Developing a framework for roading infrastructure projects procurement system selection

A thesis submitted to Auckland University of Technology

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Doctor of Philosophy

by

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LIST OF ABBREVIATIONS

AC	Auckland Council
AHP	analytic hierarchy process
ANN	artificial neural networks
AR	augmented reality
AT	Auckland Transport (a Council Controlled Organisation of Auckland Council)
AUT	Auckland University of Technology
AUTEC	Auckland University of Technology Ethics Committee
BIM	building information modelling
BVP	best value procurement
BWM	best worst method
CEM	construction, engineering and management
CBA	case-based analysis
CBR	case-based reasoning
CI	consistency index
CR	consistency ratio
DB	design and build
DBB	design-bid-build
D&C	design and construct
DST	decision supporting technique
ECI	early contractor involvement
FST	fuzzy set theory
GDP	gross domestic product
ICN	Industry Capability Network New Zealand
IM	interaction matrix
MBIE	Ministry of Business, Innovation & Employment
MCA	multi-criteria analysis
MCDA	multi-criteria decision approaches
MUV	multi-attribute utility value
NIU	National Infrastructure Unit (a body within the New Zealand Treasury)

NZCID	New Zealand Council for Infrastructure Development
NZGP	New Zealand Government Procurement
NZLJ	New Zealand Legislation Journal
NZTA	New Zealand Transport Agency
PESTLE	political, economic, social, technological, legal and environmental (analysis)
PPP	public-private-partnership
PS	procurement system
PSC	procurement selection criteria
PSS	procurement system selection
RA	regression analysis
SMARTS	a simple multi-attribute weighting technique with swing weights
TCBA	transaction cost-based approach
TCE	transaction cost economics
UM	unascertained mathematics
VR	virtual reality
WS	weighted sum

LIST OF PUBLICATIONS

Zhao,* N., Ying, F, & Tookey, J. (2021). Knowledge visualisation for construction procurement decision-making: a process innovation. *Management Decision (ahead-of-print).* https://doi.org/10.1108/MD-01-2-21-0051

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Zhao*, N., Ying, F., & Naismith, N. (2019). *Using data analysis techniques in procurement method selection: evidence from urban rail projects.* Smart City. CIB World Building Congress 2019. Hong Kong.

Zhao*, N., Ying, F., & Naismith, N. (2019). *Challenges of public-private partnership project evaluation: A perspective from public sector agencies.* Smart City. CIB World Building Congress 2019. Hong Kong.

ATTESTATION OF AUTHORSHIP

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

Nan Zhao

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ETHICAL APPROVAL

The ethics application for this research project was approved by the Auckland University of Technology Ethics Committee, AUTEC Reference number 12/161.

ABSTRACT

The ability to select an optimal procurement system is critical to project success and can potentially contribute to the sustainability of the construction society. Although its importance has been recognised, current systematic approaches for procurement system selection (PSS) are far from efficient or automated. Although New Zealand has taken a series of steps to expedite the rate in adopting innovation procurement, only a few infrastructure projects have applied novel procurement strategies successfully in the last decade.

This thesis aims to improve the quality of the decision-making process for New Zealand roading infrastructure procurement. A mixed research strategy was employed to construct the framework of a PSS procedure, describing potential improvements in the outcomes of procurement activities. The research started with a systematic analysis of the relevant literature to identify the key themes of PSS. Using a pilot study and interviews, the research then investigated these core components of PSS from the perspectives of public administrators, contractors and consultancies within the New Zealand roading infrastructure projects sector. By analysing relevant documents and the interview data, an algorithmic decision-making framework was developed with the aid of computer programming. Finally, a case study was employed to validate the framework.

The framework is designed to achieve the dual outcomes of enriching the cognition of PSS practices and promoting the understanding of alternative procurement options. It is anticipated that these insights into the standardisation of procurement activities will not only help the roading infrastructure sector in New Zealand to improve procurement success but also other sectors that have similar decision-making conditions. Furthermore, the insights could aid other countries with small construction markets to gain a better understanding of effective and efficient PSS processes, as these countries often struggle to determine a procurement system that is seemingly successful elsewhere.

1. CHAPTER ONE: INTRODUCTION

The research aims to improve the quality of the decision-making process of procurement system selection (PSS) in the context of roading infrastructure projects. The research questions addressed within the thesis are:

1. What comprises a decision-making process for procurement selection in New Zealand roading infrastructure projects?
2. How should a procurement system (PS) be determined?

This chapter consists of seven sections. Section 1.1 provides the general background of the research and then the research problem is presented in section 1.2. Section 1.3 expands on this by discussing the research aim, specific research objectives and corresponding research questions. Section 1.4 presents a summary of the research methodology. After that, the significance of the research, and the scope and limitations of the research are highlighted in sections 1.5 and 1.6. The chapter concludes by listing a synopsis of the research.

1.1 Research background

Construction sectors play a pivotal role in modern society, accounting for one-tenth of the global economy and consuming 30–40 per cent of international energy requirements (Agbesi et al., 2018). As a PS specifies contractual processes for all phases of a project (Oyegoke & Kiiras, 2009), increasing sustainable potentials are being demanded to meet client and project needs, particularly for infrastructure projects. Infrastructure development is growing at a fast pace in many countries around the world. The core drivers of the demand for infrastructure are trends towards urbanisation and globalisation (Kumaraswamy et al., 2017) In light of the changing business trends and stakeholder influences, organisations nowadays must explore procurement issues from both financial and broader construction engineering management contexts. These perspectives include updated laws regarding procurement strategies, innovative procurement

methods (such as economic modes and delivery methods), and governance incentives (Bruno et al., 2018; Murphy & Eadie, 2019; Tran et al., 2017). Accordingly, many infrastructures over the past decade have been commissioned using novel PSs (Kumaraswamy et al., 2017). These novel PSs include public-private partnership (PPP), best value procurement (BVP), early contractor involvement (ECI), and alliance (Ibrahim et al., 2017, Chen et al., 2018, Zhao & Ying, 2019).

Choosing a suitable PS is a challenging task (Luu et al., 2005). Recognition of a suitable PS significantly contributes to the project success, and so interest in PSS draws immense attention in the construction project management arena. Indeed, PSS has been on policymakers' agendas since 1994, as policymakers strive for changes in the construction sector as advocated in the Latham and Egan reports (Egan, 1998; Latham, 1994). Specifically, PSS research addresses diverse challenges, such as identifying factors that have an influence on the PSS, developing evaluation techniques and specifying the main characteristics of various PSs (Love et al., 2012). As the knowledge of PSs spreads across various domains, previous studies have discussed PSS from multi-dimensional aspects using a plethora of analysis techniques. Consequently, a systematic PSS process is extensively in this thesis explored to encourage the use of novel PSs.

1.2 Statement of research problem

Successive New Zealand governments have planned to increasingly invest in infrastructure development to stimulate economic growth (NIU, 2011). However, Stats NZ data indicate that investment in the construction industry has fallen since 2012 (Stats NZ, 2017). Despite being the 4th largest contributor to the country's gross domestic product (GDP), several studies have claimed that low productivity in the construction sector and long-term fiscal burdens have resulted in poor performance by the sector, particularly for roading infrastructure. The New Zealand Council for Infrastructure Development believed the construction productivity is highly influenced by the PSs its uses (NZCID, 2009). To lift infrastructure productivity and improve long-term economic performance and the social well-being of New Zealanders, acts and

regulations encouraging the expedition of novel PSs have been developed to facilitate novel PSs implementation.

The Government has also highlighted its requirement of "value for money", which is defined in the Australia New Zealand Government Procurement Agreement as "the primary determinant in government procurement of goods and services. Application of the value for money principle aims to achieve the best available outcome for money spent in terms of the procuring agency's needs. The test of the best available value for money requires relevant comparison of the whole of life costs relating directly to the procurement." However, there is a paucity of practical studies and guidelines on achieving best values and promoting social values in communities (such as the particularly New Zealand-centric concept of *vision Mātauranga* – a term associated with the unlocking of innovative potential of Māori knowledge).

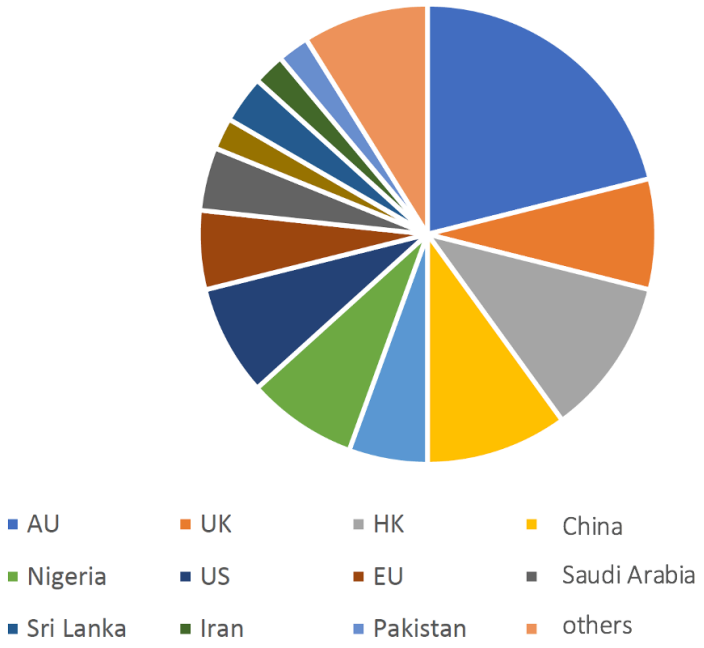
Considering the complexity of infrastructure projects, including their engagement of multiple stakeholders, novel PSs have prominent benefits and advantages in the sector (Rowlinson, 2017). In this thesis, the term *infrastructure projects* refers to complex roading infrastructure projects incurring relevant high costs (e.g. more than NZ$10 million), with complicated designs, high risks, multiple project interfaces, intricate contractual arrangements, and targeting strong economic and social impact. As a classic type of infrastructure projects, roading infrastructure provide ideal cases for exploring construction procurement from the perspectives of value creation and innovation requirements in New Zealand.

Even though novel PSs, such as PPP, ECI and alliance, have been globally implemented in infrastructure projects, they are still relatively new to the New Zealand construction industry (Liu & Wilkinson, 2011). It seems the New Zealand Government is not confident in adopting alternative PSs. This hesitancy was identified in the review report of the first PPP project in New Zealand – the Transmission Gully project – which highlighted various challenges in

implementing such a procurement system (NZTA, 2014). While the report confirmed that the Government was satisfied that PPP was an appropriate strategy for the size and complexity of the Transmission Gully project, it also noted that the ambiguous decision-making process was problematic and project team relatively isolated (NZTA, 2014). For this reason, it is conceivable that the public officials favour adopting traditional PS that lie within their "comfort zones". As time-consuming and low-collaboration PSs can hinder infrastructure delivery, it is expected that novel PSs are more likely to be implemented in the future. Therefore, the need to have a sound PSS framework is pressing. The framework should consider the characteristics of each available PS and the perspectives of various stakeholders, to illustrate the procedure of PSS and its key inputs.

Interestingly, there is no legislation or guidelines that specify the best PSS process for public infrastructure projects in New Zealand. Rather, government policy considers that government organisations are responsible for their own project (New Zealand Law Journal, 2005). Procurement policy in New Zealand is facilitated through the Industry Capability Network New Zealand (ICN). The practitioners can access the website for purchasing information. The ICN database includes "lessons learnt" reports from other agencies, procurement training courses and international courses. Much of the literature over the last three decades discussing PSS in infrastructure projects has focused on cases in Australia, UK, Hong Kong, China, US and Nigeria, as shown in Figure 1.1, and there has been limited research explicitly on such cases in New Zealand. The modern construction industry has also suggested that a private investment needs to be undertaken into procurement activities (New Zealand Treasury, 2021). Yet, without a clear and detailed PSS process implementation of novel PSs in infrastructures is impossible as most participants do not have enough experience with them.

Figure 1.1 Distribution of focus of peer-reviewed journal articles from 1998 to 2020 on PSS in construction projects



It is thus essential to facilitate the implementation of novel PSs to expedite opportunities for adopting the expected outcomes such as increasing sustainable potentials in New Zealand. An informed process is needed to show the step-by-step decision-making phases required for a practical path to comprehensively and effectively obtain information. With indicators of potential future demand into a "ideal" guidance framework would be very helpful for procurement decision makers.

1.3 Research aim, research objectives and research questions

1.3.1 Research aim

Procurement systems (PSs) have evolved over time and around the world. Novel PSs have been explored as a catalyst for change, galvanising stakeholders to re-evaluate traditional construction procurement practices, particularly in complex projects (Mohan et al., 2017). Selecting a suitable PS offers significant opportunities to advance process excellence in the construction sector. Some novel PSs – such as PPP, alliance and BVP – have attracted attention from the New Zealand

Government. Yet to date, government officials' lack of experience and guidance in novel PSs has led to missing information and limited confidence in using novel PSs in infrastructure projects. The situation calls for a robust process to indicate how a suitable PS can be selected to enhance procurement decision outcomes. Accordingly, this thesis aims:

- ***To improve the quality of the decision-making process for procurement system selection in roading infrastructure projects***

1.3.2 Research objectives

To achieve its overarching aim, the research has three objectives.

Research objective one (RO1)

- ***To investigate the key components of procurement system decision-making processes.***

Before determining how a PS could be selected in the context of New Zealand infrastructure projects, it is essential to gain an overview of the current PSSs from the existing literature. Since processes to support decision making in PSS have been explored worldwide, a comprehensive review is needed of current PSS procedures. Thus, RO1 attempts to investigate the key components of the PS decision-making process.

Research objective two (RO2)

- ***To discover the current procurement system selection processes being used in New Zealand roading infrastructure projects***

There is a consensus that while a particular PS may best suit a specific project, there is no one PS that will suit all projects (Love et al., 1998). In the context of New Zealand, RO2 intends to explore current PSS processes, identify the barriers for their implementation, and provide the suggestions for potential improvements. To improve the quality of the decisions made during procurement for New Zealand roading infrastructure projects, it is critical to understand the challenges in current procurement practices to assure roading infrastructure project success

through a guided PSS process. Therefore, this research will explore the debates on the New Zealand roading infrastructure PSS to determine the fundamentals of current PSS processes.

Research objective three (RO3)

- ***To develop and validate a procurement system selection framework.***

Based on the critical elements identified in PS decision-making procedures and potential improvements to address the current challenges, the initial purpose of RO3 is to develop a framework for PSS that can support infrastructure procurement decisions. Validation of the constructed framework will then be carried out to examine how "real world" issues could be solved and their potentials improved. The validation step ensures the proposed framework contains valuable information that contributes to understanding characteristics of roading projects, the relationships of each element in the framework, and how the proposed framework could meet future community expectations through empirical results from a local procurement practice. The validation step could also assist further research in comparing international best practice and other sector performances.

1.3.3 Research questions

From the stated research aim and objectives, three research questions, with sub-questions, are being addressed.

The first research objective is investigated by research question one (RQ1) and its two sub-questions.

Research question one (RQ1)

What are the key elements of the procurement system selection process?

- RQ1 (a) What are the key themes in the procurement system decision-making process?
- RQ1 (b) What is the significance of these key themes to the procurement system decision-making process?

Research question two (RQ2) intends to focus on a specific situation of PSS. After a pilot test, an empirical study was conducted to discover answers to the follow question.

Research question two (RQ2)

How are procurement systems currently being selected in roading infrastructure projects in New Zealand?

Five sub-questions were formed to supplement RO1 and RO2:

- RQ2 (a) What are the characteristics of PS in the context of roading infrastructure projects in New Zealand?
- RQ2 (b) What are the factors that influence the procurement system decision?
- RQ2 (c) What are the techniques used for procurement system selection and how are those techniques used?
- RQ2 (d) What are the challenges in the roading infrastructure project procurement system selection process?
- RQ2 (e) What are potential improvements to the current procurement system selection processes for roading infrastructure projects in New Zealand?

The aim of RO3 is to develop and validate a PSS framework. The proposed framework should consider the applicability of the PSS for future demand as well as avoid deficiencies in current PSs.

Therefore, research question 3 (RQ3) and its sub-questions ask:

Research question three (RQ3)

How useful is the constructed framework?

- RQ3 (a) How is the case illustrated to validate the framework?
- RQ3 (b) How does the revised framework support infrastructure decision-making?

1.4 Summary of research methodology

The research problem addressed in this thesis is primarily based on the researcher's interest and an academic review of PSS-related studies. The literature review section identified the research gaps and reinterpreted the essence of this research. A review of published procedures, policies and documents showed that PSS implementation faces challenges such as flawed understandings of new procurement strategies and platforms that are not operating at ideal levels of collaboration. Thus, the research problems were identified. Given the nature of the research problems, a philosophical position for the research was defined. The research employed a pragmatic paradigm after examining the ontological, epistemological and axiological aspects of the underlying philosophical assumptions. It is important to note that the investigation stated in this thesis comprises topics at the intersection of various disciplines, including construction technology, operational research, decision-making and sociology. Those aspects have been embraced and embedded to support the establishment of the PSS framework. Development of the framework also necessitated the adoption of computer science technology and advanced artificial intelligence perceptions.

The research employed a mixed method approach. The research process comprised three stages. Figure 1.2 shows how the research stages are related to the research objectives listed earlier. The first stage of the research was a quantitative study involving a systematic review of PSS literature. The data collected from the literature review were analysed using descriptive statistics and content analysis, and through this process, fundamental themes of the PSS decision-making process were identified. The findings from the review contributed to answering RO1 and set up the interview protocol. The second stage involved semi-structural interviews to explore the PSS processes used in New Zealand roading infrastructure projects. However, because there is no consensus on PS in the existing empirical studies and PSS stakeholders are widely found along the whole supply chain, a pilot study was undertaken with the aim of identifying potential interview participants in New Zealand roading infrastructure contexts. Although conducting a pilot study is time

consuming, it was necessary to establish key parameters and definitions for the research. The pilot study also meant any practical problems in data collection could be identified and solved before the main data collection phase of the research started. Full approval for the research was obtained from Auckland University of Technology Ethics Committee (AUTEC) prior to starting the data collection for the qualitative study. The interviews explored challenges existing in the current New Zealand PSS process and identified potential improvements for future demand. Through analysing the interview data, RO2 has been addressed. Finally, a decision-making framework was developed based on both the qualitative and quantitative research findings, with computer programming help (C+ and Matlab). A case study validated the framework. A revised framework was then synthesised based on the initial research findings and the findings from the case study validation.

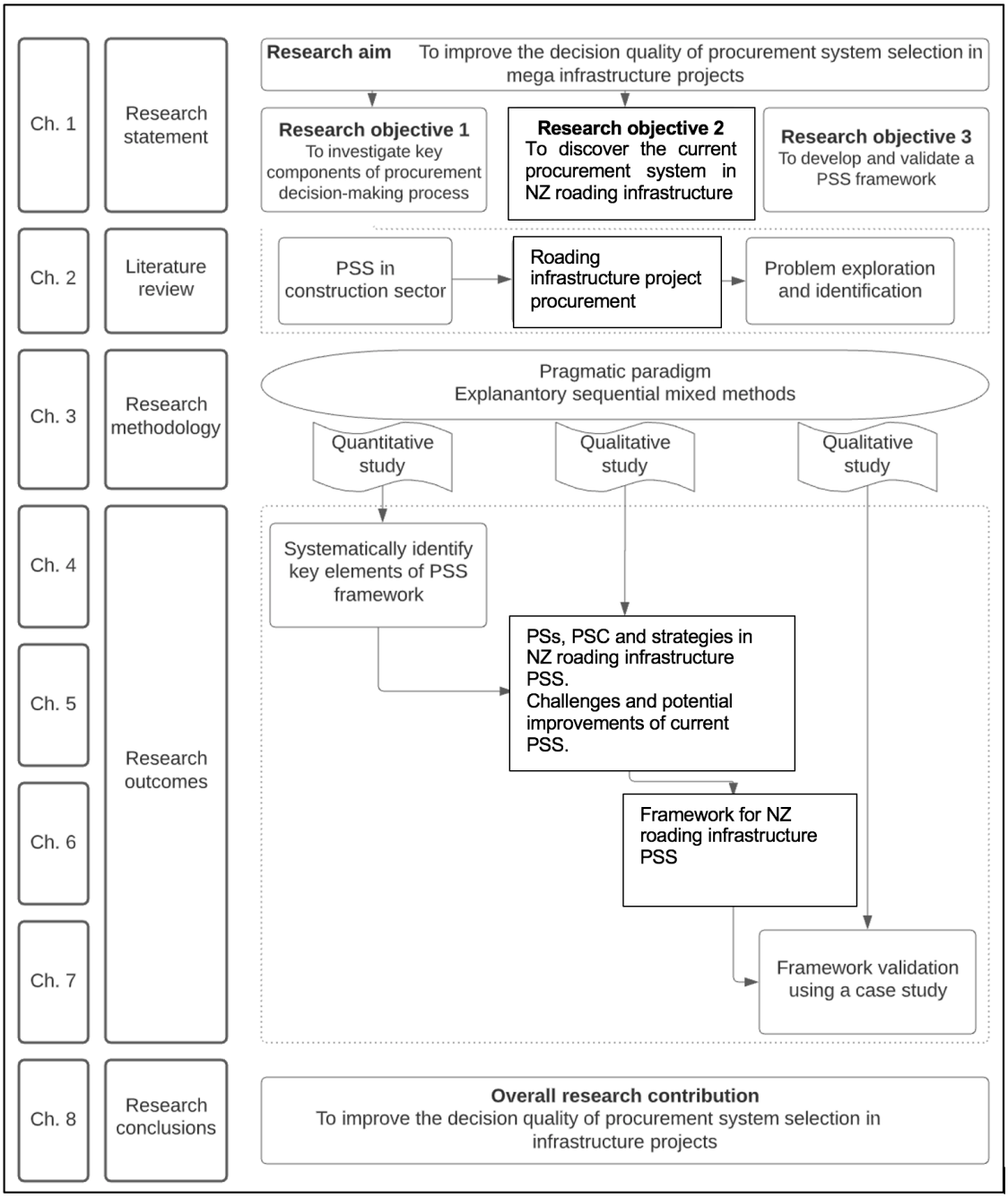
A summary of the research outline can be seen in Figure 1.2.

1.5 Rationale and significance of the study

1.5.1 Contribution to knowledge

The initial purpose of the study is to contribute to the body of existing knowledge. Research has been defined as a "voyage of discovery" – even if nothing new is discovered, the voyage may lend further support for existing knowledge. "Knowledge" is defined in the *Concise Oxford Dictionary* (2011) as "The fact of recognising someone or something already known or known about, or of being recognised". The dictionary also explains research as "original critical or scientific investigation carried out under the auspices of an academic or other institution". Based on the research questions presented above, the research comprises two components: what (facts) and how (original critical or scientific investigation).

Figure 1.2 Research outline



First, the quantitative study presents a comprehensive view of the existing literature. An in-depth analysis objectively maps the critical scientific knowledge areas that need to be investigated to learn what we already know and how we can learn more (Zhong et al., 2019). A systematic bibliometric review found a shift of procurement decisions from perspectives between projects to perspectives between supply chains. As a result, this paradigm shift has led to procuring

organisations focusing on the identification of novel procurement selection criteria (PSC) or promoting the application of technologies. Novel PSs thus grow into a prevalent PS in the roading infrastructure project sector.

Recognising each business model is diluted and commoditised (Matthyssens, 2019), this framework aims to share the experts' knowledge. Based on "lessons learnt" shared by the interviewees from their experiences working in roading infrastructure projects, the thesis presents the latest experience and has employed it in the proposed framework. The framework is a vision and method for procuring and tendering that is driven by a systematic selection process that dynamically and transparently presents the key information provided.

The proposed framework emphasises the vital role of participants. Compared with existing decision-making charts, this framework qualitatively offers dynamic outcomes of each step's decisions that enable knowledge and information to be recorded and displayed. It sheds light on the advantages of using methods that encompass expert and intelligent systems of collaborative decision-making in general, and in particular, highlights the fundamental cognitive aspects of construction procurement decisions. It highlights the fundamental cognitive aspects of construction procurement decisions. Rather than just ending at organisational choices, the participants' cognitive processes are also central in considering the decision quality.

Furthermore, the guidelines presented in the framework are based on the barriers and potential improvements to PSS implementation identified by the research participants in the context of New Zealand roading projects. Thus, the framework is not merely theoretical but is also based on practical outcomes as it enables a better understanding of what PS means and what needs to be improved. Taking this into account, similar small-size markets around the world would be able to consider the applicability of novel PSs for their procurement decisions.

1.5.2 Contribution to cognition

This research nurtures the characteristic of each PS, not only from the view of economic and social impacts but also from the innovative process aspect. In this context, process innovation involves the adoption of an improved method, comprising new strategies that are capable of proceeding with changes continuously. It is evident that two types of construction innovation – technology-based process and organisational process – prevail in the construction sector (Akintoye et al., 2012). Recognising technological attributes of processes, modern process innovation components consist of processes, modern process innovation consists of human, organisation and information components (Akintoye et al., 2012). Accordingly, this framework shows the possibility of improving decision quality through a radical (organisational) process innovation. The framework also visualises the thought processes involved in procurement decision-making, which in turn, reflect construction epistemologies. Thus, the framework provides future researchers with a comprehensive picture of the procurement decision-making process, including the philosophies behind the decisions made. This to say, the framework sheds light on the construction epistemologies in terms of the decision-making process.

1.6 Scope and limitations

1.6.1 Research scope

The research focuses on roading infrastructure construction projects in New Zealand. There is a consensus that differences exist between different types of construction projects. The context of roading infrastructure projects in New Zealand has been selected for this research for two reasons. First, novel PSs, such as alliances and PPPs, have been acknowledged as a platform to provide a collaborative way of managing stakeholder complexity, which is the main challenging issue of roading infrastructure projects (particularly mega infrastructures) (Penyalver et al., 2019). There is a pressing need to provide valuable insights into features of novel PSs and understand what the processes are needed to enable objective decisions to be made regarding procurement activities for New Zealand roading infrastructure projects. Secondly, New Zealand has historically tended

to be slow in adopting novel PSs (Liu & Wilkinson, 2011), and the Government is still hesitant to implement novel PSs. These issues will have to be fully addressed by both Government and industry if procurement innovation can take place.

1.6.2 Research limitations

The study employed a pragmatic view to developing a decision-making framework for PSS in the New Zealand roading infrastructure project sector. The research has explored PSS with the aim of increasing our understanding of PSs and improving quality of decision-making process. The thesis started with quantitative research to achieve generalisability. It then went on to use qualitative research, exploring unequal sample sizes in a specific context, so that it's theoretical findings could be applied to solve real-life issues. Given the rigid selection criteria employed and the relatively small number of roading projects using novel PSs in New Zealand , there are few people who could be considered experienced roading infrastructure project stakeholders. Thus, the research findings may not perfectly reflect the issues of the total population from which the decision makers are drawn. The limitations of a study will also vary depending on whether it addresses different or the same phenomenon (Creswell, 2013). This thesis topic is relatively new, so it was difficult to find individuals who have experience in all the research phenomena under investigation. Therefore, the proposed framework may represent only part of the whole situation.

1.7 Synopsis

Chapter One has provided an introduction to the thesis. It has presented general information about the background to the research, the research problem, research aims and objectives, research questions, and contributions the research findings might make. The chapter has also briefly justified the philosophical position of the research and its design and finished with a discussion of the scope and limitations of the research.

Chapter Two provides the literature review of PSS research and New Zealand roading infrastructure PS utilisation. It describes the process of making procurement decisions in the context of the construction sector. Different PS definitions are presented from various authors and from multiple viewpoints. The review reveals that the PS decision might be influenced by PSS factors and the strategies adopted during the PSS procedure. Chapter Two continues with findings from the literature review about the current application of PSS in New Zealand infrastructure, considering the practical procedures, policies and legislation, and related strategies for decision making being used in this context. The chapter concludes by identifying the research gaps and addressing the research problems in real-world contexts.

Chapter Three discusses the research methodology. It explains the development process of the research from the beginning to completion. The methodology chosen was determined by the research questions being asked and the philosophical assumptions behind different research paradigms. The research strategy, methods and procedure of data collection that were chosen are then discussed, as is the analysis used. This is followed by a discussion of the validation strategy, ethical issues, and generalisability of the research.

Chapter Four presents the overall findings from the quantitative analysis. The chapter presents key components of PSS in the construction sector, thus addressing RO1. It begins with the results of a bibliometric review of extant studies. Based on a systematic process, three key themes are discussed. Also, research of the PSS and techniques adoptions suggests the relationships of the element in PSS.

Chapter Five starts with the pilot study, and then presents the semi-structural interviews. The aim of the pilot study was to identify the potential participants to interview for the research. The data from the semi-structural interviews indicate the key elements of PSS in the context of New Zealand roading infrastructure projects. The data from the interviews are further addressed in Chapter Six in relation to the results of the quantitative study. Additionally, the interview data

pinpoint the challenges that exist in the current PSS procedures. The interview participants were also encouraged to provide their suggestions for potential improvements. The qualitative data from the interviews were used to address RO2.

Chapters Six and Seven focus on RO3; that is, the framework development and validation. Chapter Six presents and discusses the framework which was developed based on the integration of the research findings explored in Chapters Four and Five. A case study was carried out to validate the framework, and this is discussed in Chapter Seven.

Chapter Eight summarises the research findings and how they answer the research questions. It also outlines the contributions of this research to existing knowledge and cognition. Although this is a New Zealand-based study, the thesis has an international research contribution. The chapter concludes with research limitations and further research directions.

2. CHAPTER TWO: LITERATURE REVIEW

Chapter Two begins with an overall introduction to PSS in the construction sector. It highlights essential aspects associated with PSS which need to be included within the decision-making process. Sections 2.1.1, 2.1.2 and 2.1.3 describe the primary considerations (including PSs), factors influencing the procurement decision, and strategies adopted for PSS. Section 2.2 looks at application of PSS in the context of New Zealand roading infrastructure projects, drawing attention to current policies and practice of PSS in this sector. Finally, Section 2.3 presents examples from extant literature of how the current research problem could be identified and explored.

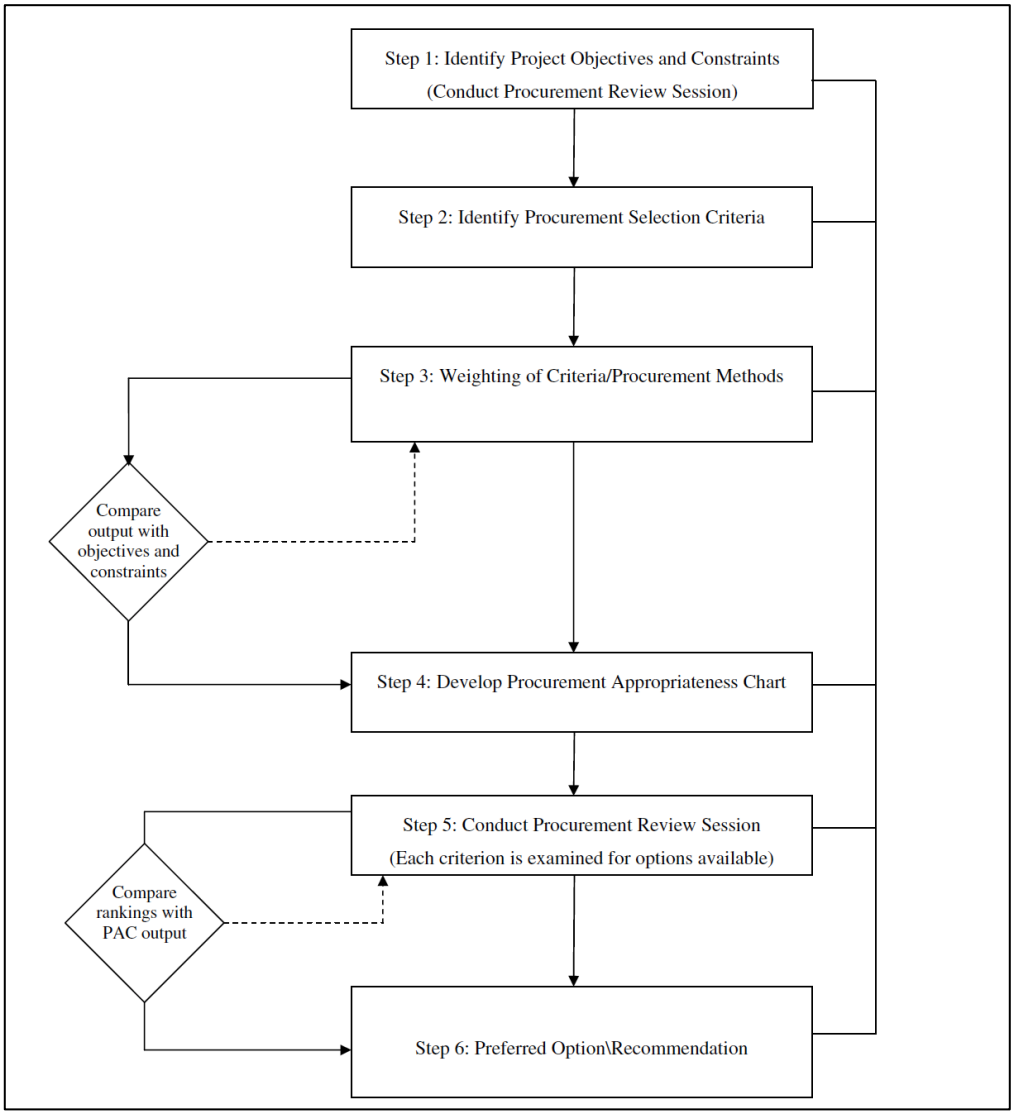
2.1 Overview of procurement system selection

A notable innovative change in the construction sector is the proliferation of PSs (Chen et al., 2018). Post the renowned Latham and Egan reports (Egan, 1998; Latham, 1994), construction practitioners become aware of various PSs (Ng et al., 2002). Consequently, numerous issues have emerged related to the choice of PSs (Love et al., 1998). An unsuitable PS may lead to significant project failures such as cost and time overrun, disputes and claims (Kumaraswamy & Dissanayaka, 1998). For this reason, decision makers are keen to employ various PSs for their projects (Ng et al., 2002) and understand how each procurement route contributes to project success at multiple levels (Chang & Ive, 2002).

It is universally agreed that a particular PS may best suit a particular project, but there is no one PS that suit all projects (Love et al., 1998). With an increasing number of construction projects in operation, numerous empirical studies (for example, Luu et al. (2005)) and reviews (for example, Qiang et al. (2015)) have attempted to select the optimal PSs to achieve the clients' needs. The development of procurement decision-supporting systems is an urgent need within the construction sector.

Procurement selection is defined as "a set of rationalistic decisions within a closed environment, aiming to produce generic, prescriptive rules for clients and advisers to use to select the 'best' procurement route for their project" (Tookey et al., 2001). This definition highlights the importance of decision-making strategies and clients' rules. A classic procedure of procurement selection is presented in Figure 2.1. It shows a fundamental discussion of PSS from three aspects: (1) procurement systems and project objectives (Step 1); (2) the factors or criteria that influence procurement system selection (Step 2); and (3) strategies for PSS (Steps 3 to 5).

Figure 2.1 Procurement system selection process



Note: Adapted from Love et al. (2012).

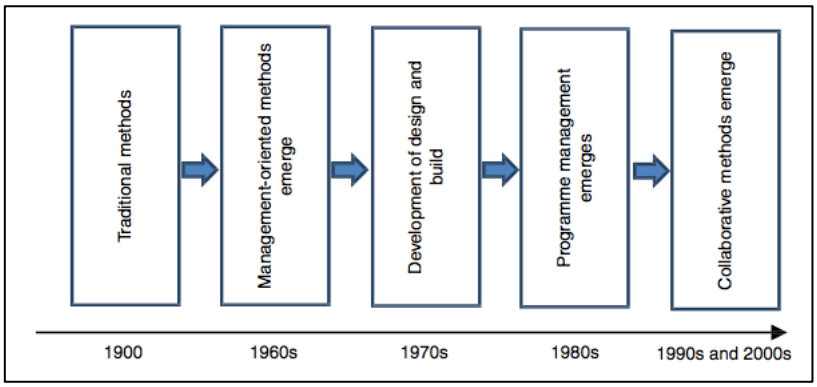
Unquestionably, the construction procurement process is more difficult than procurement in other sectors due to the contracting industry's fragmented nature, the temporary structure of construction project organisations, the constant changes in the clients' needs, and the uniqueness of construction projects. Many problems have been identified during the PSS process, such as inadequate understanding of PSs, communication lapses, different interests among stakeholders, clients' needs and cultural diversity (Dzeng & Chang, 2005; Luu et al., 2005; Naoum & Egbu, 2016). As a result, numerous studies of PSs, PSC and strategies have been undertaken over the last two decades. Sections 2.1.1, 2.1.2 and 2.1.3 briefly discuss related studies from these three perspectives.

2.1.1 Procurement systems

In the context of construction procurement, an early paper defined PS as *"*an organizational system that assigns specific responsibilities and authorities to people and organizations, and defines the relationships of the various elements in the construction project" (Love et al., 1998), while a recent paper noted concerns about PS: "[T]here have been concerns about problems associated with the type of procurement, risk allocation, procurement methods for design and the procedure for projects and tendering" (Ansah & Sorooshian, 2018). Clearly, there have been significant changes in construction PS over the last two decades.

Types of PS have been evolving through time, as shown in Figure 2.2, which reveals the development of novel PSs in the construction sector. For example, academic papers point out construction PSs, changed from exploring traditional methods to discussing various options, such as design and build and management-oriented and collaborative approaches.

Figure 2.2 Evolution of procurement system



Note: Adapted from Rahmani et al. (2017).

Clients' changing priorities and expectations have also influenced the evolution of PSs. Clients are becoming more sophisticated and require better project performance (Akbiyikli et al., 2012). One of the drivers of innovative changes is clients pursuing better, more accurate and customised PSs (Eriksson et al., 2007), particularly after the proliferation of PSs proposed in the Latham (1994) and Egan (1998) reports.

