × IAOCB

35. VCB = 1/3 × (CCA + HOSD + SPE)

36. CMRC = 4.28

37. CI = IIC × VC

38. IIC = 1/5 × IAOCB

39. CPA = 4.38

40. PPMAC = 4.06

41. PTC = 4.21

42. VC = 1/3 × (CMRC + PTC + WOI)

43. BCP = 1/4×AVMRps

44. GMC = 1/4×AVMRps

45. GMP = GRAPH(GMC)

([(0,0)(100,80)],(0,0),(10,3),(20,6),(30,11),(40,16),(50,22),(60,26),(70,29),(80,31),(90,32.5),(100,33))

46. GS=DseBC+EPNpc+IHSE

47. HI=GRAPH(AIPWE)

([(0,0),(10,10)],(0,0),(1,0.1),(2,0.25),(3,0.4),(4,0.52),(5,0.6),(6,0.66),(7,0.7),(8,0.72),(9,0.74),(10,0.75))

48. IHSE=EI+HI+SI

49. IRMS=GRAPH(EIMS)

([(0,0),(40,1)],(0,0),(1,0.1),(2,0.18),(3,0.25),(4,0.33),(5,0.4),(6,0.47),(7,0.55),(8,0.58),(9,0.6),(12,0.6))

50. MDF= 0.782

51. MRS= 0.791

52. NM= 1/4×AVMRps

53. OS= BCP++EMM+IHSE+MDF+MRS+NM

54. SI=GRAPH(AIA)

([(-10,0)-(10,10)],(-10,0.5),(-9,0.48),(-8,0.46),(-7,0.44),(-6,0.4),(-5,0.36),(-4,0.3),(-3,0.22),(-2,0.15),(-1,0.1),(0,0))

55. HRMI = IIHRM × VHRM

56. IIHRM = 1/5 × IAOCB

57. VHRM = 1/2 × (BHRS + PPMAC)

58. HOSD = 4.37

59. IAOCB = 1/4 × (AVPP + GMP + BCP + AVPC-1)

60. IBI = IIIB × VIB

61. IIIB = 1/5 × IAOCB

62. VIB = 1/2 × (ATAI+PPII)

63. IPP = MPP

64. PPII = 3.98

65. VMRps= 1/3×(EIMS+EPNpc+MDF+MRS)

66.VMS=WVoBCP+WVoDseBC+WVoEPNpc+WVoGS+WVoIHSE+WVoMDF+WVoMRS+WVoNM+WVoOS

67. WoBCP= 1/9

68. WoDseBC= 1/9

69. WoEPNpc= 1/9

70. WoGS= 1/9

71. WoIHSE= 1/9

72. WoMDF= 1/9

73. WoMRS= 1/9

74. WoNM= 1/9

75. WoOS= 1/9

76. WVoBCP= BCP×WoBCP

77. WVoDseBC= DseBC×WoDseBC

78. WVoEPNpc= EPNpc×WoEPNpc

79. WVoGS= GS×WoGS

80. WVoIHSE= IHSE×WoIHSE

81. WVoMDF= MDF×WoMDF

82. WVoMRS= MRS×WoMRS

83. WVoNM= NM×WoNM

84. WVoOS= OS×WoOS

85. OCBA = AROCB × TVOCB

86. VPC = 1/3 × IPP

87. PCI = AIRPC × VPC

88. PCI-1 = IIPC × VPC-1

89. IIPC = 1/5 × WAOCB

90. VPC = 1/3 × IPP

91. VPC-1 = 1/2 × (CGR + CPA)

92. IIPP = GRAPH(OCBA)
([(0,0),(100,1)],(0,0),(10,0.02),(20,0.08),(30,0.13),(40,0.18),(50,0.24),(60,0.31),(70,0.35),(80,0.39),(90,0.41),(100,0.42))

93. PPOI = AIRPP × VPP

94. SPE = 4.41

95. TVOCB = IF THEN ELSE((AVC +AVCB + AVHRM + AVIB + AVPC) > 100, 100, (AVC + AVCB + AVHRM + AVIB + AVPC))

96. WOI = 4.29