Although PSs have evolved from the traditional PS to more complex PSs, there is no accord in the categories of PSs (Rahmani et al., 2017). A PS can be classified in accordance with its contract administration types/laws, integration of stakeholder involvement or by various project life cycle phases.

Skitmore and Marsden (1988) classified procurement methods based on seven contract types: negotiated traditional, competitive traditional, develop and construct (competitive), negotiated design and build, competitive design and build, management contracting and Turnkey contracting. Later, Kaka and Khosrowshahi (1996) identified three PSs: traditional, design and build (DB), and management contracting (MC).

In terms of integration of stakeholder involvement, PSs also can be classified as: a fragmented system (such as the traditional method), fully integrated system (such as DB), or a partially

integrated system (such as management contracting) (Kumaraswamy & Dissanayaka, 1998). Later, the same authors added in partnership philosophy as the fourth PS (Kumaraswamy & Dissanayaka, 2001, cited in Naoum & Egdu, 2016). Despite the synergy and overlap (Smith et al., 2004), the various PS provide a coordinating (separated), integrative and control approach to deliver a project.

PSs can also be broadly classified according to the different project life stages. For example, into: "design separated from construct" and "design combined with construct" (Masterman, 1992); design-tender-construction methods, design-build methods, and management methods (Love et al., 1998); or traditional PSs with cost-plus and provisional quantities contracts, DB systems with design, management and construction and novation contracts, and management-oriented systems including design and management, management contracting and construction management (Smith et al., 2004).

Previous studies have highlighted how novel PSs have developed due to the evolution of PSs and the requirements of modern construction. For example, Kumaraswamy and Dissanayaka (1998) added a novel PS: the collaborative PS. In the same year, Love et al. (1998) classified Australian construction PSs into traditional PS, design and construct, management and collaborative methods, and they updated their classifications in 2012 to include such new approaches as novation, design and manage and alliancing from the view of practical use (Love et al., 2012).

Truly, the vague classification of PSs causes confusion in procurement selection. As explained by Love et al. (2012), it is not helped that processes such as contract forms and price determination mechanisms are inextricably related to PSs. Thus, it is critical to be able to clearly distinguish between different PSs and their subsystems. Indeed, unclear classifications lead to difficulties to compare and assess the PSs. For example, DBB (design-bid-build) could be a type of PPP if the private sector is involved in procurement procedures. Besides, there are many terms related to "procurement systems" in the literature: they have also been called "procurement routes" (Lædre

et al., 2006), “procurement options” (Smith et al., 2004), “procurement strategies” (Ren et al., 2012), “procurement methods” (Love et al., 2012), “procurement choice” (Plantinga et al., 2019), “procurement paths” (Smith et al., 2004), “procurement form” (Davis et al., 2017), and “procurement delivery systems” (Rahmani et al., 2017). Although some terminologies are synonymous, others have different meanings. For example, Nguyen et al. (2018) argued that “procurement systems” are equal to contracting methods that point out the forms for contractor selection (e.g. low bid or pre-qualification).

It can be inferred that the unstructured classifications and fuzzy PS definitions identified in the literature review could result in a vagueness and unclear discipline to decision making when planning a suitable PS for a project. For example, one cannot be sure that the decision makers even recognise all the PSs whether all available.

2.1.2 Procurement selection criteria

Just as there is no universal definition and categorisation of PSs, there is no consensus on which criteria to use during PSS. The first step in standardising a criteria-based selection process is to identify the factors that influence the procurement decision. There are two consecutive stages in PSS: formulating then evaluating the procurement selection criteria (Luu et al., 2005).

Selection of the best PS is strongly dependent on identifying PSC that achieve the clients’ objectives. Consequently, a list of PSC concisely and precisely reflecting the requirements of project success is critical in PSS. The list of PSC should include descriptions and measurement of each PSC.

While contemporary studies have highlighted the significance of PSC in the PSS, they have also indicated that a universal set of PSC is impractical in the construction context. This is mainly because of the uniqueness of each construction project due to, for example, differences in client

requirements, project size, condition, influences and constraints (Pan & Zhang, 2021). Some standard measures – such as speed, certainty, flexibility, complexity, risk allocation and quality level – have been identified in the early studies (Cheung, Lam, Leung, et al., 2001; Love et al., 1998; Ng et al., 2002). In contrast, some modern factors such as value for money (Smith et al., 2004), payment mode (Ling et al., 2004), and building information modelling (Naoum & Egbu, 2016) have been developed later.

Researchers are now aware of the evaluation of PSs and agree that identifying the factors influencing the choice of PS is about recognising a pattern. However, it would still be helpful to clarify the classification problems identified earlier, such as classification of project delivery systems (Liu et al., 2015). To date, few studies have investigated the relationship between PS and PSC. Instead, PSC identification is becoming the study of expressed sentiments of stakeholders, rather than systematic analysis of "project performance".

After related PSC had been identified, frameworks were developed to analyse the factors influencing the choice of a procurement system. For example, the Delphi technique was introduced to develop a selection model that would overcome the shortcomings of traditional multi-attribute decision analysis (Chan et al., 2001). Factor analysis was employed by Luu et al. (2003) and Chen et al. (2011) to elicit the underlying relationships between the PSC. However, the recommendations of only a few studies have been adopted in practice, mainly because of the absence of a universally applicable set of criteria for PSS (Ng et al., 2002). Studies have also found different clusters of PSC in matching the project context. The challenge here is that complex variables are needed to identify PSC that match the project context. For example, Rowlinson and Yates (2003) indicated that the PSC for a particular project should contain an amalgamation of various parameters due to the uniqueness of each project, while Luu et al. (2003) argued that there is no clear definition (scope) of those criteria. Similarly, Ng et al. (2002) pointed out some PSC might be "fuzzy" in nature, requiring decision makers to make judgement calls. It seems the literature has not reached a robust conclusion about PSC identification and analysis.

With construction PSs having changed so rapidly in recent years, the question arises whether these PSC are still reliable for choosing the optimum procurement route in the modern construction industry. As a result, researchers seek state-of-the-art PSC to match the unfolding project context. While scholars recognise the need to consider modern concepts when identifying critical factors for PSS, there has been limited research focusing on updating PSC and analysing the trend of modern criteria for PSS. Since there is no consensus as to how agreement of factor identification should be reached, researchers are not capable of deciding the "correct" way of identifying criteria that will deliver a suitable PS for a project. This lack of consensus also leads to difficulties in ascertaining the suitability of a proposed PS.

2.1.3 Strategies for procurement system selection

PSS strategies are used to support decision makers in choosing a suitable PS. PSS strategies will be theoretically discussed in this section. Section 2.1.3.1 explores the evolution of adopting decision-supporting techniques in the PSS process, and explains the theoretical requirements of these strategies, and section 2.1.3.2 presents decision-supporting strategies identified in the literature. Those strategies have been embedded in the PSS, supporting a criteria-based procurement selection process.

2.1.3.1 Theoretical decision-supporting strategies

Strategy plays a vital role in the success of construction projects. Advances in data analytics and information technologies have enabled organisations to use relevant criteria to determine an optimal PS for their project. Nevertheless, PSS is not a straightforward task. By productively contributing to crucial strategic decisions, PSs have continuously transformed themselves into integrated systems (Naoum & Egbu, 2016). As stated above, PSC are unstructured in real-life situations and involve a more extensive range of factors, such as social values (Loosemore, 2016).

Decision-supporting strategies, therefore, have undergone a progression of expansions to reach the place they are today.

In acknowledging the arguments in PS decisions, constructing algorithms with PSC choice could initially promote objectivity. The algorithms can range from simple to complex. The core issues of PSC include non-universal PSC (Luu et al., 2005) and the modern requirements of the construction society have already been described in this chapter. The difficulties in supporting inexperienced clients in their decision making (Love et al., 1998), and issues arising from uncertainty and possibilities (Perng & Chang, 2004) have also been noted when evaluating PSC. Numerous models have attempted to meet these challenges with step-by-step problem-solving structures and decision-making charts designed to deal with the requirements of multiple PSC. The models can be distinguished by evaluating the specific PSC in each one and performing direct knowledge accessibility by experts.

Adoption of decision-supporting strategies can also be made easier with the use of organisational computing, which can assist in the integrated engagement of stakeholders. Organisational computing is particularly useful in facilitating PSS when multiple participants are involved; for example, project managers, procurement specialists, engineers, and general managers from the firms in the supply chains. It is obvious that novel PSs are well placed to be meaningful drivers in encouraging multiparticipant decision making. The next step, then, is to realise the potential of novel PSs to formalise dynamic information management processes into fully integrated practices of the construction team.

With the advent of sustainable concepts and data-driven demands, PSC have expanded in new directions, such as chain involvement and value involvement. Modern PSC have to consider two key sets of features: (1) the consequence of the decisions made at many stages, such as tendering procedures, methodology selection, contractor selection and contract award selection (Plantinga et al., 2019); and (2) modern construction characteristics as these determine the inputs (PSC) and

outputs (PS) for decisions (Luu et al., 2003). As PSC have become more complex, researchers have begun to investigates the costs (challenges) and benefits (profits) of superior information extraction analysis. In an endeavour to improve objectivity in the PSS process, stereo-based automated progress has attracted more attention to collect and analyse PSC. Furthermore, with the rapid expansion of construction automation and the inadequacy of integrated information, strategies are required to assist decision makers in identifying related vital functional features of PSC (Abd Jamil & Fathi, 2018).

The latest, significant expansion of decision-supporting strategies has been in the area of pervasive computing. Recent progress in computer technology (e.g. artificial intelligence) together with the availability of decision-supporting strategies and knowledge, has potential to assist decision making. Unlike traditional static tasks, the decision-making process in construction procurement is dynamic and has multiple facets. Researchers gain insights by evaluating different sharing strategies and share the latest information instruments; hence, this results in the spread of latest information instruments (Plantinga et al., 2019).

2.1.3.2 Decision-supporting techniques (DSTs)

The literature review reveals that tools and techniques have been developed for informative decision-making in PSS. Previous studies have indicated that the process of selecting a suitable PS for a particular project can be systematic and have a reliable outcome. Decision-supporting techniques (DSTs) are used during the decision-making process and for PSC identification and analysis.

Overall, there is a consistency among the approaches that use DSTs. Nevertheless, challenges remain to find DSTs that recognise and solve the inherent complexity of PSS. For example, there is a lack of consensus among experts' judgements of an objective PS. When Chan et al. (2001) adopted Delphi techniques to derive objective opinions from a group of experts, several

difficulties were encountered; for example, the techniques were time-consuming, misunderstandings arose from indirect communications, and it took several rounds to collect all the responses. Knowledge-based approaches, such as problem-solving techniques and reasoning paradigms, been developed to improve predictions of project performance(Chen et al., 2011). These techniques explicate the prediction based on a depersonalized and decontextualized analysis. Different DSTs reflect different desired outcomes, so the DST chosen for a specific project should be the one that best suits the project's desired outcomes. When several alternative PS are available for the project, the chosen DST should assess each alternative and its specific inputs.

Conventional statistical methods can also assess the relationship between PS and project success through PSC analysis (Molenaar & Songer, 1998). Conventional statistical methods can also assess the relationship between PS and project success through PSC analysis (Molenaar & Songer, 1998). For example, statistical analysis can determine if one factor's influence on another factor is significant. Thus, statistical analysis can be used to better understand the intricate interrelationships of PSC and the association between influencing variables and project performance (Chao & Hsiao, 2012).

The existing research highlights the essential role of PSC and centres on the necessity of considering PSC in terms of project performance and the PSS process. Intuitively, PSC analysis techniques aim to improve procurement outcomes. However, there has been limited research into the suitability of DSTs. For example, past studies have shown some techniques can realise the "fuzzy" nature of PSC (Mostafavi & Karamouz, 2010). Even though fuzzy set theory has been conducted in establishing a decision-making chart (Luu et al., 2006; Nazar et al., 2017), few papers have explored the application of fuzzy set theory.

PSs are always evolving because clients' requirements are continually changing and continuous technological evaluations facilitate the development of new modelling methods. The dynamic nature of the PSS field means decision makers need to be familiar with the available PSs and have a certain level of knowledge of DSTs. Numerous papers have shown how PSs can be analysed in the PSS process (e.g. Love et al., 2012; Luu et al., 2005). However, few papers have compared the techniques used for analysing procurement decisions, meaning it is still not clear which are the best DSTs to aid PSS.

Data-analytic tools and artificial intelligence techniques bring together potentials, requirements and paradigms of the PS decision process by employing big data or machine learning to deal with dynamic and complicated PSS process (e.g. Rowlinson et al., 2017; Wimalasena & Gunatilake, 2018. Previous studies, however, yield little information about techniques-enabled cognitive computing systems for PSS. For construction procurement, the core cognition is to avoid misinterpretation and to advance digitisation (Oraee et al., 2017).

Collecting information is still challenging because the unique and dynamic nature of construction activities means that PSC are often not precisely defined (Edirisinghe, 2019). The fuzzy issue explains the limitations of regression analysis (RA), multi-attribute utility value (MUV), and analytic hierarchy processes (AHP), such as subjective and uncertain judgements from experts (Chen, 2011; Molenaar & Songer, 1998). Additionally, although DSTs (e.g. nDCAD) can improve collaboration between the construction and design teams, researchers have found that the basic idea underlying DSTs may inherently miss essential PSC. For example, a lack of transparency and adversarial relationship between teams frequently occurred (Erikriksson et al., 2007).

2.2 Roading infrastructure project procurement

2.2.1 Roading infrastructures procurement decision

The characteristics of a roading infrastructure in New Zealand normally involve high capital cost and innovative approaches. *Infrastructure* in New Zealand has been defined as "fixed, long-lived structures that facilitate economic performance and wellbeing. Infrastructure includes buildings and physical networks, principally: roading, water, social assets and digital infrastructure such as mobile and broadband infrastructure, however funded" (MBIE, 2019). Examples of New Zealand roading infrastructure include Auckland City Rail Link and Transmission Gully project. New Zealand Government Procurement Rules require such projects to:

- consult with Treasury's Interim Infrastructure Transactions (ITU) (or any new entity established to take over the functions of that Unit) early in the development of the project's business case
- follow relevant published ITU guidance
- involve the ITU in the assessment of the project's business case and advice to Ministers
- invite the ITU to participate in relevant project steering and working groups, and in the selection panels for all key advisor appointments in relation to the project, and
- use any standard form documentation developed by the ITU as the basis for any infrastructure contract and consult with the ITU over any material proposed modifications.

(MBIE, 2019)

The term *procurement* is defined differently by different organisations in New Zealand. For example, government procurement "covers all aspects of acquiring and delivering goods, services and works (refurbishment and new construction)" and is considered to "future-proof the ability of New Zealand business to trade" (MBIE, 2019). Local authorities, however, have a simpler view, seeing procurement as merely "the acquisition of all goods, works and services provided by or for the Council" (MBIE, 2020). The procurement life cycle is defined as starting "with

identifying the need" and finishing "with either the end of a service contract or the end of the useful life and disposal of the asset" (Auckland University, 2020).

When selecting a PS for a project, decisions are often made without having all the information (Brockmann, 2021). For this reason, process innovation has developed significantly over the last decade. From the view of construction innovation, the literature carries the theme of distinguishing different types across a multitude of dimensions, such as product verses process, and technological verse administrative (Akintoye et al., 2012). The literal definition of *procurement innovation* is "procurement of innovation". Examples of procurement innovation could be procurement of innovative products such as new materials, and robots in procurement activities across the industrial spectrum, including the construction sector. In contrast, *process innovation* involves adopting an improved method or implementing new strategies, and the innovation is as continuous as the changes and demands in the relevant sector. An increasing number of procurement innovation researchers have investigated organisational and management systems changes since the earlier Latham and Egan reports. These changes have been articulated as an innovative manner to carry out procurement responsibilities and tasks (Yu & Wang, 2012), an innovative collaboration of diverse participants (Love et al., 2008) and an innovative finance allocation (Teo & Bridge, 2017).

The world has developed rapidly in this digital age, and there are dramatic needs in the modern construction sector with technologies blooming. Economists define *technology* as everything that improves output while keeping inputs constant (Brockmann, 2021). As procurement innovations, AutoCAD and BIM enable greater and more comprehensive data to be collected. However, the issue is the gap between technology implementation and outcomes. As explained by Akintoye et al. (2012), there are two types of process innovation: the primary one is a technology-based process, and the recent one is a radical (organisational) process created by innovation. The case for innovation is heightened because of the growing need to enhance an integrated process of complexity and agility between human and machine (Lu et al., 2017). In the industrial 4.0 era,

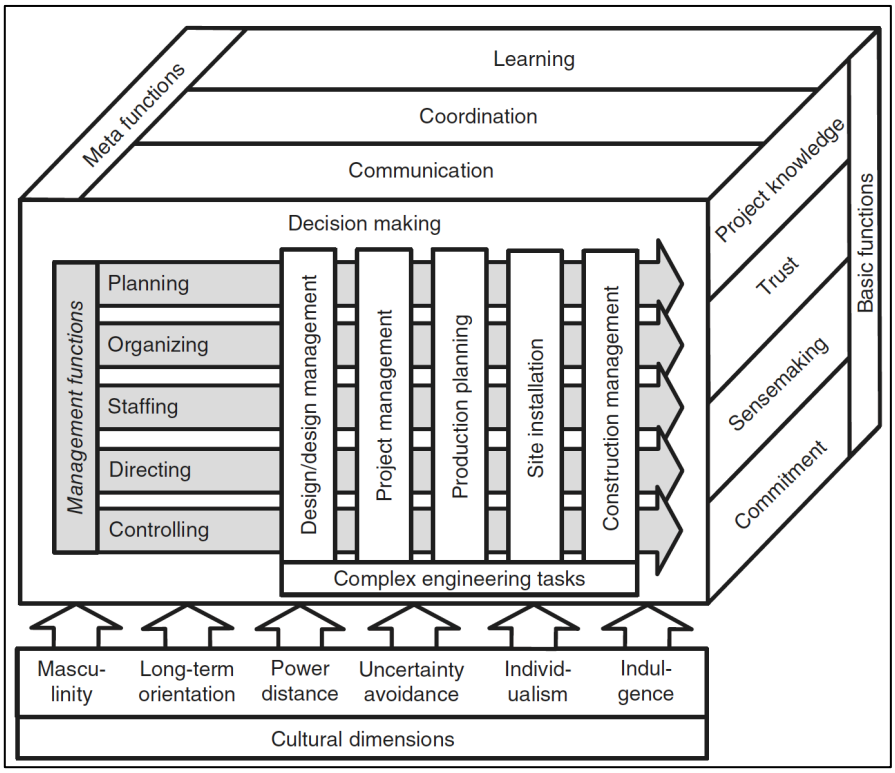
digital marketplaces and innovative tools have played a significant roles in the cultivation of procurement innovation.

The Western world prefers sequential work (Brockmann, 2021). There has been steady growth in the construction project sector in the delivery of non-technological construction innovation; for example, embedding knowledge and skills within an entire organisational network relationship in an alternative procurement procedure. For example, knowledge and skills would be embedded with an organisational entire network relationship in an alternative procurement procedure. Sometimes, innovation means radical changes to stakeholders' mindsets in order to find a productive path, sustain a competitive advantage, achieve low costs and ensure superior customer value (Kleber & Volkova, 2016).

Institutional analyses have been undertaken of the role of a broader social system in influencing construction innovation trajectories via various functions (Akintoye et al., 2012). For example, the function of procurement is strategically turned into a different organisational process, such as operational stage (Berghman et al., 2013). Greater and more comprehensive knowledge of future demand and potential long-term improvements can help to provide new solutions (Edler & Georghiou, 2007), such as value for the community. However, compared with organisations in other sectors, the construction sector, in general, has traditionally been slow in terms of innovation performance, particularly in PS (Love et al., 2008).

Furthermore, the roading infrastructure project process is particularly complex and could be considered as megaprojects. The complexity arises because some roading infrastructure projects typically comprise various stages, involve a variety of people and have higher levels of requirements. As shown in Figure 2.3, megaproject management's meta functions focus on people, such as communication, coordination and learning long-term orientation from cultural dimensions.

Figure 2.3 Management functions in the descriptive management model for megaprojects



Note: Adapted from Brockmann (2021).

2.2.2 New Zealand roading infrastructure projects

The construction sector ranks 4th in New Zealand in terms of its contribution to the nation's overall GDP. Nationally, the total volume of construction rose over the last decade due to big increases in infrastructure construction (NZ States, 2020). To obtain future economic growth and overtake other OECD countries, the New Zealand government has taken a series of steps to expedite infrastructure activities and has had plans to increase investment in infrastructure since 2009 (Liu & Wilkinson, 2011). Given the immense costs of roading infrastructure projects, it is essential to improving the value invested in such projects.

The literature review found few reports of experiences related to roading projects, particularly from New Zealand. A notable exception, however, is the Transmission Gully PPP -Lessons Learnt Review (NZTA, 2014). The report highlighted the importance of stakeholder management in a

roading project, noting that this Transmission Gully project had suffered from mistrust, time overruns and ineffective communication. It is not easy to manage many stakeholders in such complex projects, and the report suggested "providing for a less complicated governance structure perhaps by combining multiple governance groups into a single steering committee" (NZTA, 2014).

The current situation in New Zealand raises a question about how current roading infrastructure PSS processes affect procurement outcomes. At the same time, it also highlights the challenge for PSS implementation and decision-making processes in New Zealand roading infrastructure procurement.

2.2.3 Legislative and regulatory frameworks in New Zealand

Recognising the importance of infrastructure development in New Zealand, the government has taken a series of steps to promote national investment. Since then, novel PSs have attracted a great deal of attention by New Zealand academics and practitioners. Novel PSs include PPP, BVP, alliance, and ECI. Nearly 25 years ago, the Egan (1998) and Latham (1994) reports highlighted the need for changes in the construction sector, and since then, there has been global recognition of the benefits of adopting novel PSs in the sector and PSS has been on policymakers' agendas. In the context of New Zealand, Acts and related policies associated with construction projects encourage consideration of each of the decision-making principles set out in the stakeholders' procurement strategy.

The term *procurement* covers all aspects of acquiring and delivering goods and service in New Zealand. Roading infrastructures often involve government procurement. The New Zealand Government Procurement rules (MBIE, 2019) state that "procurement must adapt and stay relevant to the changing needs of society, the economy and the environment. The inclusion of these wider procurement benefits will ensure procurement practice in New Zealand remains

flexible and productive in relation to global trends." To encourage mandated agencies to consider wider social, economic, cultural and environmental outcomes, the New Zealand Government Procurement rules (MBIE, 2019) produced a framework of key performance indicators for broader outcomes. As shown in Figure 2.4, the framework has been developed to add the priority outcomes in the Rules.

Figure 2.4 Key performance indicators align to the priority outcomes

Priority outcome	Key performance indicator
1. Increase New Zealand business access to government procurement	1.1. Increase in the number of contracts being awarded to New Zealand businesses 1.2. Increase in the value of contracts being awarded to New Zealand businesses 1.3. Increase in the number of New Zealand businesses being awarded contracts, at an increasing value
2. Increased size and skill of construction sector workforce	2.1. Increase in number of workers in construction 2.2. Increase in number of construction workers receiving formal and informal training 2.3. Increase in employment opportunities for targeted worker groups
3. Improve conditions for workers and future proof ability of New Zealand business to trade	3.1. Reduction in notifiable events in government contracts (compared to national average) (in regards to health & safety) 3.2. Increase in contractual mechanisms regarding employment standards 3.3. Increase in monitoring activities being undertaken 3.4. Reduction in number of government suppliers appearing on government stand down list
4. Support transition to zero emissions economy and assist the Government to significantly reduce waste	4.1. Reduction in average vehicle emissions from the government fleet 4.2. Reduction in emissions created by government owned buildings 4.3. Reduction in consumption of 'single-use' items (i.e. plastic pens, paper etc.)

Instead of providing a precise process for procurement system selection for publicly funded projects, New Zealand Government introduced different consultancy services. For example, MBIE assists professionals to set up services related to construction projects. The New Zealand Government Procurement Branch (NZGP, 2019) noted that procurement can range from simple and low risk to complex with high risk. The procurement activities of participants focus on understanding all aspects of the procurement life cycle, while the organisational strategy plan fails to address the characteristics of each PS.

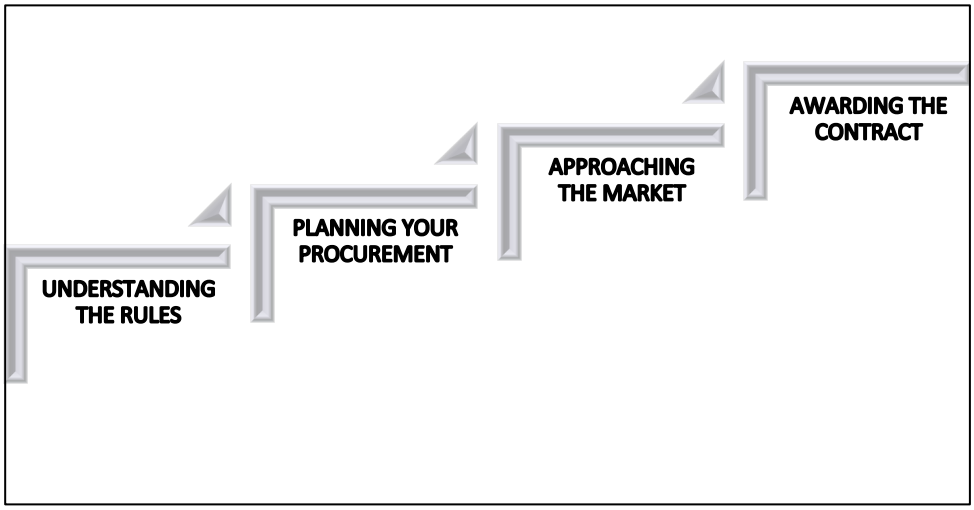
The New Zealand Government Procurement Branch (MBIE, 2020) defined procurement in terms of contracts, (see Figure 2.5) and described procurement in terms of whole chain involvement (Figure 2.6). These definitions probably imply that, in the context of New Zealand roading project procurement selection, PSS is mainly about choosing a contract type.

Figure 2.5 Definitions of procurement by the New Zealand Government Procurement Branch

Contract Type	Explanation
Sole Agency Agreement	A procurement where a sole agency is seeking a single provider, consortium of providers, or a panel of providers to supply goods and services to or on behalf of the agency.
Cluster	A procurement where a group of known and named agencies are seeking a single provider, consortium of providers, or a panel of providers to supply goods and services to or on behalf of the agencies. Only named agencies can participate in the agreement. This type of procurement is often referred to a closed cluster agreement as there are a cluster of agencies participating.
Open Syndicated Agreement	A procurement where one agency will act as a lead to seek a single provider, consortium of providers, or a panel of providers to supply goods and services to their own agency and other agencies. During the term of the contract other agencies may seek to join as a participating agency to receive the goods and services under the terms and conditions of the master agreement with the lead agency. If the contract includes a common use provision (CUP) to allow other agencies to contract with the supplier on the same terms later, it is an Open Syndicated Contract and needs to be approved by the Procurement Functional Leader.
All of Government (AoG) Agreement	A procurement established by MBIE as functional lead for Government procurement seeking a single provider, consortium of providers, or a panel of providers to supply goods and services to all Government agencies. They are designed for common goods or services (e.g. vehicles, laptops, and recruitment services) and usually involve a number of suppliers on a panel. For APP purposes only MBIE should use this contract type. Agencies intending to sign up to an AoG Agreement do not need to include this procurement on their APP.
On behalf of procurement agent	A procurements where an agency may purchase the services of a third-party agent (e.g. an external procurement consultant) to advise, arrange or manage a procurement, or part of a procurement, on its behalf.

Source: MBIE (2020).

Figure 2.6 Sections of procurement, as defined by the New Zealand Government Procurement Branch



Source: MBIE (2020).

At a strategic level, the New Zealand Government believes a strategy will usually result in better outcomes. Therefore, the Local Act requires all councils to provide quality local infrastructure and realises that procurement is one of the most effective and efficient pathways for coping with sustainable issues (MBIE, 2019). Therefore, procurement principles have been set out in local government plans. For example, the lists presented below as an example of a local plan come from Auckland Council.

Auckland Council requires a infrastructure to:

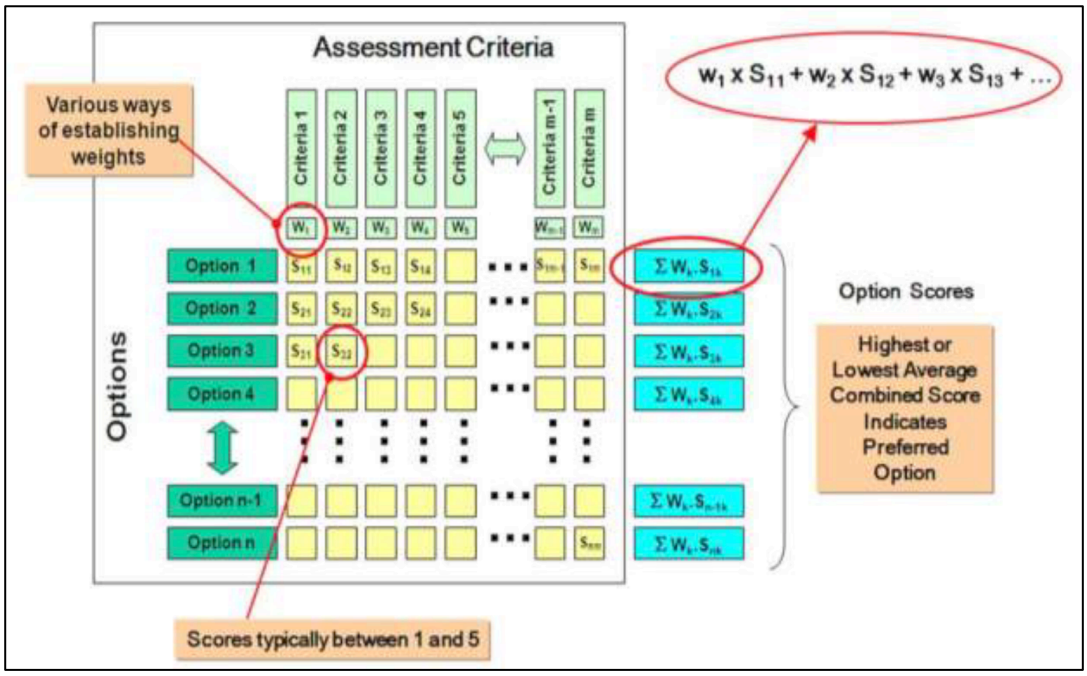
1. make the best use of resources
2. focus on preventing needs arising, and achieving better outcomes in ways that provide long-term savings for the Council
3. work across the Auckland Council family to achieve social, economic and environmental and cultural impacts, and
4. influence, where possible, the practices within the supply chain to be consistent with the goals of the Auckland Plan.

Auckland Council also has related principles to go alongside the desired outcomes:

1. Work together.
2. Value te ao Māori.
3. Be Sustainable.
4. Act fairly.
5. Make the best use of every dollar.
6. Be affordable.

At a project level, public agencies mainly discuss the decision-making process, including the criteria impact on the decision and strategies supporting the decision. At this stage, a list of options will be outlined that include different methods for delivering the project. For example, the *Ōtaki to north of Levin SH1–SH57 Connection Scoping Report* (NZTA, 2013) presents an analysis of a multi-criteria decision-supporting process for a roading infrastructure project. As shown in Figure 2.7, the process formally follows the multi-criteria rules with identifying criteria and analysing weights for each criterion. Then the decision is made by the highest score through the MUV analysis process.

Figure 2.7 The decision analysis process



Source: Adapted from the *Ōtaki to north of Levin SH1–SH57 Connection Scoping Report* (NZTA, 2013).

2.2.4 Techniques adoptions in supporting procurement decisions

Although techniques have been widely discussed in the field academic studies, hardly are sought to apply rules of facts of DST application. As PS selection comprises various participants and PSC, the PSS delivered a heuristic process that has been adopted in this context. Previous studies pointed out heuristics provide an assessment from initial values to the judgement of the final decision that is more depersonalized and requires significant cognitive effort (Arnott & Gao, 2019). It indicates those carries conscious and analytic approaches to dealing with PSC. For example, researchers may have assumed knowledge gained from prior projects to assist PS decisions (Hu et al., 2016, Luu et al., 2005, Mohsini). Reasoning process is thus valuable to be elaborated by its potential contribution to the further development strategies (Plantinga et al., 2019). However, it cannot be used for two reasons.

First, infrastructure participants in New Zealand might not have sufficient experience using DSTs. In an earlier study, Konchar and Sanvido (1998) stressed that users should have a certain

knowledge of specific DSTs as the techniques are not user friendly. Secondly, it seems there are no more recent studies on the practical use of DSTs. Hu et al. (2016) investigated the use of case-based reasoning (CBR) in construction management and confirmed that users of DSTs seldom have sufficient knowledge of the CBR approach in practice. Chen et al. (2011) assembled data from people who have experience in construction projects and used artificial intelligence to formulate a nonlinear function between PSC and PS. Yet, the target information did not include a detailed scope of the characteristics of the participants.

2.3 Problem exploration and identification

2.3.1 Procurement system selection

Previous studies have drawn attention to PSS for improving project procurement decisions. However, several problematic issues were identified in the literature review:

1. Current studies have not updated PSC to meet the changes in the modern construction sector. Some studies recycled PSC from extant studies, without validation in the applied context, fields and countries (Qiang et al., 2015). As there is no universal set of PSC, a rigorous system is probably needed to guide the identification of PSC that will meet the requirements of a specific project.

2. Generally, survey questionnaires were distributed to key stakeholders to identify the set of main PSC and/or to assess each criterion. However, the studies cover a range of geographical locations and diverse participants, so it can be difficult to generalise their findings. Two particular studies are worth noting: Liu et al. (2015) focused on the same country and Smith et al. (2004) targeted clients, designers, supervisors and contractors for their survey. The findings from Smith et al. (2004 and Liu et al. (2015) led to a better understanding of natural PSC practices in comparison idealised ones (only from

literature). However, the researchers would not have been able to achieve a robust result without a clear scope of targeted respondents.

3. Only a few researchers have investigated key stakeholders involved in the PSS process. The research identified in the literature review have various groups of respondents in their empirical studies. For example, Smith et al. (2004) collected the views of clients, contractors, consultants, designers and academics, from both the public sector and the private sector, in an attempt to identify factors that influence the choice of PSs. With the same aim, Ojo et al. (2011) surveyed distinct groups of the study population: consultants (architects, surveyors, engineers and builders), clients and contractors. By looking at individual groups, however, rather than the main stakeholders as a whole, the results from this study cannot be applied to real-world PSS processes

4. Diverse DSTs have been utilised for different goals and users. A comparative analysis by Rajeh et al. (2015a, 2015b) exposes the mixed evaluations from the PS decision-makers with the same purpose. Rajeh et al. (2015b) indicated that project managers, surveyors, engineers, architects and construction managers all play prominent roles in PSS, while Rajeh et al. (2015a) collected information from six project managers. The use of DSTs is expected to grow to compensate for the uncertainties of inadequate data. Yet, despite this expected growth, few studies have explored the adoption of DSTs from the users' perspective. Clients are frequently viewed as initial agents who can use their influence to deliver inter-organisational change in the construction industry (Lindblad, 2019).

2.3.2 Challenges for New Zealand roading infrastructure PSS

Although the New Zealand Government has reviewed the "lessons learnt" from the limitations of traditional PSs (for example, in the Transmission Gully PPP (NZTA, 2014)), and are now aware various alternative PS are available, the alternatives are still not widely adopted in roading infrastructure projects. It is noticed that the strategic guidelines provided to potential developers

from both national and local government agencies include a comprehensive view of their PS expectations, including the rationale, a commentary and consequences. Some even imply the urgent need for new PSs (such as Auckland Council). New PSs enable staff to work collaboratively which can increase the chance a project will return better value for the money spent (Tran et al., 2017); they also focus on non-traditional outcomes such as social, social, economic, environmental and cultural interests (Rowlinson, 2017). Indeed, novel PSs suit the new construction environment in Auckland created by the Auckland Plan. However, there is limited guidance to support government agencies to understand, choose and deliver novel PSs. Instead, government agencies appear to have a different viewpoint when considering PSs, as shown by this statement from the New Zealand Transport Authority: "The New Zealand model, which is based on an outcomes-focused approach as opposed to a price-based competition as in some other jurisdictions, is a hybrid. There is a period of negotiation post-bid, although detailed due diligence has often been completed and funders have received credit committee approval" (NZTA, 2014).

Poorly defined scope and variations within the whole supply chain hinder the PS from being understood, interpreted and applied differently at the project level. NZLW (2005) noted: "Given the emphasis on a commercial approach and the lack of prescriptive legislation, government procurement in New Zealand is primarily governed by contract law." The scope of PSs during PS implementation needs to be more clearly defined than it currently is. The current vagueness about the scope of the PS probably explains why the procurement strategies are totally different at different levels of an organisation in many projects. For example, the New Zealand Transport Authority defined PS as a pricing model or contract types that focus on the tendering process, Auckland Council determines PSs from a collaborative perspective, and the Treasury concluded that procurement is about contract types.

Moreover, transparency has been sought from past research and reviews of major projects. Participants interviewed for the *Transmission Gully PPP – Lessons Learnt Review*

observed that, “It was generally agreed that transparency and communication are key to the successful delivery of a complex project such as this.” Just as academic researchers have found some “fuzziness” in definitions of PS and PSC, reviews into actual projects have identified a lack of clarity as to who are the decision makers for projects and what is their scope. For example, NZTA (2014) reported that: “The public sector respondents felt that the governance was appropriate for the size and complexity of the Project; however, [they] still felt improvements could be made. The governance structure was complicated with three groups established (a governance group, decision-making team and steering group), some of which had common members and the distinction between them was not always clear.”

2.3.3 Problem identification

The review of past studies and current polices and legislations around PSS in New Zealand has identified an urgent need to improve the quality of procurement decision making. Section 2.3.3.1 discusses how the lack of a comprehensive process of PSS might reduce decision quality, and section 2.3.3.2 explains the needs of the roading infrastructure PSS framework.

2.3.3.1 A informed process for decision-making of determining a suitable procurement system

Although previous studies have provided reasons for selecting a particular PS and have described the development of sub-themes and stages of PSs in achieving project performance success, a consensus on PS concepts is yet to be reached. Extant studies have explored PS concepts at multiple levels of analysis – some addressing PSS at the macro-level (e.g. Bruno et al., 2018) and others at the project level (e.g Love et al., 2012). As a result, researchers have begun to consider the conditions for different project scenarios. Recent research has included a focus on distinct stages such as contract methods (e.g. Eadie & McCavigan, 2016), contractor selection (e.g. El Wardani et al., 2006) and supplier selection (e.g. Lo et al., 2018), showing different understandings of PSS. However, the different foci of the studies have resulted in a variety of

different methodologies and decision-making techniques. Therefore, this thesis seeks to provide a clear scope of each PS.

The literature review suggests that analysing the nature of factors that influence PSS and categorising these factors could provide insight into the evolution of PSs and assessment of PSC (Jimoh et al., 2016; Luu et al., 2003; Mostafavi & Karamouz, 2010). It is noteworthy that there is no set of universal PSC. It is also important to note that the PSC of an infrastructure project need to be identified before selecting a suitable PS. PSS for roading infrastructure projects is a relatively new topic in New Zealand, and to date, there has been no paper published with a set of PSC suitable for PSS for projects of this size in this country. The topic is especially relevant because previous studies, for example, Liu & Wilkinson (2011) have indicated that the construction industry in New Zealand has to failed to update its processes in selecting suitable PSs, particularly the factors that influence the PSS decision. Tackling this challenge will require identifying holistic PSC and seeking the empirical results of New Zealand roading infrastructure projects.

Previous studies have confirmed the usefulness of adopting DSTs and implied the importance of strategies in PSS. There is some evidence that the robustness of a selection process is enhanced by using DSTs (Chan et al., 2007). However, although such techniques can help to solve the inherent complexity of PSC evaluation and drive the collection of appropriate and accurate data to guide the decision making, learning to use DSTs requires significant cognitive effort (Arnott & Gao, 2019) . Furthermore, there are few studies centred on prior case outcomes and this lack of knowledge can hinder evidence-based suggestions for a new situation (Hu et al., 2016). Bazerman and Moore (2009) said the determination of the right cognitive system is a crucial goal for managers. Furthermore, the PSS studies were separately discussed, and there has been limited literature focused on the whole PSS process since Love et al.'s (2012) study. Therefore, this thesis

should consider the cognitive improvements in DSTs for the proposed solutions for PSS. At the same time, it is important to provide a holistic process of PSS for decision improvement.

2.3.3.2 Needs for New Zealand roading infrastructure PSS

The literature review has highlighted a current lack of explicit policies and descriptions of PSS that relate to desired outcomes for New Zealand infrastructures. The willingness to challenge existing PSS guidelines could be seen as a key characteristic of a progressive local authority. PSS is still being applied without a framing strategy, despite past experiences showing this ad hoc approach leads to misunderstanding and mistrust. As a way to promote novel PSs, PSS in the New Zealand roading infrastructure sector should initially be accompanied and reflected by practical demand measures. However, the reality is that incomplete policies and the current lack of local experience will not encourage practitioners to change their mindset from the practitioners. Likewise, to fully realise the benefits of novel PSs in the market, clarification is needed to align PSS with specific economic statutes (Wright & Fergusson, 2009). Terminology needs to be clearly defined and cross-references made to better align processes with the regulatory policies of New Zealand public agencies, at both the local and national government level. A fuzzy understanding of definitions and processes, poor communication between stakeholders, and a lack of awareness of the benefits of novel PSs all directly affect a practitioner's ability to make quality PSS decisions. For this reason, it is necessary to consider progressive enhancements towards an informed process for maximising the quality of decision making in the construction sector, particularly for New Zealand roading infrastructure projects.

Several studies in the literature review called for further research into procurement in roading infrastructure projects and in similar-size markets. Due to the complexity of roading projects, analytical modelling using algorithms and statistics has been developed. Overall, there is a notable direct association between the expertise of those making the PSS decisions and outcomes. Modern PSS strives to assess the different PS options objectively by using PSC. Nevertheless, further

research into PSC and the use of DSTs is needed as there were few studies in the literature review with empirical data on the use of DSTs. Finally, NZTA's "lessons learnt" report on the Transmission Gully project (NZTA, 2014) indicated the importance of finding ways "to ensure staff with the right skills and expertise are available to the organisation."

3. CHAPTER THREE: RESEARCH METHODOLOGY

Chapter Three describes the research methodology adopted to achieve the research aim and objectives. The chapter begins by defining the research process, followed by a discussion of the research problem. Section 3.3 presents the research aim, research objectives and research questions, and the role of the researcher is discussed in section 3.4. Section 3.5 presents the methodological framework behind the research and discusses the philosophical assumptions and theoretical paradigms for this study, before detailing the research approach, research strategy, methods and procedures of data collection and analysis, and validation strategies, and preliminary pilot study. The chapter concludes by highlighting generalisability (section 3.6), anticipated ethical issues (section 3.7), and the outcomes of this thesis (section 3.8)

3.1Research process

3.1.1 What is research

In the field of construction management, *research* is viewed as:

> a careful, well-defined (or redefined), objective, and systematic method of search for knowledge, or formulation of a theory that is driven by inquisitiveness for that which is unknown and useful on a particular aspect so as to make an original contribution to expand the existing knowledge base. (Deb et al., 2019)

The aim of research is not to gather information but to contribute to the existing body of knowledge (Kumar, 2019). Inspired by the research methodology from the views of construction engineering (Fellows & Liu, 2015), philosophy and decision-making research, three prominent aspects of research style need to be considered in the thesis: (1) descriptive and analytical; (2) applied and fundamental; and (3) quantitative and qualitative (Hesse-Biber, 2010).

3.1.1.1 Descriptive versus analytical research

Descriptive research encompasses comparative and correlational methods and may include fact-finding questions that the researcher designs to determine causes even though the variables cannot

be controlled, whereas *analytical research* studies available facts and provides a critical evaluation (Deb et al., 2019).

3.1.1.2 Basic versus applied research

Research is typically classified into basic or applied (Plowright, 2011). *Basic research* is motivated by an intellectual interest in a phenomenon and its aim is to extend the existing knowledge on that phenomenon. *Applied research* does the same but the researcher is also attempting to improve the quality of practice of a particular discipline by developing ideas for administrators and policymakers (Merriam et al., 2009). The principal intention of applied research is to offer solutions for compelling, real issues, whereas basic research aims to seek information for broad-based applications in the medium or long term.

3.1.1.3 Quantitative versus qualitative research

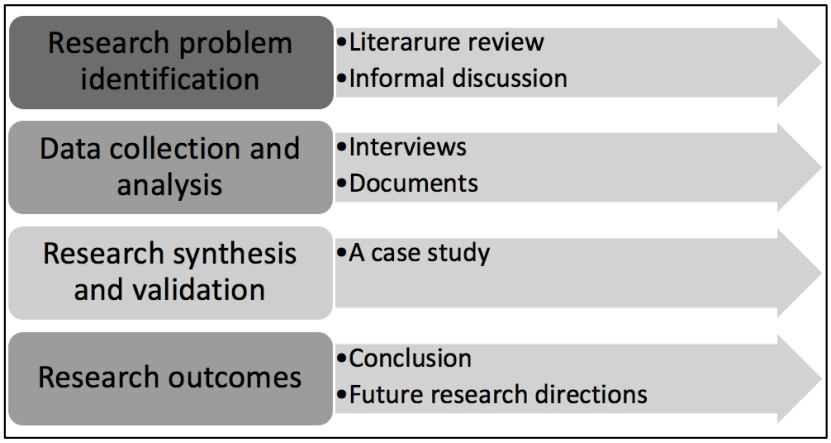
Braun and Clarke (2013) describe *qualitative research* using data, while the basic definition of *quantitative research* is using numbers to adopt some statistical techniques. From the construction management research perspective, Fellows & Liu (2015) pointed out that qualitative research is a precursor to quantitative research, from which many theories have emerged and been developed. Qualitative research is employed for scoping out the magnitude of or extending a new phenomenon or theories. In contrast, quantitative research intends to identify general patterns and making predictions.

3.1.2 Research process

Based on the understanding of "research", the thesis is guided by a logical process throughout the research journey, from identifying the research problem to the reporting on the research outcomes. O'Leary (2004) suggested that research should ask: What needs to be done? What research methods are needed to generate, validate and refine the knowledge? And what can the research contribute to the existing knowledge base? Therefore, this thesis consists of four steps:

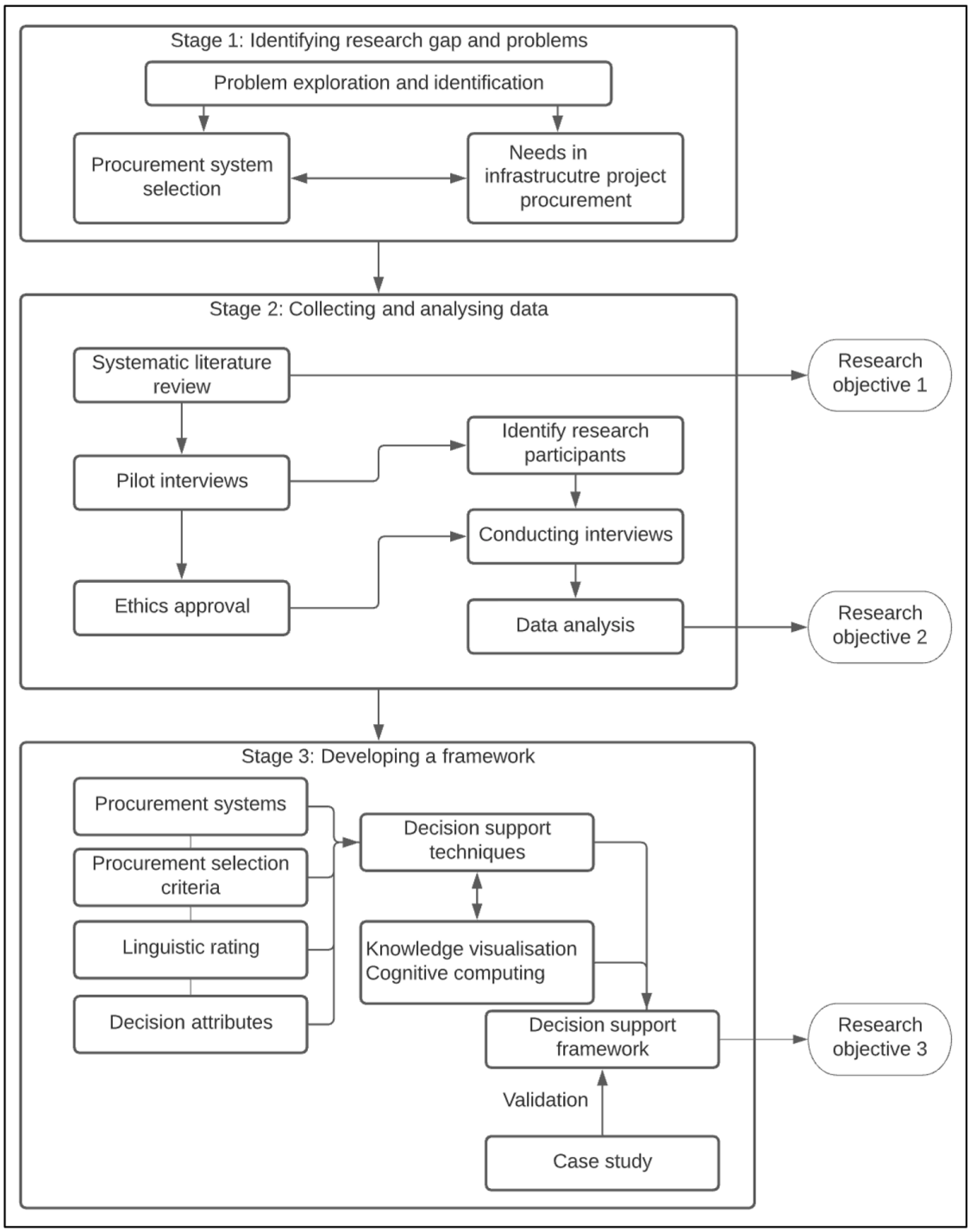
(1) research problem identification, (2) data collection and analysis, (3) research synthesis and validation, and (4) research outcomes. Figure 3.1 lists a diagrammatic overview of the research process, providing a summary of the research activities conducted at each stage.

Figure 3.1 The research process



Research process is seldom formulated in a linear manner (Lee, 2019). The initial stage involved reviewing academic PSS-related studies and having informal discussions with practitioners involved in New Zealand infrastructure projects. The purpose of this preliminary stage was to identify the research gaps and re-interpret existing knowledge. The literature review confirmed the lack of rigorous process to guide New Zealand roading infrastructure project participants in choosing a PS. The review showed that the implementation of novel PSs faces challenges, such as flawed understandings of new procurement strategies and less-collaborative platforms. Thus, there is a need to develop a framework to support decision makers to improve the quality of the decisions being made in the New Zealand roading infrastructure project sector. Based on the nature of the research problem, the thesis established an aim with three research objectives and related research questions. Figure 3.2 displays the research design of this thesis.

Figure 3.2 The research design of the thesis



The researcher chose mixed methods to achieve the research aim. The fundamentals of the PSS decision-making process were developed through a systemic analysis of the secondary data. These findings from the literature review contributed to answering RO1 and were used to set up the interview protocol. A challenge was encountered before the empirical study had even begun,

namely that there was no consensus on who the PSS roading infrastructure stakeholders were who could be considered as research participants. To solve the problem, a pilot study was undertaken to identify potential research participants in the context of New Zealand roading infrastructure projects. Although conducting a pilot study is time consuming, it was necessary to clarify who were the potential participants for the empirical data collection phase of the research. At the same time, a small pilot study can identify research practicalities and resolve these before the larger study into the research problem. Once the research participants were confirmed, semi-structured interviews were conducted to address RO2: To discover the current procurement system selection in the context of New Zealand roading infrastructure projects. Analysis of the interview data identified challenges facing and potential improvements to the current New Zealand PSS process. Based on the combined quantitative and qualitative data, the framework was finally developed with the aid of computer programming (C+ and Matlab). The framework employed a set of DSTs that enrich the knowledge visualisation and cognitive computing through an informed process. A case study with interviews validated the framework. A revised framework was then synthesised in accordance with the validation results. The developed and validated framework addressed RO3: To develop and validate a procurement system selection framework.

3.2 Statement of the problem

Research problem is the issues that exist in the literature, theory, practical works that lead to the requirements of a study (Kandhway, 2015). This section introduces the research problem, by first discussing the initial motivation for the research and then describing the research problem in detail. It highlights the importance of the thesis to both the general construction industry and government procurement authorities, and particularly to those involved in New Zealand roading infrastructure projects.

3.2.1 Initial motivation

The initial motivation behind this study was my personal interest in procurement systems. A few years ago, a company I was working for was invited by the Christchurch City Council to be involved in the development of new civic offices. At that time, I was doing risk analysis around the adoption of PPPs. After reading the "lessons' learnt" report from the Transmission Gully project, I realised the use of novel PSs is still in its infancy in New Zealand even though innovative PSs are already being used in other countries around the world. From my personal knowledge and experience in construction management, I do believe novel procurement strategies can help to solve some of the complex challenges of roading infrastructure projects. Therefore, I am interested in what barriers are hindering the implementation of novel PSs in New Zealand.

I started by discussing PSs with some of my friends who work for a New Zealand government department. I quickly found that they had neither relevant experience nor a clear understanding of novel PSs. After reviewing numerous studies in PSS, I believe that developing a framework for PSS that could be used in New Zealand roading projects would enhance the possibilities of enriching the quality of the decisions made for a specific project.

3.2.2 Description of the research problem

A research problem can be derived from many potential sources (Creswell & Creswell, 2018). In this thesis, the research problem was identified from the real-world issue of the lack of innovative PSs being used in roading infrastructure projects in New Zealand as well as the past studies. The literature revealed that few studies have addressed a rigorous method for PSS, particularly within the context of New Zealand roading infrastructure. Although the Government has realised the advantages of novel PSs and established policies to facilitate novel PSs, the lack of experience and incomplete knowledge about novel PSs among stakeholders highlights a need to focus on the quality of PS decision making and the construction sector in New Zealand.

Creswell and Creswell (2018) suggested that when choosing a research problem, it is important to identify a problem where the solution to which will benefit the individuals being studied. It was observed that there are currently barriers to the selection of innovative PSs in New Zealand because stakeholders in the construction industry and government agencies lack relevant knowledge and information to be able to make objective decisions. Therefore, the proposed framework intends to support roading infrastructure project decision makers, particularly inexperienced stakeholders.

3.2.2.1 Research scope

This research focuses on roading infrastructure construction projects in New Zealand. It is widely accepted that there are specific differences between different types of construction projects. I choose to research roading infrastructure projects for two reasons.

First, roading infrastructure projects involve complicated construction processes. In New Zealand, novel PSs, such as alliance and PPP, have been acknowledged as a collaborative platform that can manage such stakeholder complexity. Compared with medium- and small-sized projects which mainly adopted traditional PS, roading infrastructure stakeholders need to have valuable insights into characteristics of novel PSs and pursue the goal of making objective decisions regarding procurement activities. Secondly, the New Zealand government is still struggling with stepping into PSS implementation due to the range of challenges already identified earlier in this thesis. These issues will have to be fully addressed by both government and industry if novel PSs are to be implemented in future roading infrastructure projects.

3.2.2.2 The nature of the problem

It is essential to define the nature of the problem as it drives the choice of research methodology (Ivankova et al., 2006). Considering the complexity of roading infrastructure projects and the diverse range of decisions that need to be considered during the PSS process, the research problem

could be described as both a complicated and practical issue. Therefore, to answer the research problem, the thesis needs to ask what should be considered and how the quality of decision making can be improved in the PSS process. The research initially adopted a quantitative approach to identify key themes for the proposed framework. It then investigated the suggested themes in the New Zealand context by interviewing some key individuals who work in New Zealand roading infrastructure projects. Interviewing these experienced individuals was important because the goal of the research is to solve a real problem, not just a theoretical issue, by identifying the challenges stakeholders in the construction sector currently face and providing potential improvements for the decision-making process to enhance decision quality.

3.3 Research aim, research objectives and research questions

The research aims to improve the decision quality of procurement system selection in roading infrastructure projects. More detailed questions aid to shape the coding phase. Aligning with Creswell's (2013) suggested approach, the questions include: What is central to the process? What factors influence the procurement decision? What strategies are employed during the procedure? Research objectives and research questions are distinguished separately in the thesis. The research questions intend to narrow the research aim to address the three research objectives.

The three research objectives were formulated to address the overarching aim of the research:

- RO1: To investigate the key components of procurement system decision-making processes.
- RO2: To discover the current procurement system selection processes being used in New Zealand roading infrastructure projects
- RO3: To develop and validate a procurement system selection framework.

The following research questions underpin the thesis.

- What are the key themes in the procurement system decision-making process?
- What is the significance of these key themes to the procurement system decision-making process?
- How is a procurement system selected in New Zealand roading infrastructure projects?
- What are the characteristics of PS in the context of New Zealand roading infrastructure projects?
- What are the factors that influence the procurement system decision?
- What and how are the techniques used for procurement system selection?
- What are the challenges in the roading infrastructure project procurement system selection process?
- What are the potential improvements for the New Zealand a roading infrastructure procurement selection process?
- How does the case illustrated validate the framework?
- How does the revised framework support roading infrastructure decision-making?

3.4 The role of the researcher

The role of the researcher sets the stage for a discussion of issues related to data collection and data analysis (Davies & Fisher, 2018). The researcher is the primary data collection instrument in qualitative research, and so their role necessitates philosophical assumptions. The role of the researcher provides a valuable and positive contribution to a clear statement of the research process. Although this thesis aims to solve a real-world issue and employed mixed methods, the research outcomes are influenced by the qualitative approach. This section, therefore, attempts to clarify the researcher's role by considering my academic background and ontological and epistemological position, as well as how my philosophical position might influence my view of the research problem.

3.4.1 My academic background

My academic background is in project management research, with infrastructure project management experience in a range of industries. Therefore, the framework I aim to develop in this research has construction management at its core. The complexity of roading infrastructure project management required research into multi-disciplinary fields including construction technology, operational research, decision-making and sociology. The findings from each of these fields have been embraced and embedded to support the establishment of the PSS framework.

My master's study focused on a comprehensive review of climate change in construction management. With a solid skill in literature review and industrial experience in infrastructure procurement, I have a strong belief that a PSS framework is urgently needed. The research aims have been developed out of this need. Inspired by this, the research aims have been developed. After reading more than 200 related academic papers, I realised the research scope should focus on roading infrastructure projects as procurement in this field is complex and considers all types of PSs. The pilot study tested my intended industrial audience in the New Zealand context. My prior experience in qualitative social research enabled me to better explore and explain the collection and analysis of the data. The research also involved computer science technology and required adopting of advanced artificial intelligence techniques and I have developed my skills in these areas.

3.4.2 A summary of my philosophical positions for this study

The ontological issues consider "What is reality?" As a big word in philosophy, the researcher may address ontology in different ways. *Ontology* is about the nature of the world and what is known about the world (Creswell & Creswell, 2018). There are two main ontological stances in the construction field: *realist ontology* believes there is one truth, and the reality comes from people's understanding and beliefs, while *relativist ontology* argues that reality is relative to each individual's experience (Fellows & Liu, 2015). Indeed, there is no agreement about which stance

is correct. In this thesis, I believed there are single and multiple realities to achieve the procurement decision. Reality is meaningful through multiple human understanding and socially constructed meanings, as well as the result of extant studies. However, rather than focusing on philosophical positioning, this thesis developed a framework to solve a "real world" issue.

Epistemology is essential as it constructs the research frame to discover knowledge. In the context of construction research, there are three main epistemological stances: *objectivism*, such as hypothesis testing, *subjectivism* and *constructivism* (Fellows & Liu, 2015). I agree that knowledge is socially constructed, and believe that subjective values and opinions make the procurement decision. Therefore, the thesis needs to describe and explore the PSS procedure and gain knowledge from the participants' experiences. As few studies have focused on New Zealand roading infrastructure projects procurement activities, qualitative methods of data collection for this research to explore the interactions among individuals and understand decision-making experiences in the context of a new research area. At the same, the proposed framework has a scientific basis which complements the knowledge of individuals' subjective experiences. Overall, to solve the real-world issue, the knowledge claims in this thesis arise out of actions, situations and consequences rather than antecedent conditions, which is consistent with pragmatic knowledge claims (Creswell & Creswell, 2018).

In my research, I am influenced by critical realist, pragmatist and constructivist perspectives. As a pragmatist, I believe that "knowledge" is "experiences". Pragmatism has merits when trying to solve a real-world issue. A research method often evolves as the researcher seeks to confirm results by the convergence of findings from a mixed qualitative and quantitative data set (Bryman, 2006). It would not be possible to answer the research questions completely by collecting and analysing data from only a quantitative or qualitative method. Quantitative analysis is direct, providing general patterns and making predictions, whereas qualitative research is suitable for interpreting a phenomenon's significance (Harden & Thomas, 2010). As there are few new procurement cases in New Zealand, quantitative research is required at the beginning of the

research process to collect the data needed to be able to construct the themes of the PSS framework. As suggested by Plowright (2011), it is important to add more in-depth investigation and a broader perspective of the phenomenon because a single research method is not desirable to the development of new project research.

The consensus is that quantitative research is a traditional mode of research that could provide the researcher with systematic procedures. In the construction industry context, quantitative research is suitable for testing a pre-determined method with statistical analysis (Fellows & Liu, 2015). Qualitative research uses emerging qualitative methods to collect data in a natural setting sensitive to the people and data analysis for establishing patterns. The research problem and research questions lead to analysing emerging methods that are seldom found in practical studies. A mixed methods research methodology can be an ideal approach to collecting and analysing real-life issues. Combining the advantages of both research methods, a mixed method research methodology enabled the researcher to adopt different lenses from which to view procurement decision problems.

Furthermore, I have been fortunate to have been taught and inspired by several outstanding researchers and experienced practitioners from different industries and cultures. In the early years of my postgraduate study at Manchester University, I was taught by Paul Chan, who provided me with an insight into the pragmatic view for “process development”. After discussing the proposed research methodology with Dr Ying, who is also familiar with the pragmatic view, I believed mixed methods was the best strategy to conduct the research.

3.5 Methodological Framework

3.5.1 Philosophical assumptions

Ontology is the study of being. It comes from the Greek words *ontos* (reality) and *logos* (study), so ontology is to answer, “What is reality?”. *Epistemology*, meanwhile, combines the Greek

words *episteme* (knowledge) and *logos* (study), meaning the study of knowledge that deals with questions about how we understand reality (Pritchard, 2016). In other words, ontology is concerned with the existence and the nature of the things that exist, while epistemology poses a question of what can be known about them (Williams, 2016).

According to the literature, philosophical and scientific theories arise in diverse ways. The research method(s) chosen, including in construction studies, is influenced by the researcher's philosophical beliefs about knowledge development. Cartesians, for example, believe people can develop knowledge through reasoning, without experience or experimentational observations, whereas empiricists argue for the importance of validation and note that different branches of science require their own standards of "proof"; meanwhile, dialectic researchers will choose a method of developing theories that focuses on explaining natural phenomena through critical discussion and questioning of theories; and researchers who believe in historicism, qualitatively examine how history has influenced people's thoughts and their behaviours as they work to develop and interpret theories (Fellows & Liu, 2015). Denzin and Lincoln (2008) note that philosophic beliefs are sometimes called philosophic worldviews, philosophical perspectives or paradigms, and explain that a paradigm encompass the concepts of ontology, epistemology, axiology and methodology.

3.5.1.1 Ontology

Ontology is related to the nature of reality and its characteristics. When the researcher compiles a phenomenology, the actual words of different individuals may present different perspectives (Creswell, 2013). O'Leary (2004) defined ontology as "a formal, explicit specification of a conceptualisation*".* Conceptualisations include informal rules and a set of domain relations (Novikov & Novikov, 2013). To some extent, that means ontology has at least two parts: (1) what it is; and (2) what the relations of these things are. Construction ontology has evolved out of formal ontology theories in philosophy, which, in turn, were are derived from empirical cognitive evidence and/or experiments (Issa & Mutis, 2015). Usually, there are two basic ontological

positions: realist and relative. *Realist* ontology holds that a single reality exists which can be examined and considered the truth, whereas in a *relativist* ontological stance, reality is relative to each experience at a given time and place, constructed with a human mind, and no one true reality exists (Davies & Fisher, 2018). Although one reality exists, the nature of reality is not static (Tesar, 2020). According to the degree of confidence in one's ability to define the nature of reality, there are several views within the two broad groupings of relative and realist ontology, such as critical realism, historical realism and bounded relativism (Mills & Birks, 2014).

In the work presented in this thesis, I systematically studied the relations between DSTs and the final decisions in each domain, and I intend to improve the decision quality. One of the questions to be addressed is how I can assess the ontological adequacy of a proposed framework. The ontological adequacy in this context is a measure of how close the decisions made when using the proposed framework are to the reality of the user's requirements. The aim of the research is to solve a real-world issue that is of an inherently complicated, fuzzy and multi-disciplinary nature. For this reason, I should carefully consider the ontological choices to ensure they are meeting the real-world requirements of the research problem.

In the context of this thesis, I believe that reality has both single and multiple aspects. Realities change as they are historically and culturally affected interpretations rather than the truth (Mills & Birks, 2014). For example, the classification of PSC may be different from one project to another project, which shows there can be diverse interpretations of the same phenomena at a different time and place. Considering the nature of the decision-making process and that multiple participants tend to be involved in infrastructure projects, the second research objective is to discover and describe the knowledge and understanding of experience. In contrast, the key themes of PSS, to answer RO1, were established by the descriptive results that present the single reality. An ontological stance supports using both a quantitative and qualitative approach to address the research objectives with more confidence.

3.5.1.2 Epistemology

Epistemology is "the philosophical discipline that studies the evaluative dimensions of cognition, their metaphysical bases, and the language we use to ascribe cognitive states" (Turri, 2014). The Oxford Dictionary (2011) explains epistemology as "the theory of knowledge" as it is relevant to methods, scope and validity of human cognition. Over its extensive history as a philosophical discipline, epistemology has been about the debate of a diverse range of facts from a variety of different perspectives. For example, Plato's epistemology intended to explore what knowledge consists of and how knowledge can be produced, while Kant's epistemology attempted to seek the conditions of the possibility of human understanding (Béhague & Storeng, 2013). Epistemology is essential as it constructs the research frame to discover knowledge (Pritchard, 2016).

As a topic of fundamental importance in philosophy, epistemology provides a comprehensive and through-provoking overview proper to philosophy (Turri, 2014). There are three main epistemological stances: objectivism, subjectivism and constructionism. *Objectivism* believes that the results are objective; that is, objective reality exists in an object independent of the subject. In the field of construction engineering, hypothesis testing is an example of an objective approach as it enables researchers to remain detached from their subjects. In contrast, *subjectivism* argues that subjective impose meaning on an object. In practice, a subjective approach accepts that results can be affected by the participants involved and the researcher's values, knowledge and interests. Between these two stances is *constructionist epistemology,* which assumes human beings construct knowledge as they interpret the world (Crotty, 1998).

Although philosophical researchers have stated that there is no specific epistemology for pragmatic knowledge claims (Creswell, 2013), I believe the research problem can be understood and solved by combined steps. Many previous works in construction management have explored

how interest influences our evidence and have sought to understand various cognitions. In terms of PSS implementation in the New Zealand context, this thesis agrees with Sosa (2017), who explained the nature of knowledge and the Meno problem. Meanwhile, the key themes of PSS have been developed in this thesis by taking an in-depth scientific overview of the construction industry, including its history, rather than considering individual experiences. Specifically, the proposed framework explores all the key DSTs for PSS, as well as how people interact with DST applications.

3.5.1.3 Axiology (ethics)

Value theory is rarely found in construction management studies. *Axiology* focuses on why and how specific kinds of research came to be valued as worthwhile (Xu, 2016). As a branch of philosophy dealing with ethics, aesthetics and religion, axiology contributes to the consideration of the role of spirituality in human inquiry (Bryman, 2006). It emphasises "reality" and "value" as the two major themes throughout the history of philosophies. There is value in association with a plurality of epistemologies in construction management; for example, the value of objectivist research is in its external validity and reliability (Edmonds & Thomas, 2017). Objectivist analysis can be used, for example, to enhance the suitability of a PS by identifying PSC. PSC enable the optimal PS to be selected during the decision-making process (e.g. Smith et al., 2004). Besides, those PSC could be adopted in similar socioeconomic communities. Conversely, the value of the subjectivist and constructionist approaches is that they reflect how people's experiences shape their perceptions of the world (Li, 2013). The constructivist epistemological stance claims there are multiple ways to explore the understanding of reality, which is constructed and contextualised. The subjectivist, however, believes that knowledge can only be obtained through socially constructed meanings (Harden & Thomas, 2010).

In this thesis, I discuss "value" from two perspectives: first, the value of the study, and second, the value position and its relationship with truth through the proposed framework. Value stances in this thesis assume an object is a cognitive object rather than a value project. This position

means that human participants must be included in the research, as it is humans who hold both knowledge and truth. The sim of the proposed framework is to provide a selection process (the knowledge) that reflects the reality of the construction industry. The subject-object relation requires value judgements to achieve knowledge and truth. Although values studies suggest that there needs to be a consensus on the definition of concepts, this thesis believes that values are pluralistic and that the values represented in the proposed framework will unify the truth and values through practice.

3.5.1.4 Methodology

Methodology is defined as "a particular social scientific discourse (a way of acting, thinking, and speaking) that occupies a middle ground between discussions of method (procedures, techniques) and discussions of issues in the philosophy of social science" (Mills & Birks, 2014). Methodology carries theory and thoughts into practice, questions a research's ontology and uproots established epistemology (Tesar, 2020). In the field of construction management, the research methodology determines the researcher's position, how they work with the research participants, their methods or strategies for data collection and analysis, and how they intend to find answers to the research question(s) (Mills & Birks, 2014). In this research, the methodology aided decision-making on the types of research methods that might be used and how the framework might be built to solve the research problem. The methodology intends to achieve the desired outcomes.

In addition, the linguistic terms for the proposed framework needs to be considered. How could the PSC be classified? Before this question can be answered, the definition of each criterion needs to be clearly understood as all knowledge is dependent on its expression in language. The interaction of philosophy, methodology and construction management address the importance of cultural turn or radical considerations. For example, when I was looking for the answer to the PSS elements, the human "I" represents the connectedness of subjects and objects. Practical challenges that also need to be considered included how to encourage the participants to discourse unwittingly embrace their own stereotypes. To ensure I could collect the maximum amount of

useful data from the research participants, I had to examine research skills and strategies of data collection. Therefore, I set up a pilot study, which will be discussed in greater detail in the following sections.

The research presented in this thesis is based on a pragmatic stance, as I believe the research problem could only be solved using knowledge gained from both qualitative and quantitative data. As there is limited local experience within New Zealand, the framework should be established according to international experience. Therefore, a comprehensive review of existing studies in the field of PSS informed the structured process of the PSS framework. In the context of New Zealand infrastructure projects, the framework had to display practical PSS processes. Chapter six discusses how the choices, suggestions and experience of the research practitioners interpret the procurement selection process. A series of methodological steps were broadly followed. The research started with a systematic literature review of existing studies relevant to the research objectives. At this stage, the key themes of PSS were derived from a statistical analysis of the quantitative secondary data. The research design was then tested with a pilot study. Based on the results from the quantitative research and the pilot study, semi-structured interviews were conducted. Finally, a framework was established aims to improve the decision quality in considering the New Zealand roading infrastructure project. A case study then was adopted to validate the proposed framework.

3.5.2 Theoretical paradigm for this study

3.5.2.1 Philosophical belief

Although philosophical ideas are hidden in research, academics agree that they significantly influence the research practice (Hesse-Biber, 2010). Ontological and epistemological leanings underpin a philosophical belief. The research process presented in this thesis is based on the philosophical beliefs and practices in the construction sector, including the nature of PSS in

construction projects. This section now presents my philosophical beliefs that underpin the research.

There are five fundamental philosophical paradigms adopted in construction management studies: positivist, post-positivist, constructivist, emancipatory and pragmatic (Creswell & Creswell, 2018). The characteristics of each of these significant paradigms are displayed in Figure 3.3., Pragmatic and interpretive paradigms are often adopted within construction management research (Fellow & Liu, 2015). Supporting the pragmatic view, I believe that knowledge is experience (Crotty, 1998). The merit of the pragmatist intends to solve the real-world issue. The outgrowth of this method is sought to usually confirm results by the convergence of findings from a mixed qualitative and quantitative data set (Edmonds and Thomas, 2017). Quantitative research is direct via providing general patterns and making predictions, while qualitative research is suitable for interpretating of a phenomenon's significance (Morgan, 2007). In this thesis, it is impossible to understand and solve the research problem by only adopting one approach. As suggested by Edmonds and Thomas (2017), a mixed methods research methodology is appropriate to contribute the development of construction knowledge for two reasons: (1) research in this field is still at a nascent stage, and (2) a mixed methods approach can combine theory with the practical context of the construction industry. Therefore, a pragmatic paradigm was applied in this research.

Figure 3.3 Characteristics of philosophical worldviews

Characteristics	Positivist	Post-positivist	Interpretive	Critical	Pragmatic
Other names	Scientific		Naturalistic, constructivist	Emancipatory	
Aim	Production of predictive, generalisable data	Uncover meaning of reality as understood by individuals or groups	Description, exploration and understanding of experience	Raise awareness and elicit social change	Solving "real world" problems
Ontology	Single reality; real world driven by natural causes	Critical realism	Multiple subjective realities mentally constructed by individuals	Historical realism	Single and multiple realities
Epistemology	Researcher objectivity and detached impartiality; control	Modified objectivity	Researcher entwined in production of knowledge; dialectical	Knowledge is socially constructed	None
Research methods	Quantitative	Qualitative and quantitative – triangulation	Qualitative	Qualitative	Quantitative and qualitative
Common designs/ methodologies	Descriptive, cohort, cross-sectional, case control, experimental, randomised control trials	Modified experimental, critical multiplism	Phenomenology, grounded theory, ethnography, narrative, biographical	Neo-Marxist, Feminist Research, Queer Theory, Participatory Action Research	Mixed methods research
Criticisms	Does not take into account individual experiences	Does not always produce well defined answers	Limited transferability and generalisability	Does not always guarantee its aims of emancipation	Flexibility in approach can lead to confusion

Source: Adapted from Denzin and Lincoln (2008).

3.5.2.2 Pragmatic paradigm

While there is no consensus on the definition of paradigm, all methodology guidance contains a "research paradigm" to discuss the research process and theoretical considerations. A *research paradigm* could be described as models, patterns or exemplars (Morgan, 2007). This research employed strategies of inquiry that involve collecting data to understand the research problem best. Based on the research aims and questions, the thesis adopted a pragmatic paradigm, which arises out of actions, situations and consequences rather than antecedent conditions (Creswell and Creswell, 2018).

The thesis believes the world is not an absolute unity. On the one hand, the proposed framework represents a shared way of various participants' thoughts and the framework is expected to generate knowledge from different perspectives and interactions between one another. The participants' knowledge and interactions are varied and many, leading the proposed framework

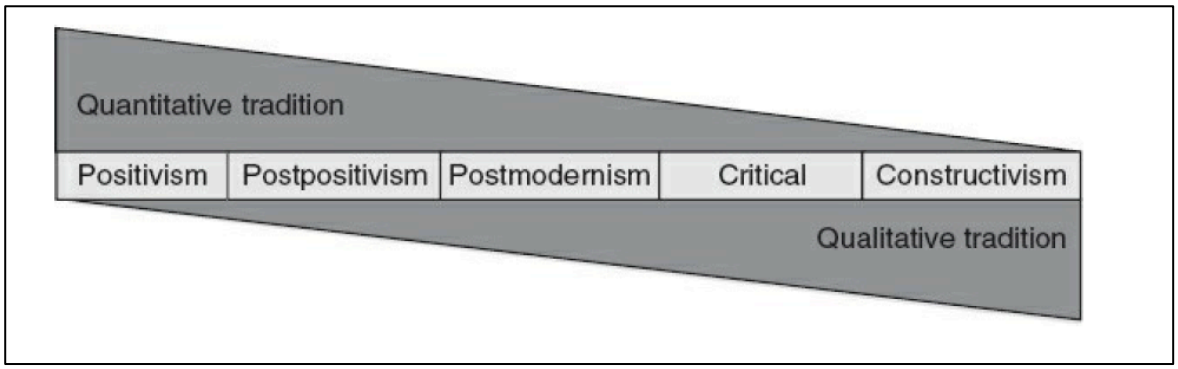
to involve a complexity of views rather than narrow the meanings into a few categories. On the other hand, the framework has been formed by deductively developing a pattern of principles and structural processes that predict the final decision in choosing a suitable PS. In practice, a procurement decision is naturally made by multiple stakeholders. As there is limited local experience in New Zealand roading infrastructure projects, the quality of PS decision-making should be improved by including both the participants' knowledge and the quantitative results of existing studies. Thus, the data collected needed to include both text and numeric information. As suggested by Creswell and Creswell (2018), a pragmatic worldview is not committed to any one system of philosophy and reality. In a practical context, this means recognising that many ways are often needed to solve a real-world issue, rather than subscribing to only one way.

3.5.3 Research approach

3.5.3.1 Mixed methods

This thesis employed a pragmatic stance that believes "research methods should be integrated or mixed building on their complementary strengths and nonoverlapping weaknesses" (Plano Clark & Ivankova, 2016). Considering the research aims and objectives, the integration of quantitative and qualitative methods of data collection and analysis is necessary to best understand the research problem. As illustrated in Figure 3.3 and Figure 3.4, the relationship between philosophical positions and research paradigms is not fixed in nature; instead, it is probably more elastic. Given the research problem, the mixed-methods approach was deemed to be appropriate for three reasons.

Figure 3.4 Philosophical moments and research paradigms



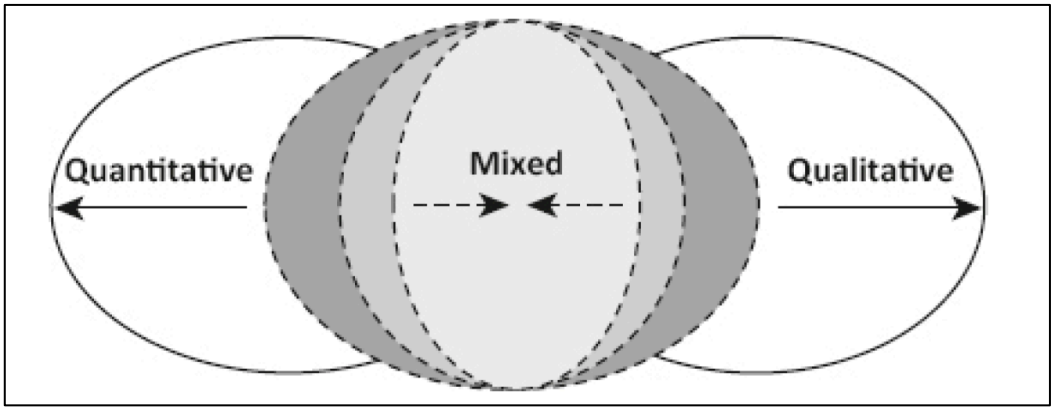
Source: Adapted from Creswell and Creswell (2018).

First, "what" and "how" questions are likely to lead to the use of mixed methods as this research method is preferred when investigating a contemporary phenomenon in depth and within its real-world context (Creswell & Creswell, 2018). In New Zealand roading infrastructure procurement activities, quantitative research is best to describe the importance of the themes and the possibilities of adopting decision-aided techniques. Meanwhile, a qualitative approach such as an interview provides a comprehensive, intensive and inductive way to deeply examine the relationships between a PS and its outcomes (Laryea, 2019). Overall, findings from combined quantitative and qualitative methods can emphasise understanding and problem-solving skills to achieve the focused effort.

Secondly, integration of quantitative and qualitative data was central for this research. The research problem, by its very nature, is complex and wide-ranging. Thus, qualitative research should be considered for examining significant projects as qualitative data can offer rich insights into a specific situation (Merriam et al., 2009). However, because there have been few studies into New Zealand roading infrastructure projects, there is a need to examine global aspects of PSS that might assist New Zealand decision makers with the development of procurement selection systems that deliver the best PS for a particular roading infrastructure project. Combining the findings from both quantitative and qualitative components would maximise the reliability of the proposed framework, and the New Zealand market would benefit from the

application of international knowledge and experience. Figure 3.5 shows the conceptualisation of mixed methods research representing the different degree of interrogation of the qualitative and quantitative methods in the mixed-method study.

Figure 3.5 Conceptualisation of mixed methods research



Source: Adapted from Ivankova et at. (2006).

Furthermore, use of mixed methods would address the issue of acceptance and application across disciplines and countries (Creswell & Creswell, 2018). This thesis developed a framework based on my personal knowledge of decision-making theories, information technologies and computer programming applications. The key themes should be constructed by a series of systematic statistically quantitative analyses. Different groups have different a understanding of PSS, which makes construction a PSS framework that incorporates all the read-world perspectives very challenging. These different perspectives are consistent with on ontological position, which indicates that the truth is not a black or white entity but is subject to various interpretations for a social construction (Mills & Birks, 2014). From the view of knowledge, the complexity of human decision-making results in a complexity of research paradigms. From the view of theory, quantitative research aims to test theory and logic patterns, while qualitative research focuses on generating knowledge and its applications through empirical testing (Ivankova et al., 2006).

Considering the alignment between the nature of the research problem and my philosophical position, I believe mixed methods research would suit the project the best.

3.5.3.2 Induction, deduction and abduction

Mixed methods research involves inductive, deductive and abductive reasoning. According to Creswell (2013), *induction* is the generation and justification of a general explanation based on numerous participants' opinions. The *deductive* explanation centres on explaining a particular situation by a deduction from a general statement. For most mixed methods research, the researcher would generate new theories or explanations through underlying inductive logic (Ivankova et al., 2006). Therefore, mixed methods could be viewed as a form of inductive reasoning which uses deductive and abductive reasoning and inferences to explain the induced finding.

3.5.3.3 Reflexivity

Reflexivity is defined as a process of developing insights into the work to guide the research (Creswell & Creswell, 2018). It is about the researcher having a critical view of their role in the research and how their personal philosophy and beliefs influence the research process and outcomes. Building on the ideas of Plowright (2011) and Ivankova et al. (2006), I developed two strategies for improving my research quality.

My experience in the construction sector had stimulated my curiosity in the PSS area and I already had some thoughts about questions that needed to be asked and how to code the results before I started the research. The systematic literature review was critical because it helped to clarify the research questions as well as identify processes for mapping the key themes in the data and producing a code for analysis. To ensure the reliability of the research, I reviewed each paper twice: first, by manual analysis, and second, with software support.

It is important that as much of the participants' knowledge and experiences can be gained during the interview as possible as this contributes to the data quality. Therefore, tape recording and memo writing were used during the data collection and analysis process. At the same time, I tried to create a record of my feelings during the research process.

3.5.3.5 Challenges of the current research approach

Although collecting data through mixed methods is relatively straightforward, every research study will have its challenges. This research proposed developing a PSS framework that would encompass a diverse range of disciplines. The proposed framework was developed encompassing diverse disciplines. For a cross-disciplined real-world issue, the journey is complicated and challenging for a young researcher. For example, the data was multi-faceted, coming from the literature review, secondary documents and the interviews. Logistically, comparing and contrasting these data throughout the research required the research strategies to be very clear; for example, should any one method be assigned priority in the development of the framework, and if so, which one?

Furthermore, unexpected results can arise from a quantitative study. To minimise the risk of the quantitative results providing fuzzy suggestions for the PSS stakeholders, a pilot study was conducted. The results from the pilot study were then used to inform the structure of the interviews for the qualitative study. Pilot studies, however, take time, so this approach is limited by the resources, including time, available.

The data collection period coincided with three lockdowns due to the COVID-19 pandemic, which made the face-to-face interviews challenging. As a result of the lockdowns, some of the original plans had to be modified; for example, the framework was originally going to be validated by a focus group, but the validation process was changed to a case study. This modification was not necessarily a bad thing as the case study yielded some exciting findings and hence ideas for

improving the proposed framework. Nevertheless, future research with a focus group that could give a more extensive expert examination of the framework is still recommended.

3.5.4 Research strategy

3.5.4.1 Sequential explanatory mixed methods

The research employed a sequential explanatory strategy (first quantitative data collection, then qualitative data collection). The choice of research strategy depends on the research questions and research aims (Yin, 2014). The conceptualisation of method designs has undergone substantial changes over the past decade. This thesis employed sequential explanatory mixed methods for two reasons. First, a sequential explanatory strategy is the most straightforward of the six primary mixed methods approaches (Creswell & Creswell, 2018), because the research implementation stages fall into clear and separate phases. Secondly, the research seeks an informed process with a contextual field-based explanation of the quantitative analysis. And so another benefit of the sequential explanatory strategy is that the qualitative results can be used to explain and interpret the findings of the quantitative study.

The mixed-methods sequential explanatory design for the research consisted of three stages: a quantitative stage followed by two qualitative stages. In the first, the quantitative research question 1 (RQ1) focused on the key themes of PSS in the construction sector. The key themes are the processes of PSS in the proposed framework that serve as predictors to the procurement decision. In the second stage, 21 participants who were involved in New Zealand roading infrastructure projects attended semi-structural interviews. In this stage, research question 2 (RQ2) intended to explore the key themes of PSS, and challenges and potential improvements of PSS in the context of New Zealand roading infrastructure projects. In the third and final stage, a case study was conducted to validate the established framework, thus addressing research question 3 (RQ3).

3.5.4.2 Priority

Priority refers to which approach a researcher gives more weight or attention to throughout the data collection and data analysis (Ivankova et al., 2006). According to Morgan (2007) and Creswell (2013), priority is normally given to the quantitative approach, with the second, qualitative stage usually being smaller. In this research, however, the qualitative study takes priority because the aim of the thesis is to focus on New Zealand roading infrastructure projects. The goal of the quantitative phase was to explore the predictive power of the PSC and DSTs identified from international experience. As the thesis aims to solve a real-world issue, the purpose of the quantitative first stage was to collect data that helped to provide the fundamentals of PSS, whereas the qualitative data research stage sought to find a specific solution for the research problem.

3.5.4.3 Research implementation

In a sequential explanatory strategy, the researcher first collects and analyses quantitative data. In this thesis, analysis of the quantitative data provided comprehensive fundamentals of the PSS process. As there have been few studies of the roading infrastructure project construction sector in New Zealand and the government has realised the benefits of learning from overseas experience, the first step of the thesis is to identify the key themes of the PSS process. Considering the limited resources and time available, quantitative PSS data from archival records (secondary data) were used to determine the structure of the PSS process. A systematic bibliometric strategy was adopted to collect and analyse quantitative data from archival records and the literature review. The findings from the analysis of the quantitative data informed the method and interview protocols for the following qualitative research. It also provides an informed method and interview protocol for the followed qualitative research.

To achieve RO2: To discover the current procurement system selection in the context of New Zealand roading infrastructure projects, phenomenological interviews were conducted with

roading infrastructure project practitioners in New Zealand. A *phenomenological study* is defined as finding a common meaning from several individuals of their lived experiences of a phenomenon that enables the phenomenon or an interpretive phenomenon to be expressed in its own terms rather than by predefined categories (Humble & Radina, 2019). Creswell (2013) described the process of a phenomenological study as: "The inquirer then collects data from persons who have experienced the phenomenon and develops a composite description of the essence of the experience for all of the individuals. This description consists of 'what' they experienced and 'how' they experienced it." To develop a framework for New Zealand infrastructure projects, therefore, phenomenological research was used to describe the experience from the practical context. The aim of the interviews was to explore how individuals experience the PSS process, with the goal of identifying the steps for the proposed framework. The interviews also included questions intended to identify and explain the challenges of and potential improvements to current PSSs, from the viewpoints of the participants A phenomenological study was chosen because it was hoped the data collected could be used to develop a more practical and meaningful framework. Procurement decisions are made by a group of people, not individuals. For this reason, the process and outcomes of the proposed PSS framework should be inextricably related to the participants' experiences and the suggestions they brought to the research.

3.5.4.4 Integration

In the spirit of Creswell (2013), a proposed framework was developed based on a combination of textural and structural descriptions of the essence of PSS in roading infrastructure projects. *Integration* means "the stage or stages in the research process where the mixing or integration of the quantitative and qualitative methods occurs" (Ivankova et al., 2006). It highlights the importance of the connection of quantitative and qualitative data. The thesis connects the qualitative data and quantitative data in three aspects.

First, both the quantitative and qualitative study addressed RO1: To investigate the key components of procurement system decision-making processes. Therefore, the framework developed was based on the combination of the key components developed after full consideration of the existing national and international studies and the results of the empirical study in the context of New Zealand roading infrastructure procurement. Clearly, the quantitative results provide the essence of the PSS process based on the numeric scores and statistical analysis. Later, one of the functions of qualitative analysis is to find patterns and produce explanations (Corbin et al., 2008).

Secondly, the interview protocol was developed based on the results of the quantitative study. The semi-structured interview included open-ended questions to explore how PSs are selected in New Zealand roading infrastructure projects. The open-ended nature of the questions enabled the identification of specific situations in New Zealand roading infrastructure projects, while at the same time, collected data that could be used to construct the proposed framework.

Thirdly, a case study was conducted to validate the framework. The fundamentals of the PSS process within the framework came from the results of the quantitative stage of the research, while the specifics in the framework had been enriched by information from the interviews. This means the case study was examining a framework that had been developed by integrating the outcomes of both the quantitative and qualitative stages of the research.

3.5.5 Methods of data collection and analysis

3.5.5.1 Quantitative research

Secondary data collection

Data types

The Web of Science (WoS) database was the main source of publications for the literature review. WoS, previously known as ISI Web of Knowledge, includes various high-indexes such as SSCI and SCI-EXPANDED that contain the most important high-impact journals in the Construction, Engineering and Management (CEM) field. Moreover, WoS is the most widely used database for generating citation data in bibliometric research (Korom, 2019). The article type was limited to peer-reviewed journals, because journal articles usually provide more comprehensive and higher-quality information than other types of publications.

Secondary data analysis

Data editing and cleaning

Although a manual review of available studies has a tendency to be biased and limits the number of studies with a large corpus (Oraee et al., 2017), it is still necessary to ensure all articles in the corpus are relevant to the research aim and scope. Therefore, the titles and abstracts of the selected papers were reviewed. Papers out of the research scope were removed from the corpus, following a discussion with my supervisors. In addition, it is important to note that WoS does not contain a full record of construction management articles. For example, WoS does not include all important journals in the construction field such as *Project Management Journal* (He et al., 2016). Also, WoS only contains issues of *International Journal of Project Management* since 2011 and *Construction Management and Economics* (CME) since 2015.

All the general information of papers was manually reviewed and edited. The information then formatted for further analysis. It is important to note that the amendments of the information have

significantly affected the results, such as the number of publications in each journal, and the key papers and authors related to PSS.

Data coding and categorising

Coding is used to define data that contains various types of information. It could be considered as a way to index and categorising text for the thematic establishment of a framework. In quantitative research, coding mostly refers to themes (Humble & Radina, 2019). During data analysis, a structural list of codes is developed along with rules for their application that are relevant to the code frame (Merriam et al., 2009). In this thesis, the term coding is used to describe and determine different themes and sub-themes.

Coding strategies range from prefigured to emergent categories. Braun and Clarke (2013) used a prefigured coding scheme to set up the expected information before their study, using categories that came from a theoretical model and previous studies. In contrast, emergent codes emerge from the empirical study.

Thematic coding of a quantitative study begins with a process of text organisation (Miller et al., 2000). In this stage, noteworthy phrases are identified and transformed into meanings that are saved as themes (Humble & Radina, 2019). These themes are linked with deep descriptions of the lived experience from archival data. Next, I used my personal experience to bracket, eidetically reduce and epoch the themes to set up meaning units and identify emergent themes and sub-themes (Braun & Clarke, 2013).

The code strategy for the research was designed to employ a systematic analytic process that would obtain an authentic understanding of how a PS could be selected. Once the initial coding had been completed, the research focused on these units of meaning; that is, on the sub-themes of each of the main codes. After the key themes for the proposed framework were constructed from

the codes, significant statements and non-overlapping statements were listed to be analysed and outlined. The statements were themselves coded and their codes used to construct the characteristics and essential nature of the main themes in the framework. At the same time, the coding process was informing the interview protocol for the qualitative stage of the research. Therefore, coding strategies adopted in the research were used in multiple ways to provide more systematic and reliable information for the proposed framework.

Scientometric analysis

A systematic scientometric analysis was conducted of the quantitative data. Scientometric analysis the most effective method when a study is focused on identifying gaps in the body of knowledge and investigating where research has already been done (Petticrew & Roberts, 2008). However, mono-method manual systematic reviews can be biased and are prone to problems of subjective judgement and interpretation. Therefore, it is necessary to use a systematic review when synthesising literature on a topic "to enhance the depth and breadth of understanding" (Heyvaet et al., 2017). Systematic review studies combine and apply bibliometric analysis and content analysis for integration and evaluation of the available literature on a topic (Harden & Thomas, 2010). The *bibliometric analysis* is used to objectively map the scientific knowledge area, while the *content analysis* aims to identify the research themes and the corresponding challenges based on the bibliometric results. Bibliometric analysis of literature has enjoyed a steady growth in different disciplines (Eugenia et al., 2018). In this thesis, bibliometric analysis refers to mapping and visualisation of a particular large-scale scientific data set in a knowledge domain (Eugenia et al., 2018; Korom, 2019; Yi et al., 2020). This enables researchers to analyse the intellectual landscape of a research area and fulfil the objectives of their research studies (Cobo et al., 2011).

Computer-aided techniques

There are a large number of computer programs for bibliometric analysis, of which *VOSviewer* (Eck & Waltman, 2010) was employed in this study. *VOSviewer* is written in the Java program language, which has been widely used as a visual-aid tool in many field studies such as computer science, medical and engineering research (Eugenia et al., 2018; Korom, 2019; Yi et al., 2020). Eck and Waltman (2010) introduced the technical details of the software. The initial step of *VOSviewer* construction is calculating a similarity matrix based on the co-occurrence matrix. Using the matrix, the computer program of mapping is implemented. The algorithm can be run multiple times at this stage in order to achieve the optimal solution (more details can be found at www.neesjanvaneck.nl/vos/).

Moreover, *VOSviewer* is specialised in science mapping, which means that a bibliometric review of research in a particular field can be built up through a connected citation network. *VOSviewer* can indicate the nature and changes of identified objects (such as keywords) across different period times and by link strength. The software is freely available to the bibliometric research community who can access source-normalised co-citation matrices in various ways. In this thesis, *VOSviewer* was employed for mapping of scientific domains based on network data and visualising of key themes of PSS.

Keywords identification

Keywords indicate the main topics of a study. Keywords co-occurrence network analysis is carried out to explore the evolution of research topics, as well as to provide collective interconnection of key research areas. “Author keywords” and “Fractional counting”, as recommended by Oraee et al. (2017), were adopted for keyword filtering in the analysis. A word’s centrality is a primary indicator that reflects its interlinkages between target keywords and the size of each node. The thickness of the connection line reflects the number of co-occurrences of two keywords; that is, the thicker the line, the more co-occurrences.

Key authors identification

The examination of the authors through co-citation is delivered by counting the frequency with which any work of an author is co-cited with another author in the references of citing documents. The primary goal of author co-citations is to define the intellectual structure of a scientific knowledge domain in terms of the groupings formed by accumulated co-citation trails in the corpus (Jeong et al., 2014). It supports seeking a group of scholars with similar epistemological styles and then explains their ways of understanding how to build the knowledge disciplines (Korom, 2019).

3.5.5.2 Qualitative research

Purposeful sampling strategy

The research used a *purposeful sampling* strategy to identify participants who could inform the understanding of the research questions (Creswell, 2005). Based on the research questions, the selection criteria for choosing participants to be involved in the pilot study and for the later semi-structured interviews were people who were: (1) employed by key organisations that are working on PSS implementation, and (2) the core people involved in decision-making around PSs and PSS. The most significant aspects of selecting the sample, therefore, were to identify the main stakeholders in delivering procurement systems within roading infrastructure projects in New Zealand and to find participants who would be willing to be interviewed. The sample of potential participants was then narrowed down using the sampling strategies shown in Table 3.1.

It is essential that all the participants had experience of the roading infrastructure PSS process being studied. However, no rigorous process or clear criteria for selecting people for the sample was found in the literature, which caused some initial confusion about which data collection methods should be used. To clarify the sampling process and data collection methods, and hence to improve the accuracy of the main research, a pilot study was conducted to identify the key stakeholders and individuals involved in procurement decisions in roading infrastructure projects

in New Zealand. Eventually, the research used a narrow qualitative approach and snowball chain sampling technique to identify the research participants and collect the qualitative data needed to answer the three research questions.

This stage focused on obtaining a sample where all the participants had roading infrastructure project procurement decision selection experience. This would not only provide an understanding of the process of procurement selection, but the identified participants were also able to describe their understanding of PSs and the use of related techniques. Data could also be collected from the same sample of experienced interviewees and analysed to address RO2: To discover the current procurement system selection in the context of New Zealand roading infrastructure projects.

Table 3.1 Purposeful sampling

Type of Sampling	*Purpose*
Maximum variation	Documents diverse variations of individuals or sites based on specific characteristics
Homogeneous	Focuses, reduces, simplifies, and facilitates group interviewing
Critical case	Permits logical generalization and maximum application of information to other cases
Theory based	Find examples of a theoretical construct and thereby elaborate on and examine it
Confirming and disconfirming cases	Elaborate on initial analysis, seek exceptions, looking for variation
Snowball or chain	Identifies cases of interest from people who know people who know what cases are information-rich
Extreme or deviant case	Learn from highly unusual manifestations of the phenomenon of interest
Typical case	Highlights what is normal or average
Intensity	Information-rich cases that manifest the phenomenon intensely but not extremely
Politically important	Attracts desired attention or avoids attracting undesired attention
Random purposeful	Adds credibility to sample when potential purposeful sample is too large
Stratified purposeful	Illustrates subgroups and facilitates comparisons
Criterion	All cases that meet some criterion; useful for quality assurance
Opportunistic	Follow new leads; taking advantage of the unexpected
Combination or mixed	Triangulation, flexibility; meets multiple interests and needs
Convenience	Saves time, money, and effort, but at the expense of information and credibility

Source: Creswell (2013).

In terms of sample size, “Adequacy of sample size in qualitative research is relative” (Bryman, 2006). The sample size is determined by several factors in relation to the research aim. For example, a large sample may provide a comprehensive result, but the generalisable result would be quite shallow. In the same way, a small sample size from one organisation would not comprehensively clarify PSS for all stakeholders but would provide a sufficient comparison of their understanding of PSS implementation. According to Creswell (2005), the sample size for interviews should be between 5 and 25 participants who have all experienced similar phenomena.

Creswell and Creswell (2018) said that a group size would vary from 3 to 4 individuals to 10 to 15. In the context of New Zealand infrastructure projects, there are few people who have both roading project and novel PS adoption experience. Therefore, a sample of 15 to 20 participants should be sufficient to develop a well-saturated theory for the study.

Qualitative data collection

There are four basic qualitative data collection approaches (see Table 3.2). According to Creswell (2013), the research strategy often directs a qualitative researcher's choice of data collection approaches; for example, interviews play a central role in the data collection in a phenomenology. Creswell and Creswell (2018) suggested that there needs to be a logical sequence of stages in any study designed around interviews. In this research, interviews and documents were chosen as the main approaches to gain an in-depth understanding of the meanings of PS and DSTs, which is the first step to identifying potential improvements to existing processes and constructing a new framework that could improve the quality of procurement system decisions in New Zealand roading infrastructure projects.

Table 3.2 Approaches to qualitative data collection

Observations	Interviews	Documents	Audio-visual materials
• Gather field notes by conducting an observation as a participant. • Gather field notes by conducting an observation as an observer. • Gather field notes by spending more time as a participant than as an observer. • Gather field notes by spending more time as an observer than as a participant. • Gather field notes first by observing as a "participant-outsider" and then moving into the setting and observing as a "participant-insider".	• Conduct an unstructured, open-ended interview and take interview notes. • Conduct an unstructured, open-ended interview; audiotape the interview; and transcribe it. • Conduct a semi-structured interview, audiotape the interview, and transcribe the interview. • Conduct a focus group interview, audiotape the interview, and transcribe it. • Conduct different types of interviews: e-mail or Internet, face-to-face, focus group, online focus group, and telephone interviews.	• Keep a journal during the research study. • Have a participant keep a journal or diary during the research study. • Collect personal letters from participants. • Analyse public documents (e.g., official memos, minutes, records, archival material). • Examine autobiographies and biographies. • Conduct chart audits. • Review medical records.	• Examine photographs or videotapes. • Have participants take photographs or videotapes (i.e., photo elicitation), and then interview them about the materials. • Examine physical trace evidence (e.g., footprints in the snow). • Videotape or film a social situation or an individual or group. • Examine website main pages. • Collect sounds (e.g., musical sounds, a child's laughter, car horns honking). • Collect e-mail messages, discussion board messages (e.g., Facebook), or other forms of social media messages. • Collect cell phone text messages (e.g., Twitter). • Examine possessions or ritual objects. • Collect sounds, smells, tastes, or any stimuli of the senses.

Source: Creswell and Creswell (2018).

Interviews can be unstructured, semi-structured or structured, depending on the research questions and expected outcomes (Carlin & Kim, 2019). It was decided that semi-structured

interviews were the most suitable for this research because the format can both focus on the three central research questions and, at the same time, gain the most data from experienced PS practitioners through the use of open-ended questions. For logistical reasons, semi-structured interviews in the construction sector field should encourage the participants to expand on their answers, which increases the possibility of new issues being raised (Corbin et al., 2008).

The type of interview chosen will determine whether the information obtained is useful; that is, able to answer the research questions (Creswell & Creswell, 2018). Interviews can be conducted face-to-face, by telephone or over Skype, Zoom or other internet platforms. The method chosen will also influence and be influenced by whether the researcher wants to conduct one-to-one or group interviews. Clearly, a group interview structure was not practicable for this research as it would have been impossible to gather all the interviewees at a specific time. Furthermore, face-to-face interviews can provide more additional formal information and allow research findings to be expanded by modifying the research questions during the interviews (Creswell, 2013), and so this was the preferred interview structure anyway. The interviews were recorded by audio-tape and notes were taken simultaneously.

Ideally, interviews should take place in the participants' workplaces and in a quiet place to ensure a clear recording and that participants can express their emotions (Ferme et al., 2018). All essential documents – the information sheet, consent form and interview topics – were sent to the participants prior to their interview. Backup copies of computer files were saved on my home computer and on my primary supervisor's computer.

Qualitative data analysis and representation

Transcription

The first stage in the analysis and representation of the qualitative data was transcription of the interviews. Each interview was transcribed immediately after completion. The document

summary of each interview comprises the date of the interview, participant's name, organisation they work for and a full manual transcription of the interview.

Unit of analysis

As roading construction projects get ever larger and more complex, there is a corresponding increase in the number of stakeholders and individuals involved in PSS. Therefore, individual attitudes and perceptions within decision procedures need to be explored and analysed. First, however, appropriate units of analysis need to be defined. It is reasonable to assume that people in different roles have different responsibilities for and experiences in the same project, so that the first unit of analysis is individuals. But an effective framework must also work within organisational processes. In general, how individuals cope with the situations can be quite different from how organisations cope with the same phenomenon (Yin, 2014). Although each individual belongs to his/her organisation, different organisations will make different decisions about PSS which will, in turn, affect practical PSS outcomes. Thus, the second unit of analysis is the organisations.

Thematic analysis

Creswell (2013) suggested that after reading the transcripts in their entirety several times, the first step in analysing the qualitative data could be to summarise the main ideas into memos. Looking over the documents and interviews collected, describing, classifying and interpreting the data represents the heart of the analysis. There is content analysis, discourse analysis and thematic analysis. This project adopted thematic analysis as it can be used to inform the construction of the main elements of the framework and describes the patterns from the qualitative analysis. Van Manen (2016) said line-by-line readings could be used to explore the fundamental themes, while Tergan and Keller (2005) suggested "horizontalization" to develop clusters of meaning. Meanwhile, Creswell and Creswell (2018) outlined a process that could be summarised as: (1) describe personal experiences, (2) develop significant statements and list non-overlapping

statements, (3) group these statements into meaning units, and (4) write a composite description of the "what" and "how" experience with the phenomenon.

Comparative analysis

During the data analysis process, a code hierarchy can be useful for organising a large number of codes. The first step was to simply outline a list of codes. Based on the results from the literature review and my personal knowledge gained from working in the construction industry, I set up prefigured themes. However, problems arose soon into the analysis of the PSS main themes due to the mixed dimensions of the themes. For example, some participants stressed that the procurement system process focuses on delivery method selection; as a result, this PS criterion was identified as actually belonging to the set of contractor selection criteria. To solve this problem, the themes and sub-themes were compared. Suggested by Fellows & Liu (2015), sub-categories under the same themes were compared as were the different attributes of individuals. Table 3.3 shows an example of a comparative analysis. Through comparing columns and rows, the two participants demonstrated a shared understanding of PSs but the PSC they identified are totally different. It should be noted that one of the participants works for a government agency and the other is a contractor, so this result suggests there could be a relationship between the role of the organisation in the whole process and the PSC being used for a procurement decision.

Table 3.3 An example of a comparative analysis table

Interview participants	Procurement systems	Criteria considered when making a decision
Project manager 1 in the government	Early contractor involvement, PPP, alliancing	Best value, sustainability, social impact, political considerations
Project manager 3 in contractor category	Traditional, early contractor involvement, D&C, PPP, alliancing	Methodology, risks, value for money, complexity, construability

3.5.6 Data collection and data analysis procedures

3.5.6.1 Phase one---Quantitative analysis

- Step 1 Retrieving bibliometric data from Clarivate Web of Science (WoS)

The publications that were to be analysed for the literature review were collected from WoS bibliographic records core collection at the end of July 2020. The relevant terms as the topics in the search query "set 1". Similarly, "decision (deci*)" and "choice (cho*)" were considered as synonym terminologies of "selection (select*)", and those three terms were placed as "set 2" in the searching process.

As the research specifically focused on construction procurement, "management", "engineering civil and economics" were selected as the categories. English was set as the language, while the type of publication was restricted to "article". To achieve a comprehensive result, all-year time spans and the SCI-EXPANDED, SSCI and ESCI indexed journals were covered in the search. Combing set 1 and set 2 in the field of "construction" OR "infrastructure" OR "building", a total of 293 papers were identified at this stage.

Since manual reviews of studies tend to be biased and limit the number of studies that can be reviewed (Oraee et al., 2017), it is necessary to ensure all the articles in the corpus are relevant to the research aim and scope. Therefore, the titles and abstracts of the selected papers were reviewed. Papers out of the research scope were removed from the corpus, following a discussion with my supervisors. For example, Seifert et al. (2004) discussed PS selection for the spot market and so it was discarded.

- Step 2 Extracting bibliographic information

To map the structure of the knowledge domain with analysing co-citations and co-occurrence, the downloaded bibliographic information contained the "title", "abstract", "author", "author keyword", "journal" and "reference" of the documents based on the digital object identifier.

Identification of co-occurring keywords is considered a major measurement to clearly and concisely describe the research contents and map the knowledge domains of the research topics (Jin et al., 2019). Co-citation analysis, using the information of citations and authors, was also carried out as this can assist researchers to find theoretical aspirations and belief systems in the corpus (Korom, 2019).

The main challenge encountered at this stage was the accuracy of the downloaded data (including formatting discrepancies). For example, the same journal was presented in different bibliographic styles as *Journal of Construction Engineering and Management, Journal of Construction Engineering & Management, and Journal of Construction Engineering and Management-ASCE*. To solve this particular issue, the journal titles were manually reviewed and the information consistently formatted for further analysis.

The references of all the selected articles were checked, for example, by backwards snowballing. This helped to identify the most cited papers and ensure that the papers with more than five citations from other papers were selected for review. If these most cited papers were missing from the corpus and consistent with the inclusion criteria, they were added. By the end of this process, 198 peer-reviewed articles have been identified.

- Step 3 Science mapping and content analysis

Some descriptive statistics were then performed on the selected articles. A classification of the papers in accordance with the key themes of PSS were performed. Key areas of PSS were constructed with the software *VOSviewer* through keywords identifications, key researchers' identifications, and statistical presentation of general data information. The significance of key themes to the PS decision-making process was then provided based on content analysis.

3.5.6.2 Phase two---Semi-structured interviews

As suggested by Vogt et al. (2014), initial analysis of the quantitative data was carried out before beginning the collection of the qualitative data. This time between the two phases of data collection allowed me to think through the focus of the study and determine what questions to ask during the semi-structured interviews. It also helped me to set preliminary boundaries around the data to be collected in the second phase. In line with the pilot test, senior members of key stakeholders, such as procurement specialists, project managers and technicians, whose job duties were identified as being appropriate to interview. Attention was paid to "how" and "what" words to discover the nature of PSS in projects as expressed by the participants. All the participants had to have been involved in project PSS in the last five years; this criterion ensured that participants were selected who could for provide the latest industrial information. In addition, it was suggested the pilot study, the snowball recruitment procedures have been utilised. Snowball/chain approach is adopted to identify a research sample of key interviewees, as the knowledge and expertise of PSS are limited to New Zealand. This allowed the research team to develop an understanding of PSS from different aspects, such as procurement process elements and procurement assessment techniques. The interview process was stopped when no further new potential interviewees were referred by the participants. In total, 39 industrial members were invited to participate in the research, and 22 of them responded to the invitation and agreed to participate. According to Creswell (2005), 20 to 30 individuals would be recommended in order to develop a well-saturated theory.

Most of the interviews were transcribed using Microsoft Word, and so the participants' thoughts were very well known before the formal data analysis. A line-by-line strategy was used to provide a comprehensive and detailed analysis. Inspired by Humble and Radina (2019), the thematic analysis made use of the complexity, diversity and depth of the interviews and contributed to the structure of the proposed framework. The main thematic topics generated by the thematic analysis were used to define the main elements of the framework.

The data analysis of the sub-themes followed a phenomenological framework, focusing on the meanings behind the interviewees' comments and seeking an understanding of the information that the interviewees shared. The final analysis of the 22 participants' interview data was carried out between August 2019 and December 2020. After the final analysis was completed, the thematic analysis was re-checked for accuracy and the interview quotes coded for clarity of understanding. Finally, any opinions that differed from my personal experience or from the literature were highlighted.

Although the interview data seemed to agree with the themes identified by the thematic analysis, it was important to check whether the data could support the framework. Thus, the data was analysed once more, this time from a thematic phenomenological perspective, to look for dominant themes and subthemes regarding the lived experiences of those who are involved in PSS.

3.5.6.3 Phase three – A case study

The case study is about the procurement of a service and delivery of a specific roading infrastructure project in New Zealand. Two types of organisations were involved in this study: a public agency and the contractor. Project managers and procurement specialists, as the main decision makers in the project, were invited to test the framework.

According to Yin (2009), appropriate units should be selected to define the foundational problems. The first unit of analysis was individuals. Because the PSC and the weighting given to each criterion was selected by individuals to validate the framework, individual decisions and perceptions within PSS procedures needed to be explored and analysed. The second unit of analysis was organisations. In general, how individuals cope with the situations can be quite different from how organisations cope with the same phenomenon (Yin, 2014), so PSS had to explored also at the organisation level. The interviewees indicated disparities in information at different levels and stages of a project.

The case study contained two phases: phase one was testing the proposed framework and phase two was unstructured interviews. Key stakeholders from the public agency involved in the project were invited to decide a PS through the framework process at phase one. Then, all the participants were encouraged to express their opinions about the proposed framework. The questions were aimed to obtain feedback for improving the proposed framework.

3.5.7 The preliminary pilot study

The pilot study had a specific purpose for the research. In relation to the research paradigm and the nature of the research investigation, semi-structured interviews were conducted with participants who represented the sociocultural context of the research (Creswell, 2013). A criterion-based approach was used to select the interviewees, as suggested by Liu & Wilkinson (2011).

In line with relevant studies identified in the Literature Review (Chapter 2), the key stakeholders selected for the research comprised procurement specialists, project managers, engineers, architects and general managers/directors. As the knowledge and expertise of procurement implementation have not been clearly discussed in previous studies, academic experts were also included in the participants list. To be considered for inclusion in the pilot study, the potential interviewee had to either have worked in project procurement in the last five years, because they can provide the latest information regarding practical works, or be familiar with construction procurement activities, because they have expertise in adopting different types of PSs. The interview question was: Who are the key stakeholders making the decision?

The potential interviewees were identified by their job title on the public website. The invitation to participate and a consent form were sent to each of the original 35 through their public contact

platform; for example, over LinkedIn or through their company or organisation website. The sample size was determined by theoretical saturation, since no additional theoretical insights emerged from the data (Walder & Molineux, 2020). The recorded interviews were manually transcribed to enable analysis of the collected data. The transcripts provided a comprehensive record of the discussions with the participants, who are involved in PSS decision-making in New Zealand roading infrastructure projects.

3.5.8 Research reliability

For the quantitative study, a double-blind control test was performed on 20 papers to verify and refine the selection criteria. A manual selection of the articles was carried out to verify the papers' coherency with the inclusive and exclusive criteria. Then the titles and abstracts of selected papers were reviewed. Papers out of the research scope were removed from the corpus. Finally, 198 papers have been identified.

The analytic quality of qualitative research can be reinforced by including reflexivity and using memo-ing, which enables an audit trail of the research process to be maintained (Mills & Birks, 2014). At every phase of the research, the following questions were being continuously asked as part of the reflective process:

- Does the framework have credibility?
- Does the framework demonstrate originality?
- What the evidence is there of the framework's usefulness?

3.6 Anticipated ethical issues

I had to consider potential ethical issues very carefully at every phase of the research. Prior to commencing the data collection, I obtained approval for the data collection process from the

Auckland University of Technology Ethics Committee (AUTEC). More details can be found in Appendix B.

3.7 Generalisability

Generalisability, in research, is viewed as "a term that is used in a limited way in research, since the intent of this form of inquiry is not to generalize findings to individuals, sites, or places outside of those under study" (Creswell, 2005). The themes and patterns identified in the research as well as the overall proposed framework are particular to projects rather than about PSS in general. Even so, the barriers and potential improvements to PSS implementation that have been identified in the context of New Zealand roading projects set up a platform for framing guidance in other areas. Thus, the thesis can be seen as being specific to the New Zealand roading project context while at the same time providing a practical approach that could be generalised to other contexts because the framework gives decision makers a better understanding of what PS means and what needs to be improved. This means the framework has the potential to be used by small size markets around the world who wish to consider the applicability of novel PSs for their procurement decisions. The framework shows the possibility of achieving a wise decision through a radical (organisational) process innovation. It visualises the cognition component of procurement decision-making, thus providing future researchers with a comprehensive picture of the procurement decision-making process. Finally, the framework sheds light on construction epistemologies from a decision-making perspective.

3.8 Excepted outcomes

The proposed framework was developed from a combined analysis of quantitative and qualitative data. The framework aims to provide a suite of strategies to support procurement system decision-making. There has been little research into the management of roading infrastructure projects, and so there is a corresponding lack of relevant guidance to support participants who have to

make key PS decisions. Thus, this research is valuable because it has investigated a phenomenon about which little is known. Clearly, the New Zealand constructor sector requires to explore the suitability of novel PSs but require a systematic and solid process to aid the decision-making process. The mixed methods approach used in the research ensures quality outcomes in the form of a framework with explanatory power. Thus, the thesis can contribute to construction management knowledge and has potential practical application for those making PS decisions for New Zealand roading infrastructure projects.

4. CHAPTER FOUR: QUANTITATIVE RESEARCH FINDINGS

The first research question asks: What are the key elements of the procurement system selection process? A quantitative analysis undertaken to answer RQ1 resulted in the identification of some critical themes around PSS in the construction section. The findings of the analysis are presented and discussed in this chapter. The chapter starts with a description of the research administration, in section 4.1. Section 4.2 outlines the descriptive analysis of the bibliographic data, which is examined through a bibliometric analysis. Based on a systematic process, three key themes are numerically and statistically explored in section 4.3. The chapter concludes with a summary of the results of the quantitative research findings.

4.1 Research administration

The data collection and analysis started in May 2017 and ended in July 2019. The final corpus was updated twice (December 2019 and July 2020) to obtain the latest information. At the end of the data collection process (see section 3.5.6.1), 198 articles had been identified. The downloaded information was saved in the software *Vosviewer.* The information collated from the articles included “title”, “abstract”, “author”, “author keyword”, “journal” and “reference”.

A three-phase descriptive analysis was conducted to explore the key themes in the PS decision-making process: a statistical analysis of the general data information, keywords identification, and key researchers’ identification. The key themes of PS decision-making process were then mapped based on descriptive (including co-citation and co-occurrences) analysis of the quantitative data.

Three themes were identified around the process of PSS: *procurement system* (PS), *procurement system criteria* (PSC), and *decision supporting techniques* (DSTs). Content analysis identified 10

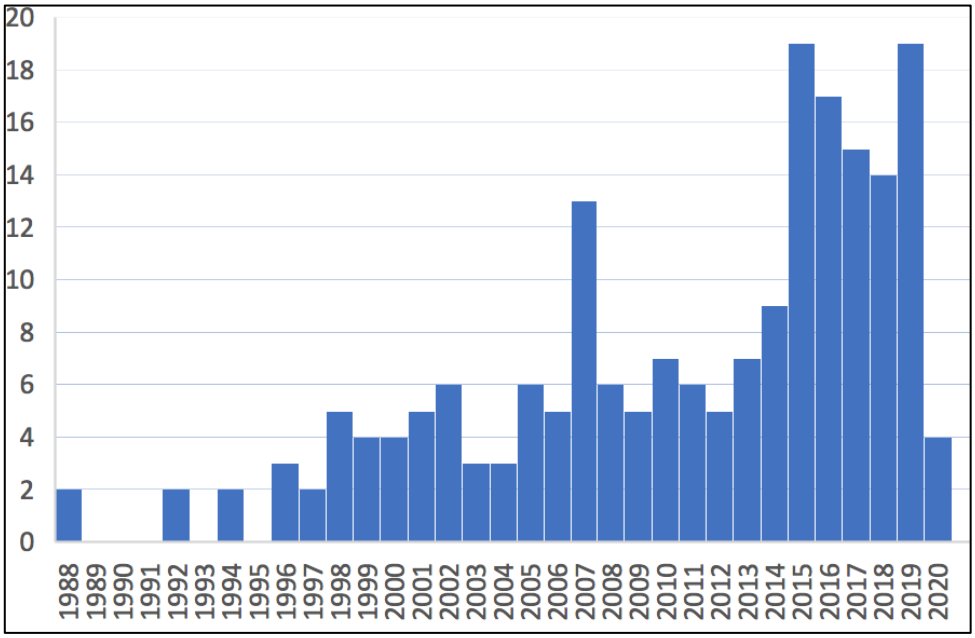
articles leading to the PS corpus, 51 articles to the PSC corpus, and 62 articles to the corpus about DSTs. Seventy-five articles focus on the relationship between PSs and project performance, and these would be considered as supporting material for PSS. The following section provides detailed descriptions of each of the key themes. The chapter then goes on to analyse the significance of each theme in terms of how the quantitative research findings related to PSS can be used for further framework development.

4.2 Descriptive analysis

4.2.1 Overall studies of procurement system selection

The literature review identified 198 peer-reviewed articles related to PSS. As shown in Figure 4.1, the number of articles published in this field has trended upwards over the last three decades with the largest number in 2015 and 2019 (19 articles each year). It can be expected that this trend of increasing research outcomes in the PSS field will continue.

Figure 4.1 The numbers of articles published on PSS each year



Note: Data collection finished July 2020.

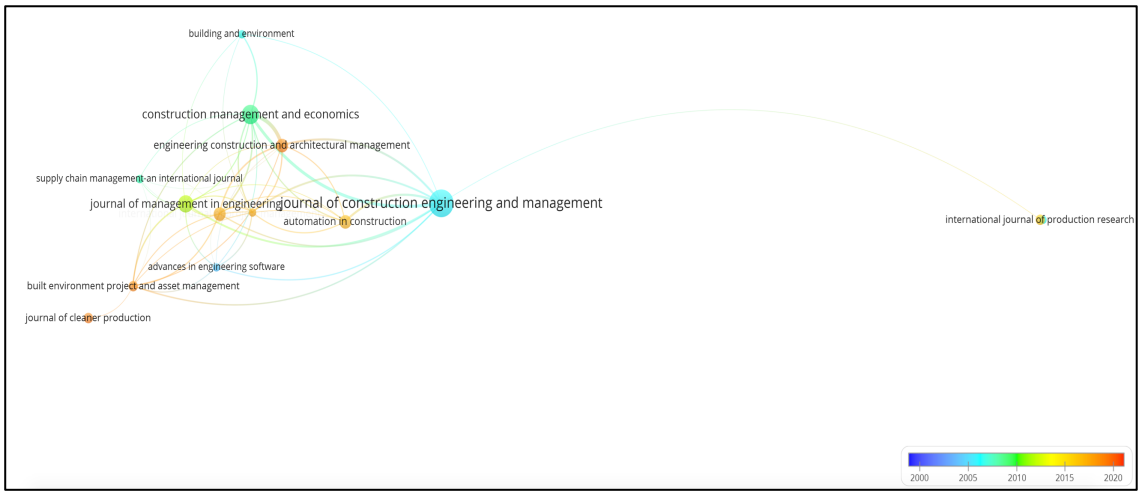
In line with Jin et al. (2019), journal sources were identified through bibliometric analysis. To be included in the analysis, a journal had to include at least three related documents and be cited at least 10 times. Twelve of the original 90 journals met this threshold. Quantitative measurements of the contributions and total link strength of each of these 12 journals are presented in Table 4.1.

Table 4.1 Details of top journals

Journal	No. of documents	No. of citations	Total link strength
Journal of Construction Engineering and Management (JCEM)	23	956	139.97
Construction Management and Economics (CME)	19	189	162.38
Journal of Management in Engineering (JME)	13	314	98.83
Engineering, Construction and Architectural Management (ECAM)	9	25	101.93
Automation in Construction (AIC)	7	116	37.00
International Journal of Project Management (IJPM)	6	104	45.00
Advances in Engineering Software	4	193	9.00
Built Environment Project and Asset Management (BEPAM)	4	11	35.93
Journal of Cleaner Production (JCP)	4	66	11.33
International Journal of Production Research (IJPR)	4	70	20.00
Building and Environment	3	32	3.05
Annals of Operation Research	3	48	4.39

The strength over time of the bibliographic coupling links of each of the 12 journals with other sources was calculated, and a visualisation of this is displayed in Figure 4.2. The connection lines show the journals' inter-relations; the scale of each label (size of the circle) reflects the number of articles from each journal; the colour bar shown in the bottom right corner of the visualisation indicates the average year of the publications of the journal; and the font size represents the number of articles with a larger font size representing a higher number of articles.

Figure 4.2 Mapping the trend of journal source



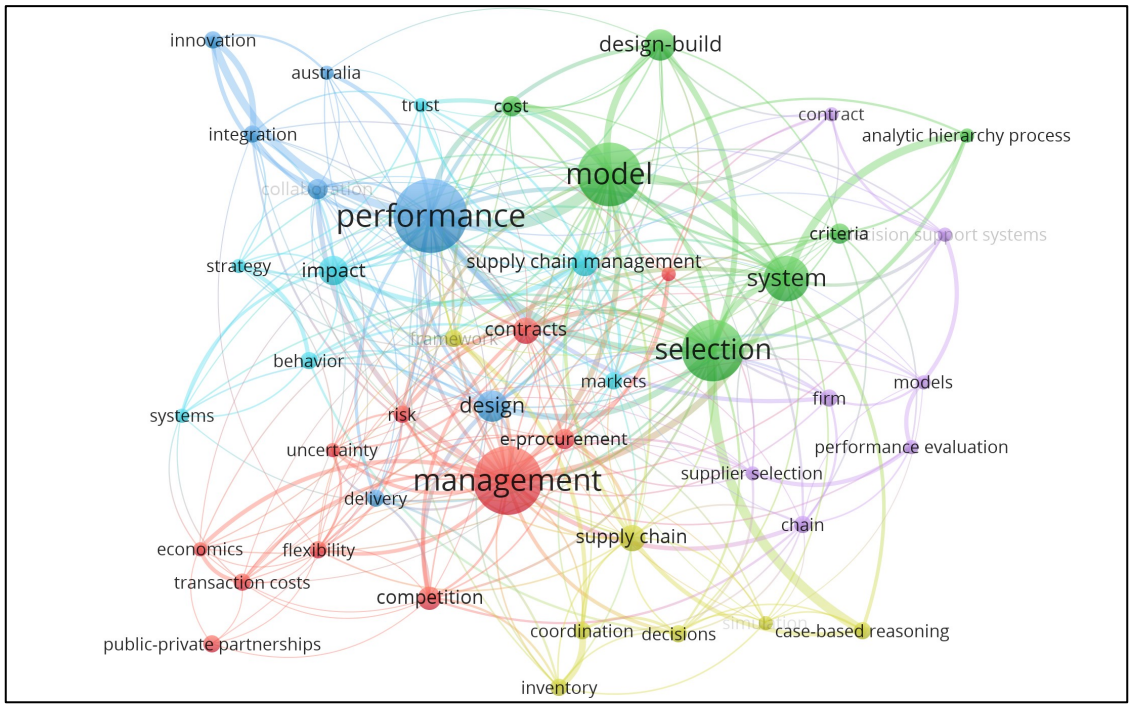
According to Figure 4.2, two journals had the most contributions to PSS research outputs in the years 2005–2010: *Journal of Construction Engineering and Management* (JCEM) and *Construction Management and Economics* (CME). This result reflects the continuous research interests in JCEM and CME in the construction engineering and management research community. However, in more recent times, research outputs have also been found in *Engineering Construction and Architecture Management* (ECAM), *Automation in Construction* (AIC), *Journal of Cleaner Production* (JCP), *Built Environment Project and Assets Management* (BEPAM) and *International Journal of Production Research* (IJPR), indicated that PSS-related studies have attracted increasing attention from the field of management science and operation research.

Clearly, JCEM and CME have been the most influential, in accordance with both the number of citations and total link strength, as shown in Table 4.1. Furthermore, the strong lines in Figure 4.2 show that the two journals are also strongly connected to each other. Both IJPR and JCP had only four (recent) articles each, but the two journals received higher citations in the corpus so could be considered as having higher impacts in the latest research contributions. While ECAM is one of the top journals in terms of the number of articles and its total link strength, the number of citations of PSS-related research in this journal is not high compared with the other journals.

4.2.2 Keywords in procurement system selection

Of the 435 keywords listed at the beginning of the 198 articles, 59 initially met the threshold, as shown in Figure 4.3. The words *performance*, *management*, *model* and *selection* are the most frequently listed keywords, with *supply chain management* being one of the core areas with a close connection to procurement. Figure 4.3 shows a strong connection between *performance* and *model*, which may indicate project performance is highly affected by procurement models or that different procurement models could lead to different project performances (e.g. Ling et al., 2004). *Performance* is also strongly linked with *design*, *integration* and *innovation*. These factors have yet to be extensively studied in the academic and industrial realms.

Figure 4.3 Holistic keyword co-occurrence network



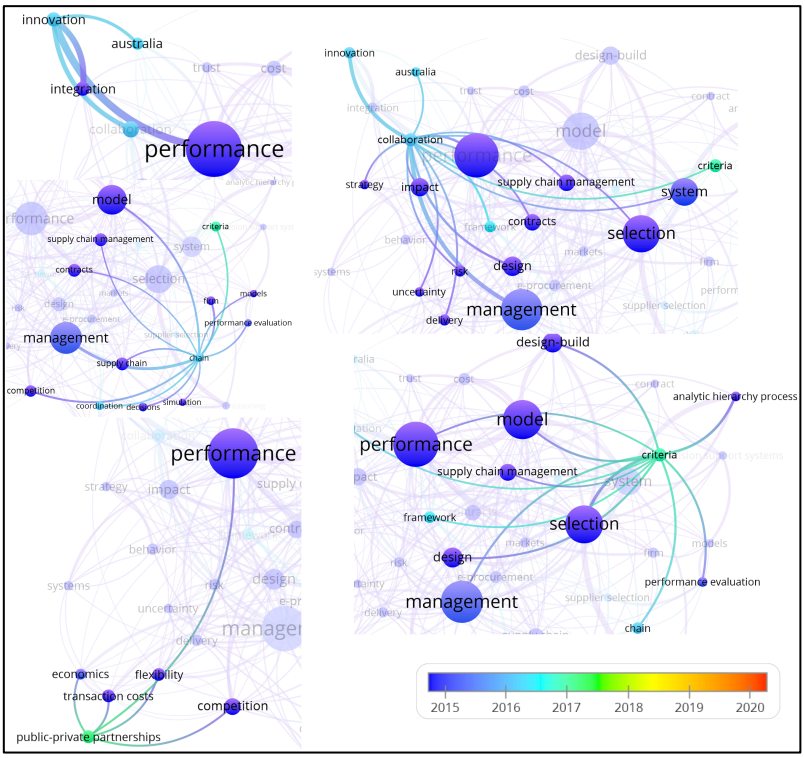
Management is clustered together with keywords related to economics (economics, transaction costs), selection criteria (uncertainty, risk, competition, flexibility), and procurement systems

(public-private partnerships, contracts). This finding indicates the intertwining challenges and multidisciplinary characteristics inherent in procurement management.

Model, system and *selection* are classified into the same cluster, with diversified nodes on the edge of the network. Figure 4.3 also illustrates that this cluster has the strongest total link strength, indicating that the cluster attracts significant research interest. These targeted nodes can be divided into two primary types: (1) alternative PS (*design-build*) and PSC (*criteria*); and (2) decision-making support tools, such as AHP and case-based reasoning (*CBR*).

A detailed analysis of the keywords in the corpus published from 2015 to 2020 was carried out to seek the latest research trend. As illustrated in Figure 4.4., *framework, criteria, innovation, collaboration* and *public-private partnerships (PPP)* were identified as the latest keywords.

Figure 4.4 Keywords co-occurrence from 2015 to 2020



Innovation is a by-product of a PSS process or a PSS approach. It includes process innovation and product innovation (Akintoye et al., 2012). Product innovation has been found in the PSS

process as a supporting tool for project success improvement, such as BIM and e-procurement (for example, Ramkumar (2016); Rowlinson (2017)). As a process, PSS innovation also demonstrates alternatives in achieving project performance by considering novel collaborative requirements (for example, Eriksson et al. (2019) and Khwaja et al. (2018)), and is aimed at exploring innovative practice to suit clients' modern needs. Innovative practice contains innovative structure, functional teams and agreements (Ibrahim et al., 2017). Consequently, to achieve a better performance, *innovation* has been attracted much attention when developing a PS through the integration of stages and collaboration of stakeholders.

Collaboration is a fashionable keyword in the PSS field. As the main characteristic of novel alternative procurement strategies, collaboration refers to the level and time of stakeholder involvement. In this corpus, early contractor involvement, collaboration with external suppliers, and the degree of contractor freedom have been discussed (Eriksson et al., 2017; Ferme et al., 2018). Past research has shown that uncertainty and risks can be properly reduced through team collaboration (Walker et al., 2017). For this reason, existing studies centred on the benefits of collaboration have promoted the establishment of models, guidelines and contracts that reflect the demands of the modern construction sector (Aktin & Gergin, 2016; Eriksson et al., 2019).

The inclusion of the keyword *Public-private partnerships (PPP)* reflects ongoing interest in the exploration of collaborative PS. Scholars have explored PPP from different aspects: success factors, economic benefits, transaction cost theory and team collaboration (Li et al., 2005; Teo & Bridge, 2017). Accordingly, the selection process has been facilitated to examine the suitability of PPP for a specific project through its competitive advantages or as a decision-making model (for example, Shalaby & Hassanein (2019) and Zhao & Ying (2019)).

Consistent with novel alternatives and collaboration, *chain* has become an influential keyword in recent years. Compared with typical procurement elements in project management studies, chain studies, to some degree, are out of the scope. Traditionally, chain studies belong to operational

research topics or supply chain research areas. However, there are intersecting points where the two areas cross with the evolution of PS. As a close branch of management science, the *chain* has a fundamental impact on the PSS throughout the whole project. Numerous studies have noted the research trend in this specific domain.

Criteria is the final keyword identified in recent publications. It had 16 links with other keywords, with the links being from all clusters in the corpus that were influenced by studies into construction management and selection modelling. The trend implies PSC should be dramatically considered in future research directions. While the latest articles show interest in PSC, only a few have directly explored and updated the sets of PSC used in PSS.

4.2.3 Key authors in procurement system selection

The authors with the highest total link strength in the corpus are Love, Luu, Chen, Kumaraswamy, Ng, Chan, Walker, Molenaar, Eriksson, Cheung and Saaty (see Table 4.2). Similarly, a correlation can be found between the ranking of articles and the ranking of authors. For example, AHP (for example, Alhazmi and McCaffer (2000) and Cheung et al. (2001)) was frequently adopted when developing a decision-supporting model. Furthermore, Figure 4.5 shows that there are three clusters of the most influential authors based on the co-cited studies. The first cluster comprises Chan, Kumaraswamy and Molenaar, and their research mainly focused on the PSS process and PS development; the second cluster has Cheung, Ng, Luu and Saaty, and their studies utilised procurement selection modelling; and the last cluster contains Eriksson, Walker and Love whose works were on the practical evolution of alternative PS and project performance. Co-citation analysis provides the potential to take research to its next stage of development (Ekanayake et al., 2019). The descriptive analysis of the most frequently cited research articles and the most influential authors in PSS research resulted in three key findings. First, the most influential studies mainly focused on applications of PSC and decision-supporting techniques; secondly, the key

authors in this area work on PSS process, PS and performance, and PS development; and finally, few papers have had a significant impact over the last two decades.

Table 4.2 Key authors in the PSS field and their total link strength

Authors	Total link strength
Love, P. E. D.	192
Lu, D. T.	171
Chen, S. E.	128
Kumaraswamy, M. M.	128
Ng, S. T.	116
Chan, A. P. C.	105
Walker, D. H. T.	91
Molenaar, K. R.	90
Eriksson, P. E.	81
Cheung, S. O.	75
Saaty, T. L.	36

4.3 Research themes of procurement system selection process

Three key research themes can be identified from the co-occurrence analysis and co-citation analysis:

- Key theme 1 (KT1): Procurement system
- Key theme 2 (KT2): Procurement selection criteria
- Key theme 3 (KT3): Decision supporting techniques for procurement system selection

Identification of these themes is important because the findings from these themes could be used to construct the proposed procurement system selection framework.

4.3.1 Procurement system

The first theme focuses on the development and comparison of assorted PSs. With the evolution of PS in the construction sector, the existing studies have presented PSs by addressing each system's characteristics. As indicated in Figure 4.3, the keywords group in red of *management* field research are closely related to PS terms, such as *public-private partnerships*. PSs identified

in the corpus include different delivery methods and strategies such as DB, PPP, alliance and BVP. These subthemes initially investigated the views on a specific PS from different core procurement people, such as contractors (Akintoye, 1994), clients (Songer & Molenaar, 1996, Rahmani et al., 2017), agencies (Tran et al., 2017) and financial providers (Bolanos et al., 2019). For this reason, various aspects are embedded in the comprehensive chain of the PSS, including contractor selection, supplier selection and design team selection (for example, Eadie and McCavigan (2016) and El Wardani et al. (2006)). PSS also covers contract method decisions, and determining contract type such as lump sum, unit rate and price plus (for example, Chen et al. (2016)).

Figure 4.5 Most influential authors

Authors	Publications related to PSS cited the author's studies	Total link strength
Love, P.E.D.	Kumaraswamy and Dissanayaka (1998), (Cheung et al., 2001b, Tserng and Lin, 2002, Luu et al., 2005, Rweiamila and Edries, 2007, Koppinen and Lahdenpera, 2007, Chao and Hsiao, 2012, Mandell and Brunes, 2014, Cheaitou et al., 2014, Rajeh et al., 2015b, Chua et al., 2015b, Chua et al., 2015a, Brezovnik et al., 2015, Qiang et al., 2015, Rahmani et al., 2016, Naoum and Egbu, 2016, Jimoh et al., 2016, Obi et al., 2017, Ibrahim et al., 2017, Eriksson et al., 2017, Eriksson, 2017, El Sawalhi and El Agha, 2017, Aghimien et al., 2017, Sackey and Kim, 2018b, Lines and Kumar, 2018, Ferme et al., 2018, Chen et al., 2018, Zhao and Ying, 2019, Su et al., 2019, Lam, 2019, Kwofie et al., 2019, Dabarera et al., 2019, Li et al., 2019, Ordinola-Zapata et al., 2020).	192
Luu, D.T.	Ng et al. (2002), Chong and Preece (2014), Rajeh et al. (2015b), Chua et al. (2015b), Chua et al. (2015a), Qiang et al. (2015), Naoum and Egbu (2016), Jimoh et al. (2016), El Sawalhi and El Agha (2017), Aghimien et al. (2017), Sackey and Kim (2018b), Zhao and Ying (2019), Kwofie et al. (2019).	171
Chen, S. E.	Ng et al. (2002), Chong and Preece (2014), Rajeh et al. (2015b), Chua et al. (2015b), Chua et al. (2015a), Qiang et al. (2015), Naoum and Egbu (2016), Jimoh et al. (2016), El Sawalhi and El Agha (2017), Aghimien et al. (2017), Sackey and Kim (2018b), Zhao and Ying (2019), Kwofie et al. (2019).	128
Kumaraswamy, M. M.	Palaneeswaran and Kumaraswamy (2000), Luu et al. (2003), Luu et al. (2005), Luu et al. (2006), Koppinen and Lahdenpera (2007), Ojo et al. (2011), Lu et al. (2013), Rajeh et al. (2015b), Chua et al. (2015a), Qiang et al. (2015), Naoum and Egbu (2016), Ibrahim et al. (2017), Eriksson et al. (2017), Eriksson (2017), Lines and Kumar (2018), Hasanzadeh et al. (2018), Khwaja et al. (2018), Zhao and Ying (2019), Dabarera et al. (2019).	128
Ng, S. T.	Chua et al., (2015a), Chua et al., (2015b), Jimoh et al., (2016), Aghimien et al. (2017), Kwofie et al., (2019).	116
Chan, A. P. C.	Tserng and Lin (2002), Luu et al. (2003), Kauffman and Mohtadi (2004), Luu et al. (2005), Khalfan et al. (2007), Farahvash and Altiok (2008), Chang et al. (2008), Leach (2009), Zhang et al. (2010), Alaez-Aller and Longas-Garcia (2010), Aboelmaged (2010), Liu et al. (2011), Gurnani et al. (2012), Chao and Hsiao (2012), Huang et al. (2013), Emuze and Smallwood (2013), Xing et al. (2014), Jaskowski et al. (2014), Chong and Preece (2014), Strahorn et al. (2015), Rajeh et al. (2015b), Rajeh et al. (2015a), Chou et al. (2015), Ashuri and Mostaan (2015), Qiang et al. (2015), Li et al. (2015), Stanford et al. (2016), Naoum and Egbu (2016), Jimoh et al. (2016), Chen et al. (2016a), Bag (2016), Eriksson (2017), Aghimien et al. (2017), Sackey and Kim (2018b), Lines and Kumar (2018), Bruno et al. (2018), Zhao and Ying (2019), van der Walt et al. (2019), Su et al. (2019), Phochanikorn and Tan (2019), Penyalver et al. (2019), Kwofie et al. (2019), Cholette et al. (2019), Biazzin and Carvalho (2019), Ordinola-Zapata et al. (2020), Fathi et al. (2020), Elhag et al. (2020), Chowdhury et al. (2020), Aghajani and Torabi (2020).	105
Walker, D. H. T.	Kumaraswamy and Dissanayaka (1998), Luu et al. (2005), Yik et al. (2006), Khalfan et al. (2007), Chan et al. (2011), Lu et al. (2013), Li (2013), Rajeh et al. (2015b), Rajeh et al. (2015a), Rahmani et al. (2016), Naoum and Egbu (2016), Aktin and Gergin (2016), Ibrahim et al. (2017), Walker et al. (2017), Ferme et al. (2018), Chen et al. (2018), Lam (2019), Kwofie et al. (2019).	91
Molenaar, K. R.	Palaneeswaran and Kumaraswamy (2000), Luu et al. (2005), El Wardani et al. (2006), Koppinen and Lahdenpera (2007), Lam et al. (2008), Abdelrahman et al. (2008), Ojo et al. (2011), Chao and Hsiao (2012), Rajeh et al. (2015b), Rajeh et al. (2015a), de Albuquerque et al. (2015), Ashuri and Mostaan (2015), Li et al. (2015), Stanford et al. (2016), Ramsey et al. (2016), Chen et al. (2016b), Chen et al. (2016a), Tran et al. (2017), El Sawalhi and El Agha (2017), Alleman et al. (2017), Stanford and Molenaar (2018), Hasanzadeh et al. (2018), Ferme et al. (2018), Zhao and Ying (2019), Wondimu et al. (2020)	90
Eriksson, P. E.	Lu et al. (2013), Rajeh et al. (2015a), Naoum and Egbu (2016), Lines and Kumar (2018), Kwofie et al. (2019), Wondimu et al. (2020).	81
Cheung, S.O.	Chan et al. (2001), Luu et al. (2003), Luu et al. (2005), Dzeng and Chang (2005), Yik et al. (2006), Zhang et al. (2010), Aboelmaged (2010), Mostafavi and Karamouz (2010b), Liu et al. (2011), Chen et al. (2011), Chao and Hsiao (2012), Love et al. (2012), Doloi (2013), Chong and Preece (2014), Rajeh et al. (2015b), Chua et al. (2015b), Chua et al. (2015a), Qiang et al. (2015), Naoum and Egbu (2016), Nazari et al. (2017), Eriksson et al. (2017), Eriksson (2017), El Sawalhi and El Agha (2017), Aghimien et al. (2017), Teo and Bridge (2017a), Sackey and Kim (2018b), Hasanzadeh et al. (2018), Zhao and Ying (2019), Ordinola-Zapata et al. (2020).	75
Saaty T.L.	Chua and Li (2000), Alhazmi and McCaffer (2000), Cheung et al. (2001b), Lambropoulos (2007), Mafakheri et al. (2007b), Abdelrahman et al. (2008), Gupta and Narain (2015), Chua et al. (2015b), Chua et al. (2015a), Ramkumar (2016), Nazari et al. (2017), Salem et al. (2018), Hasnain et al. (2018), Phochanikorn and Tan (2019), Chowdhury et al. (2020).	36

PSs from relevant theoretical lenses with regards to engineering technology, management and economics have also been introduced (Koppinen & Lahdenpera, 2007; Warszawski, 1996). Variables in this cluster means that the articles in the cluster explored and analysed PSs based on a specific perspective. "Understanding of PS" in the theme, meanwhile, means that the analysed article emphasised particular characteristics of a certain PS, and demonstrated the ability to deliver the novel needs of modern construction, such as value for money (for example, Haynes and Roden (1999)), sustainable development (for example, Yik et al. (2006)), and specifications (for example, Bruno et al. (2018)). Procurement systems have developed over the years, reflecting

the evolution of the traditional system of DBB to more postmodern systems of management and integrated (also known as DB) PSs (Rahmani et al., 2017).

This thesis used a bibliometric review to identify 198 peer-reviewed journal articles from the CEM field that displayed a holistic picture of PSS studies. Through context analysis, only 5% (10/198) of the identified articles provided a definition of PS; see Table 4.3.

Table 4.3 Different definitions in the literature for a procurement system

References	Definition and Description
Ansah and Sorooshian (2018)	*"…there have been concerns about problems associated with the type of procurement, risk allocation, procurement methods for design and the procedure for projects and tendering"*
Mosley Jr and Bubshait (2017)	*"Procurement systems define the roles and responsibilities of the parties involved in a project. They also determine an execution framework in terms of sequencing of design, procurement, and construction."*
Rahmani et al. (2017)	*"The term remains broadly defined and is used to describe a variety of entities such as functions, organisations, resources, systems, processes and strategies…resources is a part of the procurement system and can be referred to a process of combining these necessary resources together."*
Love et al. (2012)	*"A procurement system is typically the sourcing strategy for delivering projects and assigns specific responsibilities and authorities to people and organizations."*
Tawiah and Russell (2008) cited McDermott (1999)	*"the framework within which construction is brought about, acquired or obtained"*
Rwelamila and Edries (2007)	*"A procurement system is hence defined as an organizational structure that defines and describes the roles of participants; the relationships between them, both formal and informal; their individual responsibilities; the sequence of activities and timing of events required to provide a facility; and the practices and techniques of management that are used."*
Kuprenas and Nasr (2007)	*"…is the term used within the design and construction industry to define the process by which the project phases are accomplished, the parties involved in each phase, and the parties' contractual relationships."*
Lædre et al. (2006)	*"…procurement route delivers procurement strategy. It includes the contract strategy that will best meet the client's needs…the combination of procurement procedure, contract model, and compensation format…"*
Luu et al. (2005)	*"…provide a strategic framework (in terms of work packaging, functional composition, contractual arrangement, and team selection)…set out the specific authorities, responsibilities, and relationships of various project participants…"*
Love et al. (1998)	*"an organizational system that assigns specific responsibilities and authorities to people and organizations, and defines the relationships of the various elements in the construction a project"*

4.3.2 Procurement selection criteria (PSC)

The second key research theme explores procurement selection criteria (PSC). As shown in Figure 4.4, *criteria* had the highest connection with the other key research themes, with the articles in the cluster that generated this theme mainly exploring PSC for PSS. The most influential studies identified in Figure 4.5 are also evident in this theme. PSC identified in the early studies in the corpus included cost, quality, speed, certainty, risk allocation, complexity, price competition, responsibility and disputes (for example, Love et al. (1998) and Ng et al. (2002)), whereas later studies established PSC such as value for money, sustainability, building information modelling (BIM), collaborations and innovation to accommodate procurement system developments (for

example, Luu et al. (2005), Naoum and Egbu, (2016), and Qiang et al. (2015)). The following section introduces PSC that have been identified in the literature review as well as their classification, and discusses how PSC have evolved to meet the changing needs of the modern construction sector.

4.3.2.1 Identifying procurement selection criteria

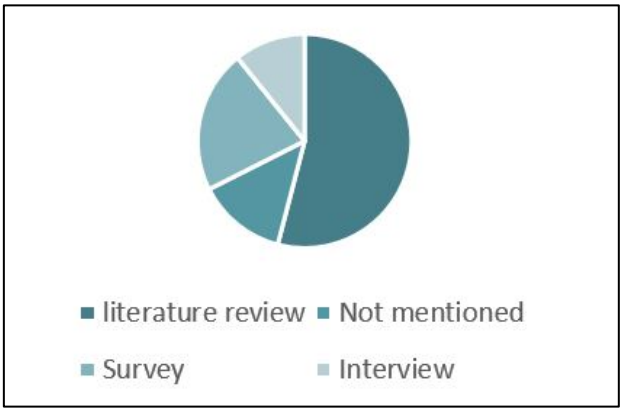
Table 4.4 presents the 256 PSC that were identified in the literature review, and the frequency of each criterion. Interestingly, the review was updated to the end of June 2020, but there were no PSC-related articles in the first half of 2020. The wide variety of PSC identified from the articles suggests that there is no consensus around PSC in the construction industry. Indeed, only 16 criteria occur in more than five articles. Furthermore, descriptions of some of the criteria are vague and fuzzy; for example, *culture* or *applicability*. Most of the articles did not explain the definition and context of the criteria. It appears there is a high degree of subjectivity and intuitive judgement in PSC identification, perhaps because PSC are determined by various players and at different levels and stages of construction projects. Performances of contractor, consultant and client are considered as selection criteria; for example, the client's management ability and the consultant's staffing level. Some articles have listed PSC relating to strategic management, such as risk allocation and economic environment, while others have focused more on PSC at the operational level; for instance, availability of materials and equipment. The vagueness and fuzziness of the definition of different PSC may lead to difficulty in their evaluation.

Table 4.4 Procurement selection criteria identified from the literature review

Criteria	No.	Criteria	No.	Criteria	No.	Criteria	No.	Criteria	No.
quality	20	ability to define the project scope	2	availability of materials	1	experience	1	previous process used	1
complexity	17	building construction type	2	availability of materials and equipment	1	experience needed for a particular delivery option	1	procurement method recommendation	1
cost certainty	14	capital cost (lower)	2	availability of procurement system in the local market	1	external approvals	1	project budget	1
risk allocation	14	certainty	2	Availability of qualified procurement personnel	1	Familiarity and establishment	1	project economic attributes	1
size of project	14	client resources	2	BIM	1	fashionable procurement method	1	project location	1
price competition	13	client specify subcontractor	2	buildability	1	fast tracking schedule	1	project nature	1
responsibility	12	client's management ability	2	building type	1	feasibility studies	1	project objectives	1
flexibility	9	client's preference to control the project	2	categories of client	1	financial arrangement	1	project ownership type	1
speed	9	client's requirement for aesthetic building	2	certainty of final cost	1	flexibility to redesign after construction cost commitment	1	project requirements	1
client's experience	8	client's requirement for on-time completion	2	certainty of initial cost	1	funding cycle	1	project risks	1
time certainty	8	client's requirement for within-budget completion	2	claims and disputes between design and builder	1	government policy	1	project technical complexity	1
cost	7	client's risk attitude	2	clarity of defined roles	1	highly serviced or advanced building	1	project technical uncertainty	1
risk management	7	clients' needs and priorities	2	clear user's requirement	1	industrial actions	1	project time constrains	1
client's financial capability	6	competitive tendering	2	client design organization	1	information at project inception	1	protect organisation interest	1
schedule	6	complexity of design	2	client's business culture	1	innovative methodologies	1	public accountability	1
uniqueness	6	constructability analysis	2	client's experience in procurement methods	1	past experience of the decision maker	1	reduction in administrative staff	1
clarity of scope	5	construction duration	2	client's in-house capability	1	knowledge of the strategy	1	regulation feasibility	1
client's in-house technical capability	5	construction speed	2	client's project experience	1	known site factors likely to cause problems	1	regulatory and statutory requirements	1
client's involvement	5	cost saving	2	client's requirement for highly serviced or technically advanced building	1	labour productivity	1	regulatory impact	1
experienced contractor availability	5	degree of project complexity	2	collaboration among project participants	1	lean construction	1	resettlement	1
financial guarantee	5	design control	2	commercial/investment reasons	1	life cycle costs	1	responsibility clarity	1
project characteristics	5	ease change incorporation	2	competent contractors	1	life-cycle efficiency	1	risk management improvement	1
risk avoidance	5	effective and efficient decision making	2	conflict of interest	1	local design and construction regulations	1	safety	1
type of project	5	enough experience to carry out the delivery option	2	construction market development level	1	local familiarity and confidence in procurement	1	schedule predictability	1
client's trust towards other parities	4	familiar project condition	2	construction quality	1	lowest cost for a given quality	1	site risk factors	1
client's willingness to be involved	4	maintenance costs	2	consultancy service	1	lowest whole-life cost	1	special weather and environmental concerns	1
disputes and arbitration	4	market attributes	2	consultant's staffing level to attend to contractor	1	market position	1	specialisation and differentiation among participants	1
expected levels of changes	4	material quality	2	contract packaging	1	materials availability	1	speed of project completion	1
flexibility in accommodating design changes	4	nature and status of local construction industry	2	contract pricing	1	non-adversarial relationship	1	stakeholder integration	1
scope change	4	need for innovation	2	contractor and architect/engineer needs	1	organisation objective or policy	1	sub-project construction interference	1
type of client	4	number of contracted parties	2	contractor capability	1	overall client satisfaction	1	suitability of the procurement method in handling complex projects	1

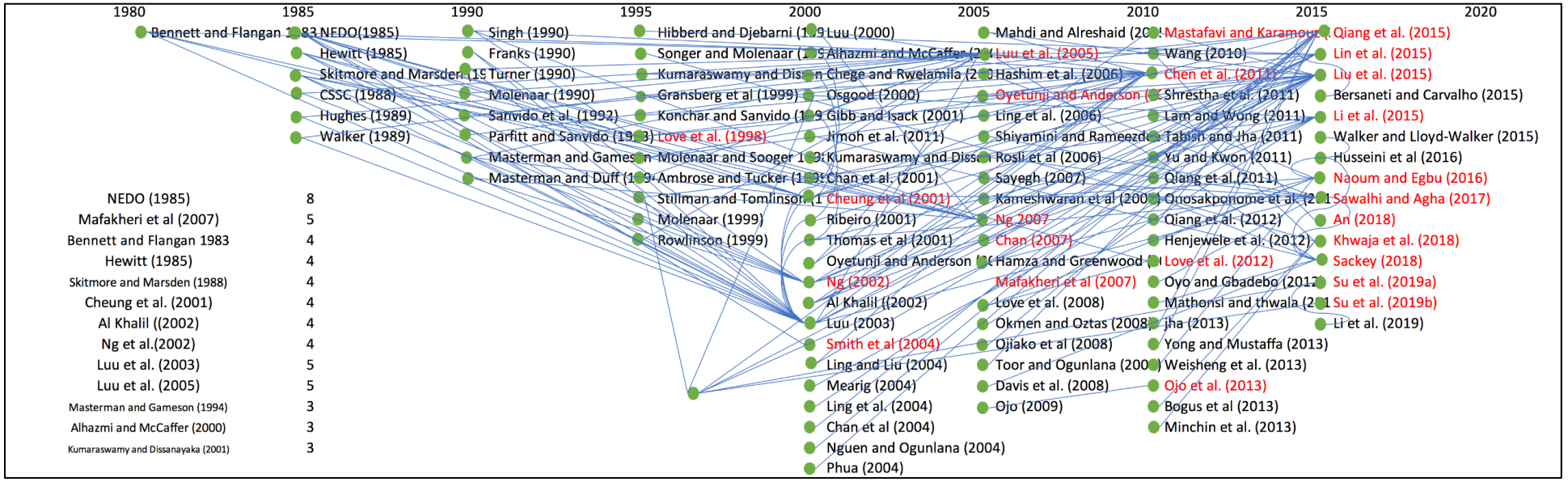
For this reason, a citation network analysis was conducted to determine how the PSC were identified and what research method was used. The classification of research methods used in criteria identification is shown in Figure 4.6. Note that some articles had adopted more than one methodology, although the maximum number of methods per article in the corpus is two.

Figure 4.6 Research methods used by articles in the literature review to identify procurement selection criteria



"Literature review" was found to be the most frequent method used in the corpus to identify PSC. This finding led to a second citation network analysis, aiming to determine the original source of some of the PSC. The indicator adopted to measure the impact of an article and its contribution to the PSC categories analysis is how often each article has been cited. As illustrated in Figure 4.7, the National Economic Development Office, or NEDO, (1985) was the most frequently cited publication over the last three decades. Thus, the citation network analysis suggests that PSC identification is largely based on literature reviews of a small number of high-impact articles, and these articles have been barely updated since 2002 (Al Khalil, 2002).

Figure 4.7 Co-citation network of papers in identifying PSC by literature review



All the PSC were fed into a Java program to identify any trends between 1998 and 2020. The PSC were mapped in five-year intervals, as shown in Figure 4.8. The density visualisation of the PSC reveals each criterion's evolution and the core clusters of a specific time interval. Overall, the density visualisation in Period I is dispersed. Some indicators related to collaborative systems emerged during this period, such as the client's financial capability (Alhazmi & McCaffer, 2000), client's involvement (Chan et al., 2001) and collaboration between all parties (Tookey et al., 2001). The articles published in period II, however, gave higher priority to mathematical models for procurement method selection. It seems that the growing complexity of projects stimulated new payment modes in this time period (Ling et al., 2004). During period III, the client's financial capability and technology/innovation feasibility became key PSC when assessing procurement systems. This could explain the increased use of collaborative systems in construction procurement. Like Period I, the density in period IV is disbanded. Some PSC, such as value for money, the client's willingness to take risks, collaboration among parties, contractor ability and political issues, obtained more attention.

4.3.2.2 Classifying procurement selection criteria

Just as there is limited agreement on what should be PSC should be used, there is also limited agreement of the classification of PSC. Fifteen different combinations of categories have been established in the corpus literature. While some articles suggest categories such as project characteristics, client's requirement, project objectives and external environment (Luu et al., 2005), others propose categories such as certainty, price competition, flexibility, complexity, quality, responsibility and risk (Love et al., 2008). It is apparent that there is no systematic mechanism for PSC classification.

Figure 4.9 illustrates the evolution of research topics about PSC. The colour bar at the bottom right of the figure indicates the mid-year of the four five-year time intervals for date of publication. The higher the frequency of an item, the larger the circle around the item. The lines between items

represent links between the items. The “hottest” spots in the figure are *project management*, *decision making* and *performance*.

Figure 4.8 The density visualisation of PSC

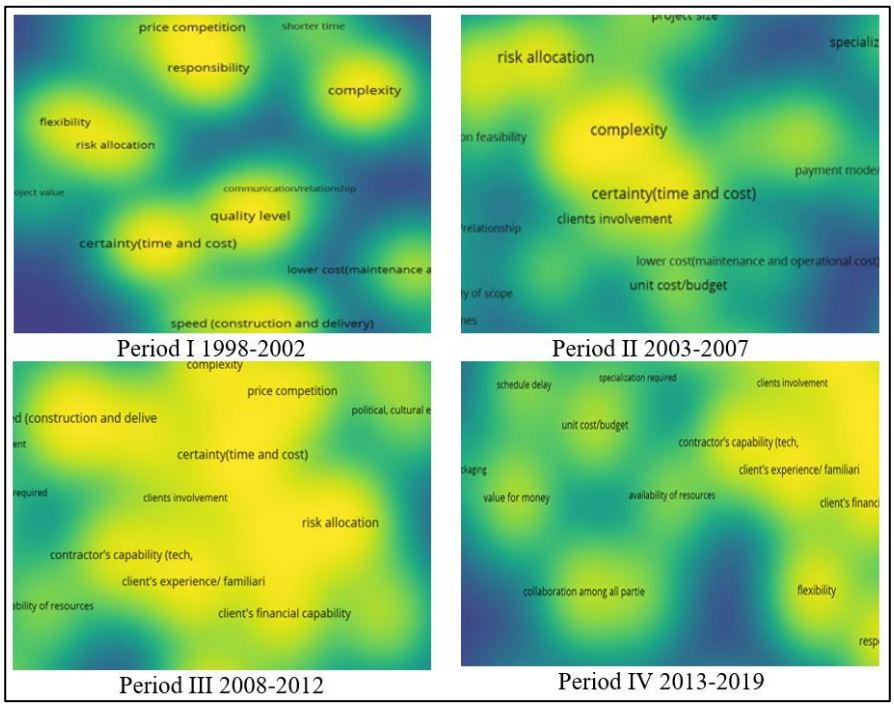
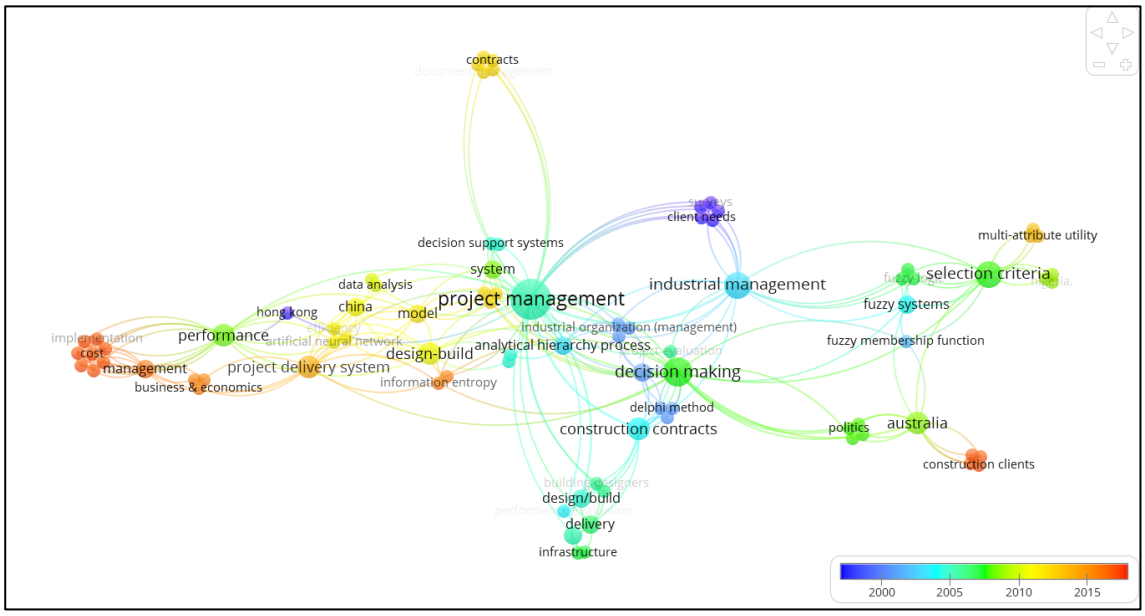


Figure 4.9 The evolution of research topics about procurement selection criteria



The earlier articles (1998–2002) mostly focused their attention at the micro-level, considering the contribution of PSC for individual project procurement selection. For this reason, *project management* has 36 links related to other keywords. The purpose of project management is to achieve the balance of triangle elements through a procurement success. In more recent times, (2008–2020), research has expanded to consider more PSC to match the construction context. Thus, the research topic of PSC is seen to have evolved from *industrial management* to *decision making* and *performance*. For example, design-build and the public sector. It is important to note that *industrial management* has not been the critical research area since 2008, and recently the research keywords have moved from *decision making* and *performance* to new areas such as *contracts, politics, model, framework, relationship* and *management*. These keywords express the characteristics of novel PS.

PSC have evolved in line with the trend of PS development. Overall, PSC in relation to project management (*shorter time, project type, regulation feasibility* and *lower cost*) were mentioned in the earlier articles. In more recent times, though, PSC have tended to focus on broader aspects of PSS. For example, contemporary aspects such as political, cultural and economic issues have been examined in the literature (Luu et al., 2005), and clients' financial capability discussed (Li et al., 2015; Liu et al., 2015; Qiang et al., 2015). At the same time, collaborative PSs such as PPP and PFI began to be implemented in the construction industry. It seems that procurement policy and clients' needs drove the changes in procurement practice. For example, the UK government promoted a paradigm shift from traditional methods to value for money and a collaborative environment after the publication of *Accelerating change* in 2002 (Chen et al., 2018). The availability of PS alternatives has a significant influence on the definition of project success elements, such as collaborations and long-term relationships. Consequently, PSC have been updated to reflect the changes demanded by PS alternatives. Modern PSC, such as collaboration among all parties and availability of resources, started to gain popularity.

4.3.3 Decision supporting techniques (DSTs) for procurement system selection

A total of 62 was identified in relation to decision DSTs. According to the usages of the DSTs in PSS, the unit of DSTs could be classified into mathematic and statistics, artificial intelligence (including machine learning), information and visualisation, multiple hybrid techniques and others (not specific), as shown in Table 4.5.

Detailed descriptions of each DST have been displayed in Table 4.6. Overall, DSTs contained evaluation techniques that explore the methods to analyse PSC, and selection techniques that discuss the approach for PSC identification. Due to significant changes in the technical and economic conditions prevailing in construction procurement, researchers in this corpus have presented many models for systematically selecting the most appropriate PS (e.g. Li et al., 2015); Zhao & Ying, 2019). These mathematic models demonstrate how to select the most suitable PS using PSC, and how to use the information to make a decision.

Table 4.5 Decision-supporting techniques (DSTs) in procurement system selection

Unit of DSTs	pre-2001	2001–2010	2011–2020	Key sample articles
Mathematics and statistics (AHP, MUV, RA, factor analysis)	4	6	2	Konchar & Sanvido (1998) Mahdi & Alreshaid (2005) Doloi (2013)
Artificial intelligence and machine learning (CBA, ANN, fuzzy set, rough set)	2	6	5	Ng et al. (2002) Oyetungi & Anderson (2006) Liu et al. (2015) Plantinga et al. (2019)
Information and visualization (BIM, TCE, e-commerce)	0	3	11	Ive & Chang (2007) Rowlinson (2017) Wang et al. (2018) Sloot et al. (2019)
Use multiple hybrid techniques	1	9	9	Mafakheri et al. (2007) Cheng et al. (2010) Austin et al. (2016)
Not specific (just indicated the techniques)	0	1	3	Ibbs & Chih (2011) Zhao & Ying (2019)

Notes: See the List of Abbreviations for definitions of the above terms.

Table 4.6 A detailed description of decision-supporting techniques (DSTs)

DSTs	Characteristics/Formulation	Benefits/Limitations	Example papers
MUV	First, structure a set of mean utility values for each procurement criterion of each method, and then weigh each criterion based on the degree of importance. The utility score would be ranked and summed, and then the alternative with the highest score would be selected as the optimum procurement method. MUV involves a quantitative decision approach that provides normative suggestions regarding the decisions	Provides decision makers a more straightforward way to evaluate various options (+). The application of MUV/SMARTS may fail to reflect the results in the actual issues (−), easy to use (+); relies on the analysis of respondents' preferences (+, −)	Love et al. (1998, 2012), Molenaar and Songer (1998), Chang and Ive (2002), Lambropoulos (2007), Ojo and Ikpo (2013), Ibbs and Chih (2011)
SMARTS	SMARTS is used for a quantitative analysis of the PSS		Oyetunji and Anderson (2006)
AHP	The theory of AHP is to break down a thorny decision problem into a hierarchy of sub-problems for objective ratings. It is a logical way to decompose a complex project context into a simple hierarchy, so that each element can be assessed quantitatively and qualitatively. The accuracy of AHP is related to experts' uncertainty and subjective judgements due to the pairwise comparison	The process of AHP is under a systematic manner (+); The lack of statistical theory and inability to fully response to uncertainty (−)	Alhazmi and McCaffer (2000), Kumaraswamy et al. (2000), Chan et al. (2001), Al Khalil (2002), Mahdi and Alreshaid (2005), Ibbs and Chih (2011)
FST	The fuzziness degree of linguistic fuzzy membership functions (1) the horizontal approach; (2) variables of procurement selection criteria can be stated by those functions. There are four steps to establish the vertical approach; (3) the pairwise comparison; (4) the membership function estimation approach with the aid of probabilistic characteristics	This model could assist experienced consultants to avoid the degree of uncertainty and subjectivity in the PSS (+); The fuzzy set theory is not a user-friendly approach and the users having a certain level of knowledge of the fuzzy techniques (−)	Ng et al. (2002), Luu et al. (2006), Mostafavi and Karamouz (2010), Cheung, Ng, Lam and Sin (2001)
WS	WS rationalises priority rating and calculates the performance of alternative procurement methods. The option with the highest score is considered as the optimum method	User friendly (+); This approach is subjective and inadequate in making an informed decision (−)	Tucker and Ambrose (1998)
OR	It is a ranking method that involves pairwise comparisons	It is used to support complex decision-making; systems (+); Complex process (−)	Ojo and Ikpo (2013)
UT	In the information theory, information is used to measure the system order degree, and the information entropy method is proposed to measure the disorder degree	More objective results (+); Not user-friendly and the users need a certain level of knowledge (−)	Li et al. (2005)
RA	RM is a predictive model that can provide owner's insight into the possibility of the project success which can be used if there is evidence that one factor can affect another factor	Complex, difficult and not user-friendly (−); The result must be confirmed by the appropriate experiential judgements (−); A performance prediction model (+)	Konchar and Sanvido (1998), Ling and Liu (2004), Dada (2012)
TCE	The pre-contract and post contract cost using the magnitude of the transaction cost for each procurement method	Clearly identify goals and objectives, requirements of capacity development, improve the adequacy of funding and define the most feasible contractual routes (+)	Chang and Ive (2002), Ive and Chang (2007), Rajeh et al. (2015)
MC	This framework explains well the hard and soft perspectives of organisational management, such as structure, strategies, systems, staff, shared values, style and skills	The compatibility of different procurement systems and organisational form (non-projectized and projectized) are identified (+)	Chong and Preece (2014)
CBR	CBR is an experience-based technique. The identification of criteria (including linguistic classifications and importance weightings) highly relies on clients' previous experiences. The framework can be established based on the data collected from experts	High accuracy of collected information (+); The performance of CBR system may be subjective and inadequate (−); Not user-friendly (−)	Luu et al. (2003, 2005, 2006), Chen et al. (2011)
ANN	ANN can be used as a predictive technique to explore the performance. Compared to linear regression techniques, ANN involves nonlinear functions which do not need to consider the weights. ANN has been defined as a knowledge-based approach, but it does not fully extract information based on experiences and knowledge	Difficulty in data collection (−)	Chen et al. (2011)
IM	Reassess and weigh clients' needs and project characteristics to fit project environment, and then it will clearly show each feature of each procurement method	It shows the benefits and drawbacks of each procurement method (+); The results highly rely on the experiences of respondents (−); Not user-friendly	Tucker and Ambrose (1998)

Notes: MUV, multi-attribute utility value; MCA, multi-criteria analysis; WS, a simply weighed sum approach; OR outranking method; FST, fuzzy set theory; SMARTS, multi-attribute rating technique with swing weights; AHP, analytical hierarchical process; CBR, case-based reasoning; ANN, artificial neural network; IM, interaction matrix; RA, regression analysis; TCBA, transaction cost-based approach; UM, unascertained mathematics; EO, economic and organisational aspects; MC, McKinsey 7 S model

Based on the studies identified in the literature review, section 4.3.3.1 introduces the current research status of DSTs, section 4.3.3.2 analyses the roles in the PSS process, section 4.3.3.3 explores DSTs from the view of a cognitive system, and section 4.3.3.4 discusses DST from users' perspectives.

4.3.3.1 Current research status

Multi-criteria decision supporting techniques

According to the nature of the construction project, the decision-making techniques utilised can be classified into two groups: (1) multi-criteria decision approaches (MCDA); and (2) predicting techniques. Overall, a multi-criteria approach leaves users to make decisions in a structured manner, considering a wide range of factors that could influence the evaluation of the PS (Zhao & Ying, 2019). It is normally used as a technique to provide the possibility to transform the subjective perception of the objective area (Chang & Ive, 2002). MUV, a simple multi-attribute rating technique with swing weights (SMARTS), and AHP are three common forms of MCDA. More than 20% (17/62) of the articles described studies that had used MUV/SMARTS as the DST in the procurement decision process. Compared with MUV, which relies on the analysis of respondents' preferences, AHP is a systematic process that uses pairwise comparison (Ibbs & Chih, 2011). AHP is the most popular ranking and evaluation method for supporting decision-makers in procurement method selection. Twenty-nine per cent (18/62) of the articles had used AHP in their studies. Two other ranking methods – simple weighted sum method (WS) and outranking method (OR) – are also used in the PSS decision process. WS has been discussed by Tucker and Ambrose (1998), and OR, as a complex ranking method, has been discussed by Ojo et al. (2011). Fuzzy characteristics have been considered during the identification of PSC. Ng et al. (2002) established fuzzy membership functions based on fuzzy set theory (FST) to reduce uncertainty in the decision-making process. In line with the framework of Ng et al. (2002), Ive and Chang (2007) tested the application of a fuzzy PSS model in Hong Kong using the weighting data delivered by Cheung, Lam, Wan et al. (2001). Similarly, Li et al. (2015) developed a

framework for using unascertained mathematics to deal with fuzzy information and grey information. FST is used to analyse the quantitatively subjective uncertainty, and it usually works as a supporting tool in MCDA. For example, a combination of fuzzy set theory and multi-attribute decision-making has been developed by Mostafavi and Karamouz (2010). In this stage, therefore, FST is categorised into the MCDA group.

Six studies had developed a performance prediction model using regression techniques: Konchar and Sanvido (1998), Kumaraswamy and Dissanayaka (1998), Molenaar et al. (1999), Chan et al. (2001), Ling et al. (2004) and Doloi (2013). Among these, Konchar and Sanvido (1998) predicted project performance of DBB, DB and construction management with risk methods based on a comparison of cost, quality and schedule using a project-specific empirical study. In the same year, Molenaar et al. (1999) constructed a DB prediction model based on the classic linear model for DB project selection in the US. Similarly, Chan et al. (2001) identified six critical success factors influencing project performance and predicted the schedule and cost performance of 19 DB projects in Hong Kong. Ling et al. (2004) summarised and developed 11 models to predict the performance of DB using traditional regression techniques.

Multi-participant decision supporting techniques

The Delphi method solicits the evaluations of experts through a series of designed questionnaires that are used to arrive at a group consensus in a decision. Multiple rounds of the Delphi process were delivered to clarify and refine related PSC accordingly. The Delphi method has been used to calculate utility factors (Khwaja et al., 2018), and to assess the weightings of PSC for further AHP analysis (Austin et al., 2016). Its use in these two research studies infers that the Delphi method has been embedded in the process of other DSTs as a data collection technique.

Artificial intelligent decision-supporting techniques (AI)

The application of some DSTs, such as CBR, ANN and IM, is highly dependent on their users' experiences. In this review, CBR, ANN and IM are grouped under artificial intelligence (AI) decision-supporting techniques. CBR involves fuzzy characteristics and examines the complicated intrinsic interrelationships of procurement system criteria. It is not widely used in decision-supporting techniques in procurement selection; instead, it is generally adopted to examine whether the system is rightly established. Another knowledge-based technique, ANN, was applied by Chen et al. (2011) to predict which route was the best for a targeted project. However, ANN needs a huge amount of data information to run the system (Chen et al., 2011).

Information management techniques

DSTs are engaged to enhance trust between different parties and to encourage collaboration for procurement integration. BIM has drawn attention from practitioners and academics. A growing number of studies realise BIM is not only a digital software tool, but also a process for data integration across all lifecycle stages with a clear focus on inter-organisation collaboration (Lindblad, 2019). In the context of the studies, system/building information modelling has been undertaken to explain the omissions and errors of information with the aim to improve the quality of information (Love et al., 2017).

Under novel PSs, advance digital technologies allow decision-makers to have unique paths to identify and analyse broader information. Those paths include big data analytics (e.g. BIM) and information/knowledge visualisation (e.g. 4D, nCAD) (Sloot et al., 2019). The initial ideas were derived from the demand for process efficiency and effective communication. Furthermore, sprouted digitalisation and procurement integration have the potential to visually and automatically support decision-makers to identify PSC in diverse social and economic contexts. Meanwhile, DSTs such as transaction cost economics (TCE) and PESTLE support information integration at the early stage (Rajeh et al., 2015b).

4.3.3.2 DSTs in the PSS process

In earlier studies, researchers explored DSTs to analyse quantitative PSC. Those DSTs include MUV, AHP and RA. Essentially, MUV adopts a utility score that is ranked and summed, then the PS with the highest score is selected (Chang & Ive, 2002). Likewise, AHP breaks down a thorny PS decision into a hierarchy of sub-issues for objective ratings (Alhazmi & McCaffer, 2000). Based on a set of universal PSC and the experience of experts, these earlier studies explored the weights of PSC for an intended project and set benchmarks for PSC-PS interrelationships.

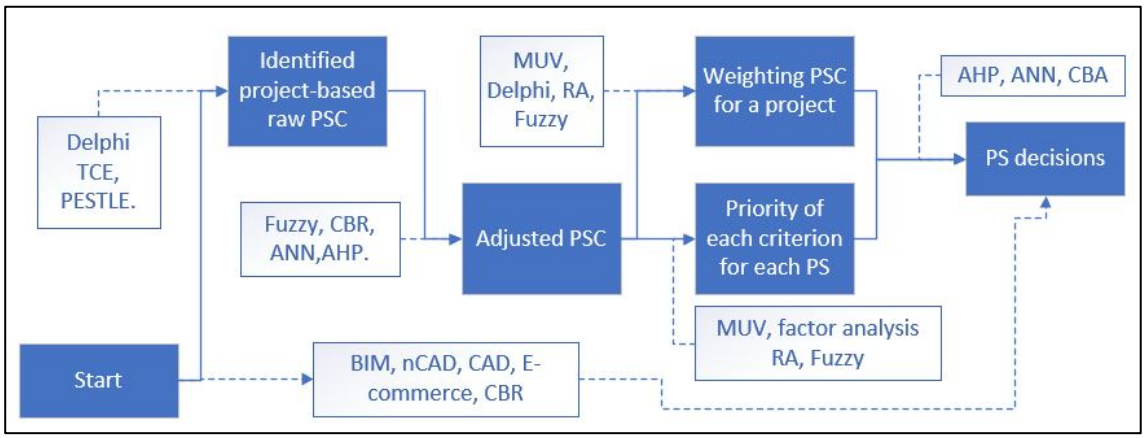
Later, numerous analyses have observed that procurement decisions are encountering linguistic fuzziness in nature, and this intrinsic reward was becoming essential. In the literature, applications of fuzzy logic and the Delphi method aimed at reducing bias at the information extraction stage. Furthermore, the absence of agreement around PSC and ongoing technological innovations in the construction sector complicate sound decision-making. For example, it is unusual even for those with expert knowledge to be able to determine the relevant factors for deciding a PS (Chang & Ive, 2002). Accordingly, TCE and ANN have been developed to produce a robust outcome. These DSTs enhance the quality of PSC, ensuring the objectivity of information at the beginning. The DSTs also ensure consideration of both qualitative and quantitative PSC.

Other studies centred on DSTs have explored the evaluation of more complicated data. Different stakeholders involved in a construction project often define their own objectives, and these may conflict with those of another stakeholder (Baiden et al., 2006). Recognising the shortcomings of traditional PSs, DSTs have been developed along with innovative PSs (e.g. PPP, alliance). This trend is visible in the literature, with DSTs to foster process innovation, information visualisation and knowledge management tools (e.g. BIM, CAD, AR and CBR). Furthermore, there has been a paradigm shift as traditional 2D drawings and paper-based documentation have been replaced by 3-D/4-D computer-aided efficient documentation (Lindblad, 2019). Occasionally, integrated and visualised information technologies such as BIM and AR have been widely promoted as

either valuable or detrimental in the construction field (Abd Jamil & Fathi, 2018). These DSTs have been suggested by researchers as ways to integrate information into PSS procedure.

Existing studies show that DSTs are used in parts of the PSS process (See Figure 4.10). However, few studies have focused on the issues encountered by practitioners involved in the whole PSS process. An example of such an issue is when the PSC have not been appropriately clarified for different parts of a project but are instead regarded as though the same PSC can be applied at all stages of the project. Another example is that a Bayesian decision maker will base their decision on the probabilities of different costs and payoffs, whereas Fielder et al. (2016) said the main criteria they would consider are the costs and impacts of different PSs. Furthermore, PS decisions may only be based on the present value of the inputs (e.g. AHP), whereas the results could be derived from the input annals (e.g. CBR). These different approaches imply that DSTs research is only meaningful if the comprehensive process of PS selection has been addressed.

Figure 4.10 Decision-supporting techniques used in the procurement system selection process



Despite the academic literature demonstrating that there are advantages in using DSTs for PSS, the techniques have some technical barriers that hinder their practical application. For example, fuzzy logic, RA, CBR, BIM are not user friendly – which probably explains why DSTs are not embedded in the whole

PSS chain. A further problem is that many organisations lack experience in the use of DSTs, which led Love et al. (2017) to suggest that training programmes may stimulate the adoption of DSTs. It is not surprising, then, to find that high training and time costs are the main obstacles to innovation in construction procurement.

4.3.3.3 Cognitive systems for PSC identification and PSC analysis

From the view of behavioural economics, there are two cognitive processes of decision-making (Piramuthu et al., 2012). As suggested by Patterson et al. (2014), I categorised the identified DSTs into two groups: the systematic and the heuristic approach. The *systematic approach* is a set of universal cognitive procedures that aims to effectively reach the optimum solution (Love et al., 1998). As a technique, the systematic process is fast and highly contextualised. Conversely, the *heuristic approach* focuses on human factors and our decision behaviours. Heuristics are viewed as a fundamental part of our brain's functions (Simon, 1997). Table 4.7 shows the characteristics of DSTs from the perspective of the two cognitive systems.

Table 4.7 The characteristics of DST 1 and DST 2

	DST 1 **Systematic approach**	**DST 2** **Heuristic approach**
PSC identification	a universal, holistic set of PSC; automatic Examples: AHP. MUV, e-commerce	Conscious ideas from experts; analytic and follows rules; prescriptive analytics Examples: ANN, BIM, Delphi, fuzzy logic, TCE
PSC evaluation	skilled experts' judgement; high contextualisation; past experience; descriptive analytics Examples: AHP, MUV, RA	depersonalised and decontextualized; cognitive capacity; slow Examples: ANN, CBR

Notes: See the List of Abbreviations for definitions of the above terms.

Systematic approaches are associated with expertise and expert judgement for PSC identification and PSC evaluation. The approaches are automatic and intuitive. In the corpus, AHP and MUV are the main systematic approaches for choosing a PS under a multiple PSC decision-making

procedure where the processes are systematically aiming at an optimal result. The difference between the two approaches is that AHP employs a pairwise comparison of PSC and alternatives, whereas MUV provides a non-hierarchical ranking process.

A PSS process involves multiple stakeholders, and their intentions can be varied. For this reason, it is impracticable to install a universal set of PSC for every circumstance (Luu et al., 2005Due to the complexity of the decisions that need to be made, analytical modelling has developed that uses scientific approaches such as algorithms and statistics. Delphi methods and fuzzy logic have been used to determine quality PSC for input into PSSs. Previous studies have explicated that the demonstration of fuzzy PSC functions is derived from experts' judgements (Chan, 2007; Ng et al., 2002), algorithms (Mostafavi & Karamouz, 2010) and chosen projects (Chao & Hsiao, 2012). Even though the PSS process is then produced by mathematical formulae, the fuzzy (and/or rough) function memberships and Delphi method were approached in a compound and nonlinear process. The findings from these studies infer that the Delphi method and fuzzy logic (and rough set theory) would not be seen as s a systematic approach when employing PSC to select a PS. Preferably, PSS should centres on decreasing cognitive biases through an undefined process that is primarily a function of heuristic approaches.

As PSS comprises various participants and modernising PSC, the techniques delivered a heuristic process which has been adopted in this thesis. Arnott and Gao (2019) noted that heuristics provide an assessment from initial values to the judgement of the final decision that is more depersonalized and requires significant cognitive effort, suggesting that heuristic approaches carry conscious and analytic approaches to dealing with PSC. It indicates heuristic approaches carries conscious and analytic approaches to dealing with PSC. For example, researchers in the corpus have assumed knowledge gained from prior projects to assist PS decisions (Hu et al., 2016; Luu et al., 2005; Mohsini, 1993). Reasoning processes like these are valuable as they elaborate on prior knowledge and can potentially contribute to the further development strategies (Plantinga et al., 2019). It is noteworthy that the reviewed papers reveal mixed results when viewed in terms

of cognitive systems. For example, ANN was used as a systematic mathematical algorithm by Kumaraswamy and Dissanayaka (2001) but applied as a knowledge-based reasoning approach by Chen et al. (2011).

4.3.3.4 DSTs users

The characteristics of decision-makers determines both the components of PSC and their choice of DSTs. Nevertheless, few papers (if any) in this corpus provide an explicit discussion on the DST end-users in the construction sector. In this research, the end-users of DSTs have been summarised into two groups: inexperienced users and experts.

Forty per cent of articles in the corpus agreed that DSTs aid inexperienced users in decision-making. Recognising that no expert understands all DSTs and the natural linguistic fuzziness of the information/data (Luu et al., 2006), extant studies have attempted to establish decision-supporting models to improve knowledge sharing and that are data-driven, which can objectively reduce human intervention. For example, Dzeng and Chang (2005) discuss the trend of investigating information online in construction procurement and create a learning paradigm to assist inexperienced users to capture the desired information. Furthermore, different economies and organisations have introduced guidelines that acknowledge the requirements of local laws and legislations in an attempt to standardise the procurement process. Likewise, players in the construction sector have worked on DSTs that formalise PSS and take into account the changing obligations of the sector and evolving digitalisation of the PSS process (for example, Abd Jamil and Fathi (2018)). These DSTs aims to establish and maintain a sound procedure that can obtain an objective decision, particularly for inexperienced users.

In contrast, some studies argue that the expert has a vital role to play in PSS, as the knowledgeable expert can determine the accuracy of the decision-making process as well as assess project performance. AHP is recognised as the conventional DST that requires experts' judgements for each criterion, while MUV is another DST that relies on input from experts. Recently, Plantinga

et al. (2019) produced the reasoning based on the expertise of the participants. As illustrated by Chan et al. (2001), the information solicited for determining a PS requires the decision-makers to have in-depth knowledge and experience in adopting various procurement systems. Likewise, data needs to be collected from experienced participants to enable modelling with hybrid methods such as the Delphi method, fuzzy logic and RA (Khwaja et al., 2018; Li et al., 2015).

Furthermore, the literature review has highlighted that it is challenging even for experts to make consistent PSS decisions. A PSS process involves a variety of participants which brings with it the challenges of human dynamics (Frada & Clyde, 2008). For example, what is important to one decision-maker may be considered irrelevant by another, and any group decision will almost inevitably differ from the individuals' separate choices. This is despite a diverse range of DSTs having been developed to meet the needs of different users and different goals. For example, comparative analyses by Rajeh et al. (2015a, 2015b) exposed that even PS decision-makers with the same purpose will have different evaluations of the PSs being considered. Rajeh et al. (2015a) indicated that a project manager, surveyor, engineer, architect and construction manager all played prominent roles in the PSS decision-making process that they studied, while Rajeh et al. (2015b) collected information from six project managers.

In an earlier study, Konchar and Sanvido (1998) stressed the users should have a certain knowledge of a specific DST as DST are not user-friendly techniques However, the literature review did not reveal any more recent studies into the user-friendliness, or otherwise, of DSTs. Recently, Hu et al. (2016) studied the use of CBR in construction management and confirmed that DSTs users seldom have sufficient knowledge of the CBR approach in practice. In their study on artificial intelligence, Chen et al. (2011) assembled data from people who had experience on related projects to formulate a nonlinear function between indicators and PS. Yet, the paper did not include detailed information about the participants.

Overall, there is a notable direct association between the expertise of the PSS decision-makers and the PSS outcomes. The expertise comprises two aspects: (1) the decision-maker's familiarity with DSTs; and (2) their experience in or knowledge of similar projects. Meanwhile, researchers have noted two key barriers that limit the implementation of DSTs: (1) the lack of consensus between PS stakeholders and differing PS experiences; and (2) the non-user-friendly nature of some DSTs.

4.4 A summary of research findings

The literature review identified 198 peer-reviewed journal articles which were then quantitively analysed to identify the key components of procurement system decision-making processes. A systematic review of these articles highlighted three key themes of PSS: *various procurement system*, *procurement selection criteria* and *decision supporting techniques*.

The articles in the literature review explored PS concepts at many different levels. Some addressed PSS at the macro-level (for example, Bruno et al. (2018)) while others at the project level (for example, Love et al. (2012)). Some articles considered the conditions for different project scenarios, while others focused on distinct stages of PS. For example, Eadie and McCavigan (2016) examined contract types, El Wardani et al. (2006) looked at contractor selection and Lo et al. (2018) investigated supplier selection. Each article showed a different understanding of PS, a finding that infers those different types of projects may need different PSs, and that fuzzy PS definitions cause misunderstanding. For this reason, the first step of the qualitative study in this thesis was to ask the interviewees to clarify available PSs in the context of New Zealand roading infrastructure projects.

Strings of subthemes in the key themes discussed how a decision would be reached involving complex factors at various stages in construction PSS. Table 4.4 lists 256 PSC that were identified in the literature review. This list gives a holistic view of PSC in the construction sector and could

contribute to the construction of PSS in terms of PSC database. However, the literature review also highlighted that there is no universal set of PSC, nor was there any no clear classification of the identified PSC. The following qualitative study, therefore, could focus on specific PSC classification in the context of New Zealand roading infrastructure projects.

DSTs have been recognised as core elements in the decision-making process. The findings from this quantitative research phase have revealed that the scope of research into PSS has extended in recent years to include a wider range of chain management and operation fields. The analysis has also shown that DSTs have been developed for informative decision-making. The analysis investigated DSTs from the view of current research status, roles in the PSS process, cognitive systems and the users of these techniques. The research findings indicate the significance of DSTs for choosing a suitable PS as the techniques can support decision-makers to work through PSC specific to the construction sector. Yet, despite their vital role in identifying and evaluating PSC, DSTs have received no attention since 2005. The research findings indicate the significance of DSTs for choosing a suitable PS as the techniques can support decision-makers to work through PSC specific to the construction sector.

5. CHAPTER FIVE: QUALITATIVE RESEARCH FINDINGS

Chapter Five presents the results of the semi-structured interviews with officials from public and government agencies, as well as consultants and contractors who work in the New Zealand roading infrastructure sector. The qualitative study intends to answer RQ2: How are procurement systems currently being selected in roading infrastructure projects in New Zealand?

The chapter is divided into eight sections. The first section discusses the administration of a pilot study and presents its results. How the main research was administered is then outlined in section 5.2. The following three sections present the findings about the characteristics of procurement systems in New Zealand roading infrastructure projects (section 5.3), PSS criteria that are used in these projects (section 5.4), and factors that influence and techniques used in choosing a PS in the context of New Zealand roading infrastructure projects. After that, section 5.6 and section 5.7 discuss the challenges in choosing a PS, and potential improvements to the current PSS process for roading infrastructure projects in New Zealand, respectively. A summary of the qualitative research findings is outlined in section 5.8.

5.1 A pilot study

A pilot study was required for this thesis for three reasons. First, a pilot study can present preliminary results that shape future work directions (Eastman, 2018). The aim of this pilot study was to ascertain practitioners' understanding of contemporary PSS and enrich the researcher's PSS knowledge in the context of New Zealand roading infrastructure projects. Secondly, a pilot study is a small-scale exploratory study that indicates a research's feasibility (Lee, 2019). This is done by reflecting on the lessons learnt during the pilot study and hence developing the research design for the more comprehensive study that follows. Thirdly, identifying the key players in New Zealand roading infrastructure projects was critical to ensure the main study would deliver

high-quality and accurate findings, and so a pilot study was conducted to clarify who the principal decision-makers are in the process of PSS in this context.

5.1.1 Research administration

Eleven interviews were conducted from May 2019 to June 2019. The interview question was: Who are the key stakeholders making the decision to New Zealand roading infrastructure PS? The suggested time for each interview was 20 minutes, but two interviews lasted between 30 minutes and 50 minutes due to the interviewees' eagerness to provide more detail. Two interviews were conducted over Skype, while nine participants were interviewed face to face. All the interviewees were coded and these codes along with the interviewees' profile details are shown in Table 5.1.

Table 5.1 Profiles of the interviewees

Interviewees' codes	Role	Organisation type	Years of Experience
PS-01	Procurement specialist	Public agency 1	25
PS-02	Procurement specialist	Government 1	22
PS-03	Project manager	Public agency 1	11
PS-04	Project manager	Government 2	11
PS-05	Procurement manager	Contractor 1	30*
PS-06	Procurement manager	Public agency 2	25
PS-07	Director/General manager	Consultancy 1	35
PS-08	Director/General manager	Contractor 2	11
PS-08	Engineer	Contractor 3	17
PS-10	Quantity surveyor	Supplier 1	12
PS-11	Architect	Consultancy 2	11

Note: * including 25 years' experience overseas

5.1.2 Research findings (key stakeholders)

5.1.2.1 The organisations

Clients and owners

All the participants from the contractor and consultancy sides highlighted the significant role of the client. More than half the contractor and consultant interviewees believe the chosen PS's primary aim is to achieve the client's need. "We will get the approved resource and discuss the delivery methods. Those procurement systems belong to strategic levels," said a contractor procurement manager (PS-05). Similarly, PS-03, a project manager who works for a public agency, said: "From a project manager view, I think procurement guideline talks about how we can plan a contract, implement the contract and monitor the contract. We just care about who we will work with and how to achieve their [the clients'] needs." PS-03's statement implies that clients are the essential stakeholders when determining the suitability of a PS. Indeed, it can be argued that PSs inherently service the development of modern construction and clients' requirements, an argument that is also consistent with the evolution of PSC. Many previous studies have mentioned that clients' needs are the main criterion when choosing the optimal PS (Luu et al., 2005).

Interestingly, the interviewees who work for government and public agencies said that one of their recent requirements is to involve professional people from other parties. The government side interviewees realise the benefits of collaboration at the procurement stage and discussed barriers to delivering a project alone. "For … projects above 5 million, we should determine whether it suits an existing panel, tier-one suppliers. Or we need to go out and multistage open market exercise," said PS-02, adding, "We need a collaborative team." All the interviewees who worked for a public or government agency mentioned the importance of other parties in delivering roading infrastructure projects, and they confirmed the trend of cooperation when choosing a PS. PS-04 stated: "If we allow the business units to drive the stakeholder relationship, they will only focus on their area, and they don't have the full visibility. We should take the lead and bring all

the business units together to meet the people. We share the knowledge, learn off from the suppliers and their value. We also raise it to a group level, meeting along with the public agency."

Consultants

Consultancy in terms of New Zealand roading projects comprises a wide range of organisations who can share industrial experience. A general manager from a consultancy firm said, "We could align New Zealand procurement practice with internal best practice, and we also foster more strategic procurement approaches for our clients" (PS-07). It was noticed that the role of consultants is to determine a PSS decision and encourage competition and innovation that would result in better solutions for sustainable requirements for the New Zealand market.

One consultancy expert, PS-04, stated his agreement with the Government's perspectives: "I understand the challenges of working in consultancy. Because big darkness [lack of experience] begins with the executive, which makes their job complicated. It is a big challenge to suggest a novel system."

(Sub)Contractors and suppliers

There were mixed results from the pilot study. Two government officials (PS-02 and PS-04) stressed the importance of contractor involvement at the procurement meeting from a strategic perspective: "The contractors will be highlighted when we have early engagement. It is exactly reasonable to find which is the best model or best industrial practice from the contractor. Then we can decide at the very early stage, on a mutual trust basis" PS-02 went on to explain that "The industrial experts mainly include designers and project managers." While the contractor interviewees espoused the need to consider current market conditions when applying novel PSs, they unwittingly eschewed the use of novel PSs. For example: "This is a need for strategic level. We just need to ensure we can achieve their [the client] requirement" (PS-08).

5.1.2.2 The roles

When asked about the key stakeholders in PSS, the interviewees held slightly different opinions. PS-06, from a public agency, said, "The procurement team mainly contains [a] project manager and our procurement specialist. Sometimes we need the designer to attend; that ensures our understanding of the design." However, PS-02, who works for a government agency, said that: "A procurement panel has one or two senior members, the project steering group members, project sponsors and technical experts. This is warranted for a big project." When a contractor may have been involved early for a sound business case, PS-02 mentioned they would invite industry experts to gain experience with their unfamiliar PSs. The interviewees' comments suggest choosing a suitable PS is a collaborative decision requiring experts from different areas. The various stakeholders involved want to bring different opinions to the decision-making table and take responsibility for project procurement considerations, particularly for a roading infrastructure project.

Procurement specialists

Procurement specialists are considered the most critical stakeholders in PSS as they provide specific procurement advice based on their experience and knowledge. PS-01 said, "This is our job/duty. I would recommend the most suitable PS for a project. Project to project are different." Ideally, procurement specialists should possess a healthy strategic mindset with extensive experience in managing procurement activities.

Project manager PS-04, from a government agency, stressed that a "procurement specialist will add value. They have a sound knowledge and understanding of the different models available." According to Love et al. (1998), there is no expert familiar with all PSs. Consultant and public agency procurement specialists involved in New Zealand roading infrastructure projects are responsible for the procurement models and contracts support and are accountable for achieving strategic requirements. For example, PS-03, from a public agency said, "I am working in

collaboration with the business stakeholders, providing procurement expertise and knowledge to enable the business to attain value."

Project managers and general managers

The project manager is a key stakeholder in the whole process of project management. The project manager performs multiple tasks from the planning stage to the turnover stage. PS-11, who is a consultant architect, described his role in PSS as "Working closely with the clients, knowing their needs, and forecasting the performance of each PS." PS-01, who is a procurement specialist at a public agency side and so has a different job scope, said: "I am leading contract selection, managing the delivery models, participating in the management of tenders, and co-ordinate crew resources in liaison with the construction manager." PS-04, who is a project manager for a government agency, confirmed the importance of project managers co-ordinating with their contractors and suppliers: "Sometimes we will probably have some supplier briefing sessions. We would get input from the industry, the project manager."

Technicians

With the evolution of PSs, collaborative PSs allow the involvement of technicians. All the manager-level interviewees recommended that technicians be involved as their attendance can positively improve successful project performance at the construction and operation stages. PS-04, a government agency project manager, emphasised, "Supposing you are in such a complex environment, and you want to tout constructability that is taken care of all aspects. The best way is to get the technicians involved in the procurement stage. They will show their ability. For example, in bridge construction, the technician could tell you to have a single span or double span. The ways will directly result in our benefits."

When the interviewees were asked to provide a PSS technician list, the results showed different ideas to those from previous studies. Engineers, architects and quantity surveyors have been noted

as the key stakeholders in determining an optimal PS in the construction sector (for example, Alhazmi and McCaffer (2000), Chan et al. (2001) and Smith et al. (2004)). However, the results of the pilot study indicate those roles from the contractor side would not be involved at any stage of the procurement decision-making process in New Zealand infrastructure projects. PS-9, a contract engineer, pointed out: "We are downstream of the whole chain. All of our technicians aim to ensure the project can be delivered to achieve the clients' requirements at the implementation stage." Instead, the designer was considered as technical experts. A consultant general manager, PS-07, said, "We need to meet the designer. The quality of the design may be questioned because the designers just sit in the office in front of a computer; they don't even know what is going on on-site." The interviewees confirmed that technicians are important in the implementation of PSs in the later stages of projects. The decision to include designers versus technicians could affect whether the chosen PS will successfully achieve the project's desired outcomes.

5.2 Interview administration

The pilot study had identified who would be best stakeholders to interview for the main part of the qualitative research project. The next set of interviews were conducted on a one-to-one basis between August 2019 and December 2020. The interviews were semi-structured, and the PSS-based questions were divided into two parts, as shown in Table 5.2. Each interview started with general questions about the characteristics of New Zealand roading infrastructure projects and the participant's role in PSS. The aim of these initial questions was for both the researcher and the participant to gain a more detailed understanding of the research context, which would then be used a basis from which to develop the conversation further. All the participants were encouraged to voice their individual opinions and share their organisation's guidelines when answering the Step 2 questions.

Table 5.2 Semi-structured interviews protocol

Structure	Topics
Step 1 – General questions	• organisational characteristics • role in PSS trajectory • characteristics of New Zealand roading infrastructure projects
Step 2 – General questions	• novel concept • understanding of PSS • transparency • guidelines • strategies for aiding decision-making • criteria for making a decision
PSS challenges	• achieving modern requirements • lessons learnt • novel PS adoption • techniques adoption • practical challenges
PSS improvements	• process improvement • techniques improvement

Signed informed consent was given by each participant before the interview began and all the participants were informed that they could withdraw from the study at any time. The data were collected using an audio-recording, and the participants were not required to give any written responses. Twenty-one in-depth interviews were held with participants from four types of organisations along the PSS chain. The detailed profiles of all those who participated in this second stage of the qualitative research are shown in Table 5.3.

Table 5.3 Profiles of the interview participants

Coding	Types of organisation	Roles	Responsibility	Experience
G1	Government	Procurement specialist	Investigation of EOI Develop strategic procurement	11
G2		Procurement specialist	Policy advisor Sustainable development Support project implementation	22 (including overseas experience)
G3		Project manager	Planning/scheduling Monitor cost, progress, and productivity Finance report analysis	12 (including overseas experience)
G4		Project manager	Contract management Estimating Project management	16
G5		Project manager	Technical inputs for business case Contract administration Implementation and management of resource	11 (including overseas experience)
G6		Project manager	Project management Monitor project process	5
G7		Technician	Technical design brief	21
G8		Technician	Engineering-based technical support	25 (including overseas experience)
P1	Public agency	Procurement specialists	Provide advice into procurement management Maintain risk management	25 (including overseas experience)
P2		Procurement specialists	Validate construction methodology Tendering documents support	8
P3		Project manager	Risk analysis Validate construction methodology Contract management Communication with stakeholders Project management	29 (including overseas experience)
P4		Project manager		22
P5		Project manager		35 (including overseas experience)
P6		Project manager	Coordinate on and off site resource Project delivery management End to end management	11
C1	Consultancy	General manager	Everything	36
C2		Technician	Structural design Special design	5
C3		Technician	Evaluate constructability Analyse risks	8
C4	Contractor	Project manager	Tendering and negotiating contracts Risk control	31
C5		Project manager	General manager	12 (including overseas experience)
C6		Project manager	Project management/site manager	4
C7		Technician	Technology-based support	6

The suggested length of each interview was 40–60 minutes, although this varied in practice. For example, five interviews lasted between 70 and 90 minutes, for two reasons: (1) two participants were eager to provide more details; and (2) three participants were initially reluctant to talk openly about PSS performance related to their organisational guidelines, although they soon felt comfortable sharing their opinions and experiences. In contrast, three interviews lasted just 30–40 minutes. It is understandable that the COVID-19 pandemic badly affected the participants' daily lives as well as their emotions.

Six of the participants refused to have their interviews audio-recorded, due to their concerns about confidentiality and ethics. As the New Zealand market is relatively small and few people could be considered potential interviewees, it was still valuable to obtain the ideas of these six potential participants, even given these constraints. As suggested by Love et al. (2008), note-taking was used instead to record these six interviews. Because I had learnt ultra-rapid note-taking when studying in high school, I was still able to record their comments accurately.

Importantly, most interview quotes have been kept in this thesis. Humble and Radina (2019) suggest that the reader may require more interview quotes in a thesis to judge the fidelity of the themes compared with the number of quotes in journal articles.

5.3 Procurement systems used in New Zealand roading infrastructure projects

5.3.1 Characteristics of New Zealand roading infrastructure projects

In response to the increasing number of complex construction projects and the overall strategy for roading infrastructure projects, the interviewees were initially asked to identify characteristics of roading infrastructure projects in New Zealand.

The characteristics of roading infrastructure projects in New Zealand identified by the interviewees fell into four groups: high capital value, complexity, multiple stakeholders and political issues. Table 5.4 shows how many of the interviewees agreed with each characteristic.

All the interviewees identified high value as a fundamental characteristic of roading infrastructure projects in New Zealand. “New Zealand market is relatively small. Normally the value of roading projects is more than 500 million,” stated G6. When I asked for a definition of “value”, interestingly, the interviewees offered mixed descriptions. Nearly two-thirds (13/21) of the interviewees said value is related to the size of the project. Since value management has been

discussed a lot recently (Kumaraswamy et al., 2017; Tran et al., 2017), 29% (6/21) of the participants stressed roading infrastructure projects have the advantages of contributing "value for money." Thus, there is no strict definition for *high value* in either theory or practice.

Table 5.4 Characteristics of New Zealand roading infrastructure projects

Characteristics	Frequency of identification by the interviewees
High capital value	21
Complex	20
Multiple stakeholders	13
Political issues	11

Complexity is a characteristic of roading infrastructure projects which has been identified in earlier studies. As the New Zealand market is very limited, all the interviewees have had experience working on megaprojects and medium-sized or small projects. All bar one (20/21) of the interviewees recognised that *complexity* is related to design, procurement, construction and operating the mega roading assets and services. In modern times, *complexity* also refers to the methods used in delivering the project.

When compared with medium-size projects, roading infrastructure project procurement involves *multiple stakeholders*. Although this study found that New Zealand has only a limited market depth due to a lack of suitably qualified and experienced competitors, multiple stakeholders are the primary component in megaprojects, particularly roading infrastructure projects. The interviewees confirmed the merit of using novel PSs in roading infrastructure projects. In particular, numerous stakeholders appear in the procedure of novel procurement activities such as PPP and alliance. As interviewee P3, a project manager for a public agency, stated, "There are only one or two contractors on the list, but they should perform on the procurement panel as we need the industrial experiences." Furthermore, most roading infrastructure projects could affect all people's daily life. C1, a general manager in a consultancy firm, said, "The roading

infrastructure projects in New Zealand mean the construction money [is] paid by taxpayers or will be paid by taxpayers."

The interviewees who worked for government and public agencies all noted the importance of projects meeting their political objectives, unlike those who worked in the private sector who did not highlight meeting political objectives as a key performance indicator. Public sector employees thought it was reasonable to manage. It was deemed reasonable to manage procurement selection with resources already available within the organisations, and that policies would guide the process, particularly for roading infrastructures. Procurement specialist P1 stated: "Political aims are always important for roading infrastructures because it is involved lots of money, multiple organisations and it may be last ten years from the planning stage to the final operation." In the context of practical works, G1, another public sector procurement specialist, confirmed that procurement selection is "heavily based on guidelines that have been customised to suit our business model. Roading infrastructures procurement is something in the government agency has done very carefully with a bit of caution. Because the property issue sometimes can be quite sensitive."

5.3.2 Definition of a procurement system

Before a suitable PS can be selected, the procurement systems that are available in the context of New Zealand roading infrastructures need to be clarified. As has already been noted in Chapter 2, there is no consensus in the literature on procurement classification. In the qualitative phase of this research, the interviewees gave a range of vague descriptions of PS, which is consistent with Love et al.'s (2012), "It is common for procurement systems, contract forms, and price determination mechanisms to be regarded as synonymous or inextricably related." It was observed that the procurement format is flexible and may concern a broader range of elements during implementation of the procurement activities.

However, recent innovate digital products such as BIM have not resulted have not resulted in the decision-making process becoming more systematic and explicit. One of the reasons for their lack of success is that there is no precise classification or definition of PSs. Therefore, the qualitative phase of this research is expected to provide a group of PS categories relevant to the New Zealand roading infrastructures context for further analysis. In essence, PSs can be classified under four themes: value management, price model, funding sources, and contract types. Within each theme are sub-categories, as shown in Table 5.5.

Table 5.5 Sub-category of procurement systems

Value management	Contract type	Price models	Funding
Value for sustainability	All-in-one	Lump sum	Public
Value for money	Design and build (construct)	Measure and value/ Reimbursement	Private
	Early contractor involvement		
	Alliance		

5.3.3 Value management

In line with extant studies, the interviewees identified value management as a core contribution to the construction sector. Eighty-one percent (17/21) of the interviewees believe that PPP is a crucial PS for achieving value in roading infrastructures. As stated by P3, “To my knowledge, the concepts of ‘best value’ come from PPP.”

The interviewees each had their own understanding of the meaning of “value” in the context of delivering New Zealand roading infrastructures. Two-thirds (14/21) of the interviewees described best value in broad terms, citing factors such as pre-qualification, low price bids, and value for money. Interestingly, five of the interviewees (G3, G8, P5, P6, C3) stated that “best value” is a weak description of what they are looking for in a procurement strategy. In their opinions, a procurement strategy is either a method combining a pre-qualification approach and the lowest-price approach or just selecting the lowest-priced bid, depending on the project size. For example, C1 said, “We don’t have a definition of best value procurement. It is not the case that it has no

clear value scope. Just as we recognise different people have different requirements, our first job was always checking the dictionary and ensured everyone in our team understood what work of scope was." P6 said best value is mainly about capital value or value for money. Meanwhile, nearly one-third (6/21) of the interviewees indicated that their understanding of value was highly constrained. For example, P2 stressed, "If you asked the 'value' in construction procurement, I do believe it just means capital value, or the project size. All rules were shown in the discussed contract." Thus, it would appear that stakeholders in roading infrastructures in New Zealand have only a vague understanding of what is mean by "value for money" and are unclear about the scope of the term "value".

Clearly, consideration of value is relevant to procurement at the strategic level. The interviewees who work for government agencies talked about sustainability concepts, which included social, economic and environmental values. For example, Auckland Council has targets related to reducing drivers of climate change, such as carbon reduction and construction waste recycling, and social targets such as aiming to have 15 per cent of the contractors' supply chain being Māori or Pacific organisations. G1, a government procurement specialist, defined sustainable value as "We procure today and result in the future". Government employees G1, G3 and G6 confirmed the sustainability values are considered when making procurement decisions and pointed out strategic level values that have been embedded in guidelines and policy. For example, G3 said, "We have recently rolled out a guideline: a 5% target to achieve employment opportunities, 5% of target for achieving direct engagement of local suppliers, and 5% of our spend are supposed to be direct engagement." The finding that sustainability values are now being considered in procurement system selection in New Zealand projects is consistent with findings of other studies in the literature review.

5.3.4 Contract types

The interviewees identified four sub-categories of contract types. First is the "all-in-one" or traditional type of contract. C1 explained the advantage of an all-in-one contract: "Easy to manage is the reason they consolidate all in one account. Contractor takes all responsibilities." Second is the design and build (DB) contract. DB has been widely discussed as a delivery method in previous studies. DB is sometimes referred to as D&C [design and construct] in New Zealand roading infrastructures, reflecting the implementation of DB in this context. P5 explained: "We call that [DB] D&C. Instead of choosing the designer, we ask the contractor to take the responsibility of working with a designer. They actually win or lose together. Therefore, D&C is really making sure that your design is 100% constructible. And it's really a construction lead." Third is early contractor involvement, or ECI, which is the contract type strongly favoured by Government agencies. G2 explained the process: "[E]arly contractor involvement is design in the long run. We engage the construction company early during the planning a scoping stage and get into a partner environment. We don't have that contractual relationship strictly but more a partner relationship to deliver the best outcome." G2 also explained the difference between ECI and DB: "ECI is a mechanism you use when you know that there could be some underground services. It means there are some inputs you want the contractor to provide as part of the design process." Globally, the most popular novel PS is public-private partnership, or PPP. Authors who have studied the level of client integration in PPP categorise this as a collaborative PS. In the context of New Zealand roading infrastructure projects, the industrial practitioners categorised collaborative PS as a type of alliance, whereas PPP was discussed from the aspect of a funding source. The interviewees said that alliance is the last choice of contract type. For example, G3 said: "I was involved in an alliance project. In a situation where the outcome is more important, timelines are tied. We need partners in delivering for such that, so we listed out all the rows, the timelines and the requirements. Auctioneering is done by assessing the advantages and disadvantages of each option. Alliance was the only delivery model we could achieve."

The four contract types identified by the interviewees would be viewed as delivery methods in the existing studies (Zhao & Ying, 2019). Traditional all-in-one, DB, PPP and alliance are the core contract types that represent the involvement of the stakeholders. The different contract types reflect how the contractor and client influence the implementation of procurement activities over the life cycle of a project. Yet, the role of consultants was not pointed out by the interviewees.

5.3.5 Price model

Plantinga et al. (2019) stated that traditional procurement systems (TPS) play a dominant position in the construction sector. However, the interviewees did not agree with this statement in the context of New Zealand roading infrastructure projects. Most of the interviewees (15/21) viewed "lump sum" as a pricing model. "Traditional lump sum has its inherent benefits for the horizontal projects, but we can't do the lump sum with roading infrastructure projects. Lump sum is only for the small and skilled projects," P2 stated. G1 has had 22 years' working experience in New Zealand and more than ten years working with government mega roading project procurement people. He explained, "We offer a measure and value, where the best [is] measured at the time of the design, which is out in the market. We are asking them to price for the purpose of tender evaluation." Furthermore, definitions of TPS in practical works are vague – the scope of the traditional system should be clarified. In term of price models and contract types, G6 and C4 called it "traditional lump sum", while P5 stated: "Traditionally, lump sum was the most preferred approach, [but] there are quite a lot of disadvantages in terms of lump-sum pricing." Meanwhile, P4, who works for the same organisation as P5, described the lump sum price model as a contract type: "Normally, a low cost with the low-risk project would be a traditional procurement system. Traditional procurement system where you will design completely. You will go out to market with a separate drawing, then they will price, and the price is locked, and that was a contract signed. In some case, they have a maintenance contract that is separated as well. This is a purely contractual relationship."

In the context of New Zealand roading infrastructure projects, nearly all the interviewees (20/21) had experienced the *measure and value* model. Measure and value is also called a reimbursement or a cost-plus price model. G4 explained why measure and value is a preferred contract type in the public sector: "Mainly central government organisations, they were going for a lump sum pricing, with a lot of risks attached to it. If we go out to market with a partially designed or with lots of uncertainties around a design, we will incur higher costs than what surely could be because they are assuming things and putting at risk premium."

5.3.6 Funding sources

When asked about their experience of implementing PPP, all the interviewees said they were not confident about delivering public-private partnerships. G1, G7, P3, and P5 emphasised they supposed the model is just about the money, with P5 saying: "I know we have to find a way to get that project built, not using too much of the public funding available, because most of our projects already got the funding approval before entering the procurement stage." Although project managers P4, P5 and G5 were keen to gain experience and knowledge about novel PSs, few roading infrastructure projects consider PPP. "Since 2016, we awarded a contract to deliver a PPP project. I think this is the second PPP for a mega roading project, and this is a second PPP project in New Zealand," said project manager P4, who works for a public agency.

In line with the Government report, it is sought that the current investments were reduced during the last five years. Government and public agencies have indicated this reduction is a temporary result of the novel strategies. They believe in the increasing trend of using novel PSs in the future. As P1 stated, "We still need to consider the private investigations very carefully. After those completed projects, I think we will have more private-funded projects for mega infrastructure projects." Interestingly, 85.7% (6/7) of contractors agreed that PSs should consider the public-funded or private-funded models. However, the contractors who were interviewed felt the private funding might not suit New Zealand roading infrastructure projects. For example, C6 stated: "I

am worried about the private-funded projects. The trust, the long-term and communications, particularly for the roading project, particularly for foreign investment."

5.4 Procurement system selection criteria in New Zealand roading infrastructure projects

The interviewees identified six broad categories of PSC for New Zealand roading infrastructure PSS: project risks, best value, price competition, complexity, stakeholder integration, political considerations, and organisational considerations. As there have been few roading projects to date and novel PS experience in New Zealand is limited, it is understandable that political consideration is a criterion. Surprisingly, it was organisational considerations that the interviewees most wanted to discuss.

The interviewees noted that roading infrastructure projects have high levels of complexity, and they had been encouraged by the commissioning agency to consider sustainable achievements (e.g. social, economic and environmental issues) through novel collaborative PSs. This is because the considerations associated with project risks and value management are totally different from those related to sustainable achievements, resulting in selection of different PSs. The following paragraphs list the main ideas from the interviewees about PSS criteria used in New Zealand roading infrastructure projects.

5.4.1 Project risks

All the interviewees emphasised the importance of risks, with 71.4% (15/21) stating that risks is the most important criterion when considering the suitability of a PS. For example, P4 said, "I think the criteria are the differences in procurement models. From my view, the difference is how you transfer risks or how you treat risks."

The interviewees identified four types of risk associated with roading infrastructure projects: *financial*, *operational*, *reputational* and *environmental*. However, they also provided solutions for dealing with these risks. For example, G3 commented: "The risk of reputational damage is higher. My confidence and expertise in the project now is very important for going [in a] smooth and controlled way", while G2 provided an example of environmental risk: "Underground geotechnical risks. What we do in a geo-tech investigation, we drill more holes to know the underground conditions. Then we will have a new price. But if we take too much time doing the investigation, it is not warranted."

Just as we all have different attitudes to risk, the interviewees had multiple opinions about the risks associated with different types of PSs. Some believe that novel PSs have inherent risk drawbacks, as stressed by P3: "It's unreasonable to ask the contractors to take all the risks without providing them all the investigative details. For example, transform the risks to the contractor market, which we don't know." At the same time, one project manager highlighted that risks are not all bad: "More risks mean we also have more opportunities. It helps us to have more communications with our stakeholders. It's okay for you to transfer most of the risks to your supplier if we all understand what will be happening."

Other PSC were raised and discussed when considering the risk of each PS for roading infrastructure projects, including the issues of price and responsibilities. For example, C1 mentioned, "With a long list of risks, sometimes it is hard to price those risks … So in reality, by doing that in a procurement plan, we price the financial risks. When something like this happens, we could know who is going to pay for the money."

5.4.2 Best value and price competition

Value for money is a common criterion when determining a PS. Value is an interesting word in procurement studies as sometimes it is referring to tangible factors such as budget, cost and price

competition, while sometimes it is used more in the sense of "adding value"; i.e. to improve intangible outcomes in the project management field such as efficiency and sustainability. Fifteen of the interviewees identified *best value*, and 13 discussed *price competition*. This section discusses price competition and best value together, as 10 of the interviewees mentioned the two terms at the same time.

Despite saying that value is a highly rated PSC, there appeared to be no clear understanding among the interviewees about what value in the procurement process actually means. Six stated that *capital value* is the only value referred to during the procurement procedure, but three others described *value* in relation to other terms, such as *price competition*. G6 stated, "We have social and sustainable procurement drivers. So we want to leverage our procurement, that we are working with our suppliers to deliver better outcomes at the same value and without much-added costs. Then we have the price competition." Interestingly, *value*, *cost* and *price* appear to have the same meaning in G6's statement. Indeed, more than one-quarter of the interviewees (6/21) pointed out that they cannot clearly distinguish the differences between these three terms.

Considering PSs and clients' changing requirements, G6, P4, C1 and C4 mentioned that sustainable values have attracted attention and become their recent strategic procurement choice. P4 stated: "Value for money was the traditional scope for procurement people, [but] we already moved away [from] this part. We aimed for sustainable outputs such as lean construction, climate change reduction … Social value is a part of the sustainable value." So it is evident that changes in value concepts in the procurement process have been addressed. From the viewpoint of public agencies and consultancy firms, "value" includes value for money, capital value and sustainable value. These conceptions of value have a direct impact on social and economic targets, as well as stakeholder collaborations. For example, P5 said: "What is a better name of value to me? Sometimes, it does not mean money. In one project, the value designed allows me to have project turn over soon; another case, it allows me to get money-back paths." Likewise, C5 commented that best value is not always about money: "Best value depends on the clients' requirements. For

government, best value means value for people involved, and for the taxpayer", and P3 pointed out that, "Instead we call it 'value for money'. I aimed for the relationships."

The ability to achieve best value from the traditional price competition approach was raised by some of the interviewees. For example, P2 highlighted that: "You're setting a stage by stage is just this one finished and then next to start. A wasting time happens because they need to pick up something from the previous one. And then, restart their own project's data set." Best value might be seen as fashionable, but the interviewees viewed best value as an essential criterion because it enables consideration of *non*-price competition. In this sense, best value can be viewed in terms of stakeholder relationships (noted by 13 of the 21 interviewees), sustainability (14/21), level of collaboration (17/21), constructability (9/21) and finance guarantees (18/21). Nearly a quarter (5/21) of the interviewees provided a detailed description of what value, and hence best value, means in the context of New Zealand roading infrastructure project PSC. However, none of those interviewed mentioned how the procurement process could support value creation and how value can be evaluated.

While the interviewees who work for public agencies clearly stated that they focus on non-price success, *price competition* was given the highest weight when evaluating the tendering process criteria. P2, P3, P5, C3, C4, C5 and C7 all pointed out that there is still too much focus on the lowest price, particularly during the pre-award stage. The interviewees agreed that novel procurement concepts help them to balance price with other desired outcomes, such as sustainable procurement and best value procurement. In contrast, P6 stated that price competition is the most important of the PSC: "Price is the most important in choosing a system. We do have different pricing models. It tells us how we can get money back." Interestingly, C3, who is a contractor, explained that: "Lowest price…they passed the pre-qualification stage that means they have met all criteria." Clearly, price competition is an essential criterion for all practitioners during the PSS process.

5.4.3 Complexity

Nearly two-thirds (13/21) of the interviewees noted *complexity* as an essential criterion in choosing a suitable PS. The complexity of mega roading projects influences capital cost. For example, C4 said, “The capital cost of more than 10 million is not suggested to go for a lump-sum contract in New Zealand because it is complex.”

P3, C2 and C7 also noted that the complex nature of roading infrastructure projects determines the choice of approaches and methods of procurement activities. P3 stated that the New Zealand market “is usually price-driven. But when you have a complex project such as mega roading project, under a complex stakeholder environment, it is probably a different story.” C4 stressed that “The infrastructure must be advertised to the public area.” C1, P4 and C6 argued that there are only two options for complex infrastructure procurements in New Zealand: measure and value, or alliance.

5.4.4 Stakeholder integration

During the PSS process, stakeholder integration plays a vital role that determines the outcomes of the PS. “Multiple construction sites will likely be operational at any given time on land owned by multiple organisational landowners”, project manager P5 said. He then added, “I personally really care about the people I would work with.” P5’s second comment is an example of why PSs have evolved here in the New Zealand market and overseas. The relationship between stakeholders has been identified as the most frequent term found in PSC, with nearly two-thirds (7/11) of the project managers interviewed stating that they believed stakeholder relationship has an impact PSS outcomes and long-term collaborations. At the same time, G2, a procurement specialist who works for the government, explained the importance of stakeholder relationships from a financial perspective: “We use a supplier relationship management with our top 20 suppliers, who would address about 60 to 70% of our spend. Our supplier relationship

management is at a very high level driven by procurement because we are a central team having visibility across procurement."

5.4.5 Political issues

In New Zealand, all policies align with the government's expectations that a procurement plan can be leveraged to achieve broader outcomes. Most roading infrastructure projects in New Zealand are government projects. Government procurement aims at promoting inclusivity, transparency and sustainability in the procurement process. In some cases, the principal legislative guidance for procurement is based on the Local Government Act or local public agency guidance. For roading infrastructure project procurement, there is very limited information to help a project manager to follow a particular procurement guidance. It is obvious that different organisations will have different desired outcomes for a project, which are reflected in their good practice guidance for procurement processes. In general, the interviewees who work for the government were more concerned about sustainability, and mentioned social and cultural PSC. For example, G1 said "In practice, all procurement in government should consider long-term benefits. We are now aiming at sustainability." G1 explained how they evaluate the conditions during the decision process: "For roading infrastructure projects, they are multi-techniques. We should consider human capability and social impacts. For example, if we go for benefit NZ$6, that means we would have two people involved, whilst we would have four people if the benefits into NZ$7."

5.4.6 Organisational considerations

Positioning yourself is essential in any decision-making process. When the interviewees were asked about PSC, those with different positions along the PSS chain provided different PSC descriptions. The interviewees' differing responses highlights the need to consider organisational issues in choosing a PS.

The Ministry of Business and Innovation has a principle of fairness to all people involved and ensuring that procurement practice in New Zealand remains flexible, productive and reflects global trends. Likewise, government agencies emphasise that the PSs chosen should be adaptable and stay relevant to society's changing needs, the economy and the environment. However, G5 said there is also a focus on local businesses: "We prefer NZ own brand. We encourage the local companies in our project, and they are more competitive." G2 explained how the organisational guidance influences PSS from a social aspect: "Indigenous procurement is absolutely a central part of the procurement process to impact eco-social benefits for New Zealanders, particularly New Zealand Māori." However, the contractors who were interviewed disagreed with the emphasis placed on social or economic value by government agencies, saying it is not competitive for the New Zealand mega roading project market. "As I said, we were only selling time, and we spent time on variations," commented C6.

5.5 Utilising strategies for New Zealand roading infrastructure project procurement decision

Chapter Four discussed how the strategies used in decision-making processes could aid PSC identification and PSC analysis. In this research, the strategies were used to: (1) objectively analyse procurement options, and (2) holistically provide information for decision-makers.

5.5.1 Decision-supporting strategies

Basic systematic data analytics techniques such as AHP and MUV were discussed in the interviews. "We should have a benchmark and breakdown. Then we have eyes on the details," said G2. It is worth noting that G2 agreed with the application of an analytical process and said that the first step in the analysis should be dividing all considerations into different sub-categories. The practice of looking at different sub-categories is also illustrated in G4's comment: "We'll consider the projects from different angles, and then we share ideas until we get a consistent answer. We give each criterion a weight. Some statements might substantiate some scores. Then

we sit in the meeting room. As all of us do ours separately, or write separately, or based on what we read, it is accepted to have different scores for each criterion." The interviewees' comments suggest that there is a systematic analysis stage that calculates the identified PSC and each score. To overcome the subjectivity of individuals' decisions, the interviewees stressed that they use a group decision-making process, with all who are involved going along with the rules and guidelines that are created.

The data collected from the interviews show that decisions around PSS in New Zealand roading infrastructure projects are mostly made based on identified PSC and by specialists with expertise in the field. It is worth noting that the interviewees said that if they were confronted with a new project in the current economic climate, they would opt for specialist options. For example, public employee P2 pointed out, "We have a procurement-specialists panel to cope with decisions in procurement procedures… complex techniques may not work." In a similar vein, the interviewees said that using experts is the primary strategy in implementing PSS as well as selection in the tendering process. As C6 said, "E-procurement may work on remote control and reach convenience for multiple geographic judgement, but the experts' knowledge still makes the decision." Therefore, PSS in the New Zealand market significantly rely on experts' judgement and subjective opinions.

Despite the apparent importance of expert knowledge, the interviewees demonstrated a range of attitudes towards procurement expertise. At the strategic level, G4, G5, P1, P2, P5 and C1 all confirmed the value of specialists during PSS. For example, P5 stated that "Techniques could help, but we need human input." At the project level, P2, P3, G1, G2, G3, C1 and C4 highlighted that there is a lack of experience of novel PS implementation in New Zealand, while P1, P4, P5 and C6 emphasised the value of "lessons learned" reports to guide decision-makers and managers of large projects. "No one knows everything. I don't think mega roading infrastructure projects can do copy and paste. It is still a challenge to provide a wise decision," C6 stated. This finding

is in line with those of previous studies (see Chapter 3) which highlighted the need for knowledge sharing, such as “lessons learned” guidance.

Another key finding of the qualitative research is that none of those interviewed used academic terms such as AHP, fuzzy or neural network to describe the method(s) they used. However, some of the interviewees were familiar with terms relating to innovative products and techniques. For example, C5, C7 and P6 mentioned BIM and its benefits and drawbacks, even though the researcher did not offer any introduction to BIM and related techniques. Nonetheless, the interview data suggest that process innovation techniques are still only anecdotal for many of the practitioners and they have not actually experienced their use. While nearly a quarter (5/21) of those interviewed were curious about how DSTs could improve their outcomes and a few (3/21) espoused the trend of DSTs adoption at the strategic level, none of the interviewees why DSTs are needed during PSS.

5.5.2 Information extraction and presenting

The interviewees were asked about their attitude towards the adoption of the techniques, which yielded interesting results. C3 felt there is a strong need to move from processed algorithms to using heuristic algorithms. Heuristic algorithms include fuzzy logic and knowledge-supported techniques. However, knowledge-based techniques are seldom considered let alone practised during PSS. The interviewees were comfortable with familiar processes, but undoubtedly, most (15/21) unwittingly eschewed the idea of employing decision analysis techniques in their PSS procedure.

Rather than focusing on decision-supporting techniques, the interviewees said it is essential to clarify the clients’ needs and identify related factors. Decision-making/-supporting practices and PSC have been separately addressed in previous studies. Currently, there is no (if any) method for multiple participants to share and exchange procurement knowledge during the procurement

decision process. As a result, PSC are updated only on a case-by-case basis. Likewise, there are no updated DSTs to evaluate the PSC and promote new ideas. As P3 stated, “We have a guide to identifying the weight of each criterion. That is not a problem. What we need is collecting more accurate information that covers the ground.” At the same time, the interviewees were open to adopting new techniques; for example, P5 said: “I may like to use a lot of algorithms to formulate the methods, to select specific elements to systems and solutions, and get them implemented. And, via your capacity, making sure that everything runs. So, at the moment, we’re looking at an AI system for analysing and evaluating. For a decision, it is a challenge but a good try.”

With respect to information-visualisation DSTs, BIM is being increasingly adopted by a wide range of decision-makers in the procurement process. However, public agencies in New Zealand inadvertently create barriers to adopting these DSTs. C1 and P4 said that BIM was expected to be able to solve all the problems around decision-making, but C2 and C5 warned that “BIM is not a panacea”. As opposed to the central role of data-driven technologies, C1, C5 and C6 said they expected augmented and virtually reality (AR/VR) will be adopted in the near future. However, most of the interviewees (16/21) were not sure if AR/VR can be executed in supporting procurement decisions in the New Zealand construction sector.

5.6 Challenges in choosing a procurement system

PSS is a process with stakeholders from different organisations and in different positions along the procurement chain. Thus, the issues encountered in delivering roading infrastructure projects should be analysed from different levels.

Previous studies have paid scant attention to PSS from the view of different organisations and individuals. The pilot study highlighted that stakeholders might experience the same PSS process but have a different understanding of a PS. For this reason, section 5.6 focuses on the difficulties that exist at both the organisational and individual level during the PS decision-making process.

Furthermore, while existing legislation and policies provide some strategic guidance, there are few detailed "lessons learnt" reports available to the public. This means the New Zealand roading infrastructure sector lacks experience in guiding project implementation. Therefore, section 5.6 also explores the challenges at the strategic and project levels.

5.6.1 Strategic-level issues

All those interviewed agreed that novel PSs can improve collaboration. A collaborative environment ideally promotes the possibility of choosing a novel PS from the strategic level. G6 stated, "We plan strategies for improving process efficiency, supplier engagement, and information visibility. We issue it through our public forum to get here, and we plan to release it as an infrastructure pipeline along with inputs of newly created infrastructure. So we give them prime market visibility of what's coming up in the next three years. They can plan and choose which areas they can, and they need to focus on and develop their strategy. This is what we called a collaborative environment." The requirements of a collaborative procurement strategy are essential for roading infrastructure projects, as noted by 7 of the 8 government sector employees who highlighted its importance in their interviews. It was also noted that strategic procurement plans should place a greater focus on collaboration. However, the majority (18/21) of the interviewees felt disempowered when working through non-traditional PSs. While sustainable procurement strategies, policies and guidelines give the practitioners a target in delivering novel PSs, the strategic procurement panel still relies heavily on previous experience. From the view of adopting novel technologies and novel collaborative models, practitioners stressed they lacked delated experience delivering various PSs and in wise decision-making when choosing a suitable PS.

Furthermore, no formal process can overcome an individual's reluctance to consider novel PSs from the strategic level. The data collected from the interviews inferred that if the participants

were confronted with a new project in the current economic climate and knowledge awareness, they would shun the unfamiliar and choose their traditional PS. For small and medium-sized projects, the traditional approach was deemed to be ingrained within the procurement implementation process. The interviewees also believed that it is not possible to fully implement novel PSs over the whole life cycle of a roading infrastructure project. G4 explained, “They will come to us when it is fully designed to go out the market. So we lose that opportunity to explore the options we have in front, whether that project requires an early contractor involvement, whether it needs to be awarded as a design and build, whether it should follow a full design to construction as a separate contract, whether you should pursue an alliance model, whether you should pursue a PPP model. Those options should be done up front when the requirements of the principles are developed.” G5 made a similar point about losing the opportunity to choose a novel PSs at the strategic level: “We were often losing that opportunity because we were not engaged … early enough. So it’s too late. It’s only one way to go.” Regarding funding of these New Zealand mega roading projects, there are no restraints or rigorous rules related to a preferred source of investment; that is, foreign or local. P3 and P6 both emphasised that a shift from traditional co-operation models to a long-term relationship between stakeholders would need considerable guidance and support.

The interviewees were keen to learn from others’ experiences and adopt the “lessons learnt” for the roading infrastructure PSS, but this could be problematic as information relating to PSS is not recorded and applied widely. Furthermore, after analysing the interview data through an academic lens, it appears the interviewees were only asking for information about the source of inputs – they did not mention seeking information about algorithms and DSTs. After translating their descriptions into academic languages, it has been sought that knowledge reasoning in interviewees’ perspectives may only contain the source of inputs, but algorithms were not included. G1’s comment “We would invite the specialists to the steering meeting” infers that current procurement decisions rely heavily on personal experience. Accordingly, practitioners in New Zealand prefer to look at and adopt methods from similar projects rather than extrapolating

that experience into general knowledge and cognitive systems. Another problem with relying on experts is that when they relocate, resign or retire, then their organisational knowledge is lost from the construction sector. Many interviewees (13/21) agreed that experience is essentially when choosing an acceptable PS. As suggested by P2, “How can we record the knowledge is fundamental and urgently needed.”

5.6.2 Project-level issues

Increasing the involvement of the private sector in roading infrastructure projects has two key advantages: 1) it can relieve the huge fiscal burdens that these projects place on the government, and 2) it can promote new technologies. However, as more stakeholders become involved, questions and uncertainty arise and projects are more likely to be delayed. C6 explained: “The delay sometimes happens because we have more than one specialist. We need to collect information. So, if one delays, the whole process will be delayed. Of course, everyone on the board tries our best to do the job, the goal and the deadline. Because the contract says so.” P5, C4, C6 and C7 also noted that uncertainty is encountered in their company at the operation stage. G2 stated, “We could provide more details about the distribution of the cooperation profits among operators, but we suggested the boundaries of the responsibilities of each party by our own experiences.” Love et al. (2012) stated that no single procurement system will suit all projects, and likewise, there is no one person familiar with all procurement methods. Despite in-depth analysis of the interview data, it is hard to judge how much personal experiences can contribute to PSS. Thus, it remains unclear as to how much information enhancement techniques alone can improve the quality of construction procurement decisions.

Asymmetric information between involved stakeholders negatively influences the choice of a suitable PS. The interviewees had varying opinions on the ultimate purpose of collecting information, innovative achievements and collaborative relationships. A roading infrastructure project typically starts with an exploratory investigation, using market consultants for the client’s

procurement plans and followed by different parties' involvement. The lack of a rigour and systematic PSS can result in asymmetric information between different organisations. For example, decision-makers at the strategic planning stage might be considering non-price attributes when looking companies to be involved in the project, but the downstream companies (e.g. contractors) might misunderstand the project's strategic requirements. Official government documents as well as comments made during the interviews by government employees indicate the public sector's desire to encourage more stakeholders to be involved in the project procurement process. Other comments made during the interviews, however, indicate that contractors have quite different opinions to those held by the people commissioning the projects. For example, C6 pointed out that price is still a critical factor: "Before starting the tendering process, we all have already known who were onboard. Price is still the most important advantage." Contractors C5, C6 and C7 did not believe novel PSs will useful in the future.

G1, G2, G8, P4, P5, C6 and C7 all stressed the difficulty in delivering a procurement plan without a detailed explanation of what is required by each practitioner at every stage of the project. Without a clear PSS process, misunderstandings arise which create barriers to delivering the project well. For example, C1's statement revealed that he felt disempowered when considering only project-level issues at what he thought was a strategic-level meeting: "The difficulty is how we operate it. I wouldn't have picked up more things if we are not sure the process and next steps." P1 was also critical of PSS, saying the process is unclear, which can result in delays to a project: "We need to consider the process carefully. We had a roading infrastructure project which used ECI, but changed to a traditional measure and value. I think we need more communications to explain our ideas."

The comments made during the interviews revealed that the practitioners confused about novel PSs and not confident about adopting them. This feeling was expressed by numerous stakeholders from different organisations and included adoption of novel PSs at all stages of the project life cycle. Nearly one-third of those interviewed (6/21) did not believe they needed to be involved in

identifying relevant PSC for a particular project or in the decision-making process. G4 stated, "All decisions are highly relying on the knowledge and experience. Our colleagues [procurement specialists] are professional. The process is simple and subjective. So I don't think I can make a wise decision." These results infer that project managers might not want to take responsibility for PSS. However, at the same time, they preferred that a familiar PS be chosen; that is, one from their comfort zone.

The interview data also revealed that many practitioners do not believe that the decisions made during PSS are objective. For example, contract project manager C4 suggested: "We are doing different jobs for procurement. People shaped variations, depending on the benefits of their organisation, not my side." Furthermore, nearly one-quarter (5/21) of the interviewees said that they haven't considered whether novel PSs bring benefits; instead, they felt novel PSs make their jobs more complicated, particularly for roading infrastructure projects.

5.6.3 Organisational-level issues

The literature review highlighted how behaviour and cultural changes are often needed to meet a project's desired outcomes. For example, Quinn et al. (1996) found that organisations that believe in experimenting with new cultures, disciplines and reward systems see these novel techniques as an investment that enhances social relationships. Consistent with earlier studies, this research into roading infrastructure projects in New Zealand has found that different organisations and different individuals seek different outcomes from a PS. The interview data suggest that contract technicians are interested in adopting novel technologies in the PSS process. C7 said "BIM is beneficial that can show more information." Although he then added a warning: "But that information may be not very powerful during the decision-making stage." Nearly three-quarters (5/7) of the contractors interviewed suggested that clients should be conscious of everybody's role in the process, then the information would be delivered as planned. Nonetheless, all bar one

(6/7) of the contractors said that government and public agencies still believe in their own experiences and experts' systems to calculate organisational risk.

PSS is complicated because there are probably few people or organisations who can clearly describe the decision-making process. Furthermore, there is often not a consensus within a company about the project goal, which results in different perceptions of what is the optimum PS for the project. Conflicts of interests and asymmetric information can lead to adverse selection, according to agency theory. During the interviews, some government employees described their role as being a bridge between the government, which commissions the project, and the contractors and suppliers who deliver it. For example, G2 stated: "We [the agents] in the project are required to make the decision on behalf of the government agencies; also, we need to understand the ability and requirements of the suppliers." However, the government employees also said they did not feel confident selecting a proper PS, saying although they were responsible for procurement choices relating to the roading infrastructure projects, they were struggling to implement different types of PSs. All the government employees were able to give detailed descriptions of the characteristics of different PSs during their interviews and could clarify how novel PSs can promote collaboration in the future, yet they failed to address a comprehensive and informed PSS process. G6 explained: "We will list all advantages and disadvantages of each PS on the table and make a decision. For example, compared to ECI, the problem is we don't really know how much the designer will take on board. For roading projects, the issue is you must be crystal clear as a client. So, we get a consultant to manage." Two conclusions can be inferred from the government employees' comments: (1) the Government has not focused on creating a PSS process for roading infrastructure projects, and (2) public agencies believe they have no responsibility in considering a completed process.

Two contractors, C4 and C5, talked about self-interest. They agreed that adverse selection might occur if there is no clear incentive, such as a guaranteed scheme. Legislation and guidelines that are not transparent and systematic can result in unclear processes and conflicts of interests among

stakeholders. For example, practitioners may be confused about applying existing laws and policies, and likewise, individual companies may be confused about their own rules and culture. Inconsistent policies could result in the PSS process carrying more legal risks for the practitioners, such as private investigators and consultant companies.

5.6.4 Individual-level issues

Knowledge and familiarity have been considered as essential skills when dealing with procurement selection. A common problem hampering the application of novel PSs is that practitioners are not experienced in selecting and structuring a rigour PSS process. Nearly one-third (6/21) of the interviewees were not fully satisfied with the expertise of other participants, with C2 adding that New Zealand should borrow from international best practice. The data supported these concerns as the interviewees' comments, especially the contractors', revealed that many of those interviewed lack basic understanding of novel PSs. The interview data also showed that one-third (7/21) of those interviewed focused most of their attention on implementing the project and exhibited carelessness at the planning stage. For example, C5 stated: "All we needed is to achieve the client's need" – a position agreed by all the contractors interviewed. Furthermore, it was clear from the contractors' comments that they do not clearly understand the suitability of novel PSs such as PPP. For public employees, the role of procurement specialists seems to be a panacea for all projects. P4 said, "You don't have to look too far to find where a public agency or a contractor could add expertise and value. We do have because of all the requirements from the communities. The public consultant department knows what it wants to achieve, and it absolutely offers a critical way to provide value for money for New Zealanders." While the importance of familiarity and a certain level of knowledge in PSs would undoubtedly be useful when choosing a specific PSs, the government employees' comments indicated that they would prefer to stay in their comfort zone. In fact, nearly one-quarter (5/21) of those interviewed were keen to discuss their unwillingness to apply novel PSs. C3 claimed: "The process is still new to

us, and it probably will stay at the pilot stage in the next ten years." Overall, the interview data imply that awareness of PSS and understanding of novel PSs is at a nascent stage.

More than half (12/21) of those interviewed recognised their personal lack of understanding and knowledge about the decision-making process behind PSS. Even so, attempts to improve the current PSS situation may not solve existing problems and may even cause unexpected consequences. For example, widespread adoption of DSTs would require training, which is costly in both time and money. Furthermore, implementation of novel PSs would increase the chance that inexperienced participants would fail. P6 stated: "We do need 'lessons learnt' reports, not only from similar countries, but also need the local experience", explaining that "Most standards are developed based on UK standard or AU standard, but we have our own situation." Indeed, advanced experience and knowledge are expected to be shared in the digital age. However, such a requirement can be challenging to apply in the New Zealand market because there is limited funding for these techniques in the construction sector and nor is there a lot of data about roading infrastructure projects available for analysis. P1 declared, "We are keen to explore an economical and effective way to gain knowledge and experience."

5.7 Potential improvements through decision-supporting techniques

At the end of their interview, each participant was asked to suggest improvements to the current PSS process. Many stated it is both important and urgent to be able to obtain information from the whole chain. They also noted that while the integration of stakeholders is expected in the modern construction environment, it is important that the decision-making process is rigorous, available for sharing and transparent to all the people involved. Finally, the interviewees gave mixed responses when asked about the possibility of novel techniques being embedded in the PSS process.

5.7.1 Knowledge sharing and visualisation

The interviewees confirmed the essence of knowledge visualisation of the decision-making process, particularly from procurement specialists side. Undoubtedly, procurement specialists take responsibility for determining the suitability of a PS. The findings of the literature review presented in Chapter Two indicate that the New Zealand government has made little progress building up PSS for the current economic market, whereas there is evidence of growing use of novel PSs overseas. Thus, international practice is initially influencing the choice of PS, and the overseas experience is giving procurement specialists more confidence in delivering successful projects. However, the problem is that procurement specialists do not attend all the procurement meetings along the construction management chain. Probably the participants expect that the procurement specialists have a rigorous understanding of the procurement process. P1 suggested, "Techniques would help us analyse the factors, but it cannot help all firms record the decisions across this project. We need visualised recording." Most of the interviewees (15/21) also highlighted that knowledge should be shared with all the people involved in the project. P6 said: "I wish [I knew] how the procurement specialists select the PS. I am not sure what the new procurement systems use for." For this reason, the proposed framework should focus on how to record and represent the knowledge used and how decisions were made during the PSS process.

Sharing knowledge also contributes to deepening organisational knowledge. The interviewees said that challenges arise because those making the PSS decisions have various levels of expertise and may also be expecting different outcomes from the procurement process. It has already been discussed earlier in this chapter how the actions of practitioners may play out differently at the individual versus organisation level. For this reason, it could be argued that novel PSs are not suitable for New Zealand roading infrastructure projects. However, the first way to solving the different goals in PSS is to share knowledge with everybody involved in the project – a point highlighted by project managers in each of the government, public agency and contractor fields (G1, C1 and P2). Sharing knowledge also builds resilience into the PSS process and mitigates against the risk of lost knowledge when a procurement specialist relocates, resigns or retires (as

stated earlier in section 5.6.1). Finally, the interviewees suggested knowledge sharing to reduce mistrust and asymmetric information between different roles and firms. G2 stated: "How to transfer the individual knowledge to the organisational knowledge is the most important step for the future works."

A procurement decision is a group decision and so knowledge has to be shared. Data from the interviews indicated that the PSS processes currently being used in New Zealand roading infrastructure projects are neither rigorous nor complete, which has led to decision-makers at different levels having only a vague understanding of procurement activities Official documentation shows that the New Zealand Government wants roading infrastructure projects to bring multiple and non-traditional benefits; for example, employment of those from the local community, or reducing the country's carbon footprint. However, the practical implementation of PSS processes that can address these expectations is proving problematic. Government employee G1 emphasised the importance of communication: "If you hope there's no bias, the best way is 'communication'", while contractors C4 and C6 suggested knowledge sharing and knowledge visualisation are important for group consensus. Their ideas are consistent with suggestions from previous studies that we need to consider how individuals can be encouraged to become involved in decision-making and what differences may exist between the groups' needs and individuals' needs. Despite the interviewees being notified of the possibility of enhancing expertise and knowledge sharing, the traditional approach might not precisely reflect the modern PSS. P3 pointed out: "The best is showing all knowledge at hand, from all involved people. It still needs to keep in mind with the group decision for roading projects." It can be inferred from P3's comment that the techniques adopted should consider the group decision during the PSS process, a point that has not been raised in earlier studies.

5.7.2 Transparent and updated information

Decisions made during procurement selection rely on experience gained from past projects, both in New Zealand and overseas. Thus, the current PSS process for roading infrastructure projects needs to be able to transfer that experience into knowledge in the system so that that experience/knowledge can be used to choice the best PS to match local needs. G2, P3 and C4 all said addressing the vagueness in the subjective decision-making process and the nature of construction projects would help when choosing a suitable PS. For this reason, it is essential to note that there exists a semantic difference when different participants use the term "knowledge." It is clear that the asymmetric information among various participants has resulted in knowledge-based DSTs and reasoning-based DSTs not being adequately applied. Therefore, to promote the understanding of novel PSs, there is an urgent demand for a platform that comprehensively displays updated PSS implementation knowledge and experiences.

Dada (2017), using behaviour decision-making theory, said cognitive biases might occur because of a lack of skills and competencies within a profession. This, in turn, suggests that the construction sector must overcome organisational and behavioural difficulties if the benefits of integration are to be comprehensively realised in the future. The interview data showed that the government sector is interested in exploring the use of novel PSs to ensure that its needs are being taken into consideration when planning roading infrastructure projects, but the contractors and public agency employees are worried about their contributions because of a lack of transparency during the PSS process. Therefore, transparency should be paramount when planning a PSS process for New Zealand construction projects.

5.7.3 Time and cost saving

Two-thirds (14/21) of the interviewees identified time and cost savings as the primary drivers for using DSTs. The consultants were keen to speed up performance and agreed that DSTs are a crucial attribute underpinning the smooth progression of PSS. C1, C7 and G6 pointed out that the

techniques are expected to improve the output quality. Past studies have shown that DSTs can reduce bias and make a process more objective. However, some of the interviewees warned that adoption of DSTs might increase implementation costs. C4 stated: “It seems very difficult to employ a complex technique considering enhanced cost and schedule uncertainty…we have limited resources to try new things that need trained employees, software, and training fees. It should be a huge cost for a project…”. Likewise, C3 stressed, “We need to balance the benefits of techniques against the budgets of using techniques.”

The contractors who were interviewed had opposite opinions to those of the public sector employees about how DSTs could be used. While the employees are not interested in techniques that support information extraction during the PSS process, the contractors agreed that using DSTs could result in significant cost and time savings. For example, C4 stressed: “It helps me to have the best information…it saves time and cost,” while C7 said that their company has “different formulate to set up information management technology…it is quite effective and efficient.” C5 revealed the different behaviours from economic perspectives, revealing the needs of DSTs at different levels.

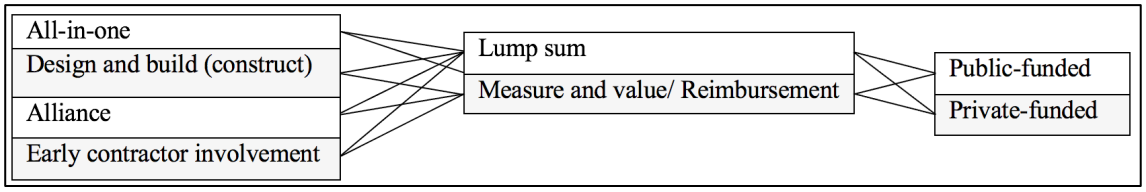
Half of the government employees (3/6) showed interest in adopting DSTs, but they also highlighted that human input is irreplaceable. Despite the evolution of ever-more-sophisticated DSTs in the digital age, human reasoning is still valuable and can contribute to a strategic decision. The interviewees stressed that DSTs have a role to play in the decision-making process, with P4 stating: “AI or high technologies could assist in collecting and displaying information. Considering long-term aims, it saves time and cost. But it cannot take place of human thoughts.”

5.8 A summary of the research findings

5.8.1 Main elements of the procurement system selection process in the context of New Zealand roading infrastructure projects

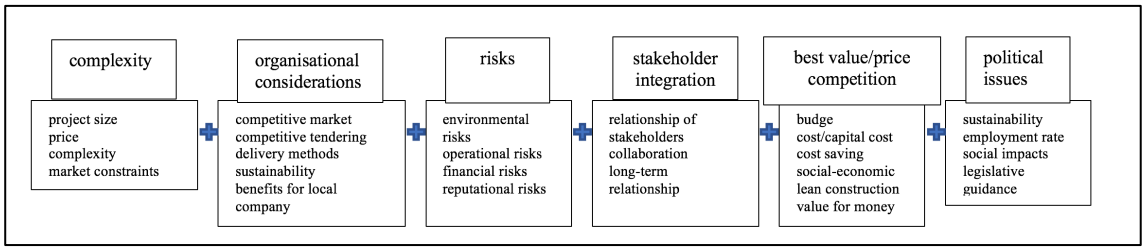
The *procurement system selection* process should be clear before starting the selection. Based on the documents and interview data, the procurement models in New Zealand construction sector consider four aspects: *value management*, *pricing modes*, *contract types* and *funding sources*. Figure 5.1 displays the possibility of *procurement systems* in the construction sector. According to the interview data, the lump-sum pricing model is not suitable for New Zealand roading infrastructure projects.

Figure 5.1 Procurement systems in New Zealand roading infrastructure projects



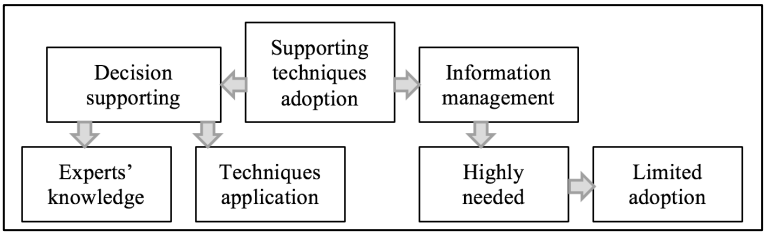
Procurement system selection criteria have been identified by key stakeholders in the New Zealand roading infrastructure construction sector. All those interviewed are familiar with the PSS process and have worked in roading infrastructure projects over the last five years. Six PSC categories were highlighted: *project risk*, *best value and price competition*, *complexity*, *stakeholder integration*, *political considerations* and *organisational considerations*. The sub-categories of each category are presented in Figure 5.2.

Figure 5.2 Criteria for choosing a procurement system for New Zealand roading infrastructure projects



Decision-supporting techniques have been comprehensively developed in the previous studies, although they are rarely adopted in New Zealand roading infrastructure projects. It has been suggested that DSTs are able to support the decision-making process and improve information management, as shown in Figure 5.3. Results of interviews indicate that the decision-supporting process needs to present experts' knowledge and apply related techniques. Information management techniques are also becoming increasingly important in this digital age, but, like DSTs, few are utilised in New Zealand roading infrastructure projects.

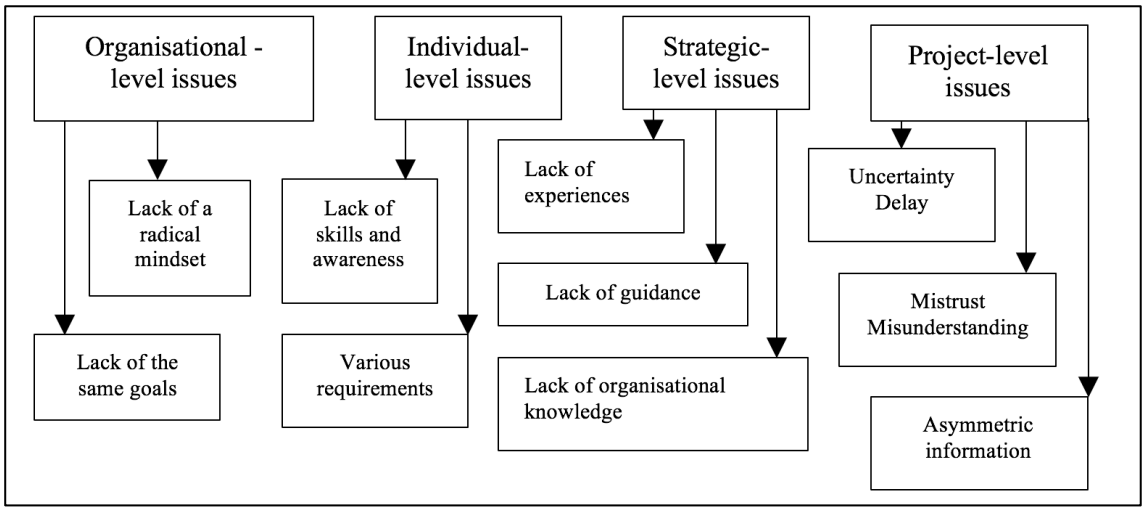
Figure 5.3 Techniques adopted for choosing a procurement system for New Zealand roading infrastructure projects



5.8.2 Challenges exist in current procurement system selection processes

The research data from the literature review and the qualitative interviews have addressed the PSS process from four different viewpoints: at the strategic level, project level, organisational level and individual level. In the context of New Zealand roading infrastructure projects, Figure 5.4 summarises the challenges that exist in the current PSS procedures.

Figure 5.4 Challenges that exist in the current procurement system selection processes



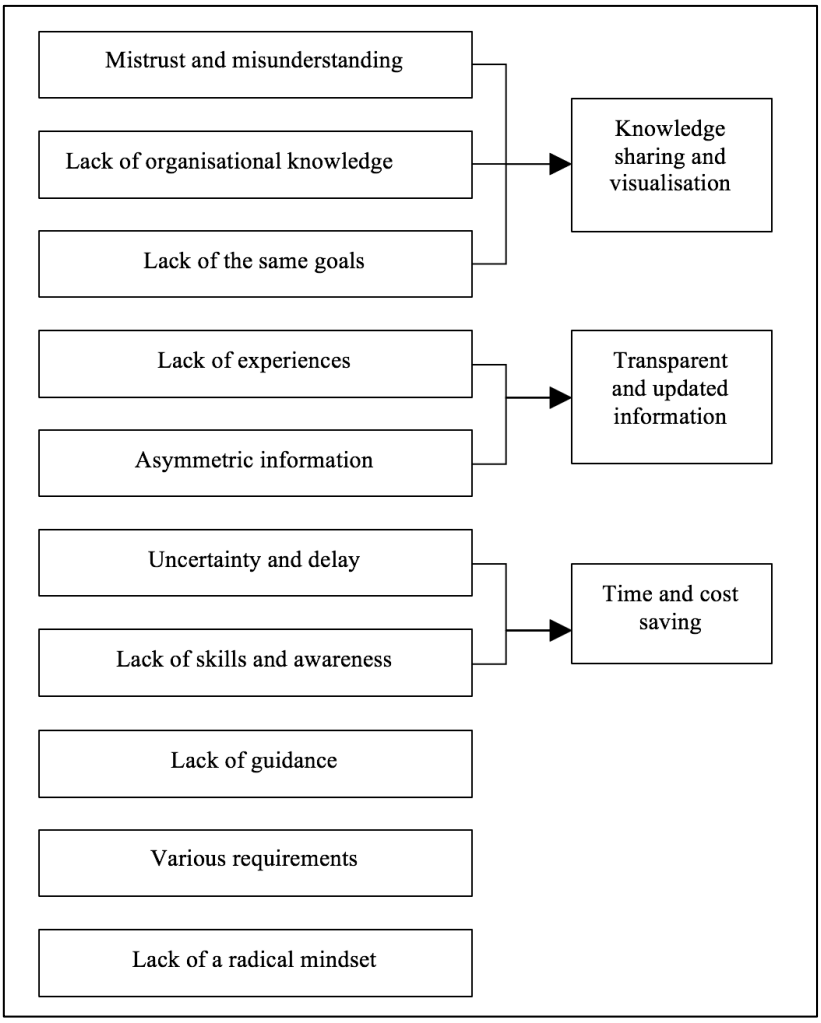
5.8.3 Techniques that support decision-making for PSS improvement

The interviewees suggested the following solutions to the challenges they currently encounter during PSS:

1. *Visualised and shared knowledge* would improve the stakeholder relationship through communication and making knowledge accessible. It would not only help to solve the problems around mistrust and misunderstanding between stakeholders but would also assist the decision-makers to clarify their goals. Last, but certainly not least, visualised and shared knowledge would enhance the transfer of individual knowledge to organisational knowledge.
2. *Transparent and updated information* is necessary for roading infrastructure PSS. It helps the participants to gain experience and obtain symmetric information from past studies.
3. The results show that the technique's adoption would save time and cost, help to avoid *uncertainty and delay* and improve the awareness of utilising DSTs.

Nevertheless, three challenges remain – *lack of systematic guidance*, *various requirements from participants*, and *lack of a radical mindset* – where the interviewees were not able to give solutions in the context of New Zealand roading infrastructure projects. Figure 5.5 displays a summary of the solutions that DSTs are expected to offer the potential improvements for procurement selection, as well as the challenges that remain.

Figure 5.5 Potential improvements in procurements system selection through adoption of decision-supporting techniques



6. CHAPTER SIX: DEVELOPING A FRAMEWORK FOR PROCUREMENT SYSTEM SELECTION

Chapter Six aims to develop a framework for PSS that can improve the quality of the decision-making process in roading infrastructure projects. Section 6.1 integrates the quantitative and qualitative research findings presented in Chapters Four and Five, respectively. Section 6.2 and section 6.3 introduce the fundamentals and tools and techniques used in the proposed framework. Finally, a framework for New Zealand roading infrastructure PSS is established in section 6.4.

6.1 Integrated findings from quantitative research and qualitative research

6.1.1 Procurement systems

The quantitative research results show that there is no consensus on PSs and suggest the need to clarifying related PS in the context of New Zealand roading infrastructure projects. Details of seven PSs identified in the context of roading infrastructure projects, based on the interview data, are presented in Table 6.1.

Table 6.1 Procurement systems used in New Zealand mega infrastructure projects

Procurement system	Mega infrastructure in NZ	Code
All-in-one + Lump sum + public-funded		
All-in-one + Lump sum + private-funded		
All-in-one + Measure and value + public-funded	√	PS1
All-in-one + Measure and value + private-funded	√	PS2
Design and Construct + Lump sum + public-funded		
Design and Construct + Lump sum + private-funded		
Design and Construct + Measure and value + public-funded	√	PS3
Design and Construct + Measure and value + private-funded	√	PS4
Early contractor involvement + Lump sum + public-funded		
Early contractor involvement + Lump sum + private-funded		
Early contractor involvement + Measure and value + public-funded	√	PS5
Early contractor involvement + Measure and value + private-funded	√	PS6
Alliance + public-funded		
Alliance + private-funded	√	PS7

6.1.2 Procurement system selection criteria

Using data from both the quantitative and qualitative phases of the research, New Zealand roading infrastructure PSC can be classified into nine groups. The final PSC in the proposed framework are presented in Figure 6.1.

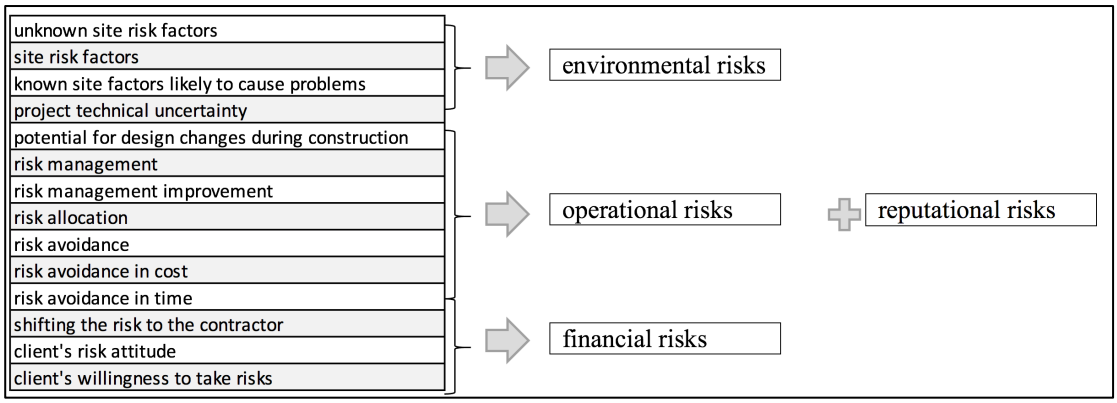
Figure 6.1 Procurement selection criteria used in New Zealand roading infrastructure projects

1. ROADING PROJECT CHARATERISTICS	Number	reputational risk	60	reduction in administrative staff	120	client's financial capability	180
1.1 project nature	1	**4. COMPLEXITY**		consultancy service	121	**5.6 client's experience**	181
uniqueness	2	**4.1 innovative methodologies**	61	client specify particular subcontractor	122	client's experience in procurement methods	182
size of project	3	BIM	62	**5.4 design control**	123	insitution and past experience of the decision ma	183
type of project	4	E-procurement	63	promote early procurement	124	client's project experience	184
project location	5	need for innovation	64	contractor input in design	125	owner's experience with similar projects	185
existing site condition	6	usage of pioneering technology	65	owner control over design	126	owner understanding the project scope	186
special weather and environmental concerns	7	technology availability	66	owner's willingness to control over design	127	owner's available personnel/human resources	187
project characteristics	8	technology feasibility	67	**5.5 coordination and communications**	128	owner's controlling role	188
1.2 cost	9	information at project inception	68	effective and efficient communication	129	**8. BEST VALUE**	
cost performance objective	10	**4.2 aesthetic building**	69	effective and efficient decision making	130	value for money	189
unit cost	11	aesthetics and confidence in design	70	working relationship	131	value engineering	190
project value	12	Effectiveness and constructability of the design	71	non-adversarial relationship	132	value engineering studies	191
project budget	13	client's requirement for aesthetic building	72	ease change incorporation	133	lean construction	192
financial arrangement	14	client's requirement for highly serviced or technically advanced building	73	5.6 long-term relationship	134	sustainability	193
financial guarantee	15	**4.3 complexity**	74	**6. POLITICAL ISSUES**		**9. OTHERS**	
life cycle costs	16	degree of project complexity	75	public accountability	135	**4.1 quality**	194
cost predictability	17	technical complexity of construction	76	policy and regulation	136	quality performance objective	195
precise cost estimate before contract signing	18	project technical complexity	77	political constraints	137	expected quality performance	196
expenditure rate	19	complexity of design	78	government policy	138	design quality	197
contract pricing	20	complexity of project	79	political impact	139	construction quality	198
maintenance costs	21	coordinate project complexity of innovation	80	regulation feasibility	140	consistent quality	199
the operation and maintenance cost	22	**5. STAKEHOLDER INTEGRATION**		regulatory and statutory requirements	141	highest quality for a given cost	200
client's requirement for within-budget completion	23	**5.1 flexibility**	81	regulatory impact	142	**4.2 schedule**	201
1.3 clarity of scope	24	flexibility in accommodating design changes	82	effects of relevant political, legal and economic systems and market conditions	143	design time	202
clarity of defined roles	25	flexibility to redesign after construction cost commitment	83	local design and construction regulations	144	pre-construction duration	203
well defined project features	26	expected levels of changes	84	employment rate	145	construction duration	204
scope change	27	**5.2 familiarity**	85	social impacts	146	schedule predictability	205
ability to define the project scope	28	familiar project condition	86	**7. ORGANISATIONAL CONSIDERATIONS**		schedule performance objective	206
clear user's requirement	29	familiarity and establishment	87	organisation objective or policy	147	time availability	207
feasibility studies	30	local familiarity and confidence in procurement	88	economic environment	148	time predictability	208
constructability analysis	31	knowledge of the strategy	89	project economic attributes	149	project time constrains	209
constructability studies	32	ability to make changes	90	commercial/investment reasons	150	the difficulty of facility start up	210
contract packaging	33	experience needed for a particular delivery option	91	external approvals	151	highly serviced or advanced building	211
number of contracted parties	34	previous experience on other procurement method	92	market attributes	152	**4.3 speed**	212
owner's involvement after award of contract	35	procurement method recommendation	93	market's competitiveness	153	shortest schedule	213
owner's level of construction sophistication	36	experienced contractor availability	94	material quality	154	time reduction	214
categories of client	37	contractor capability	95	market position	155	design speed	215
project ownership type	38	contractor's reputation	96	construction market development level	156	delivery speed	216
2. PRICE COMPETITION		competent contractors	97	labour productivity	157	construction speed	217
capital cost (lower)	39	performance of available contractors on similar projects	98	availability of information at project inception	158	tight project milestone or deadlines	218
control cost growth	40	potential contractor's management ability	99	availability of materials	159	speed of project completion	219
delay or minimize expenditure rate	41	potential contractor's project experience	100	availability of materials and equipment	160	early completion	220
owner benefits from cost saving	42	potential contractor's technical ability	101	availability of procurement system in the local market	161	fast tracking schedule	221
lowest cost for a given quality	43	potential consultant's management ability	102	benefits for local company	162	**4.4 certainty**	222
lowest whole-life cost	44	potential consultant's project experience	103	fashionable procurement method	163	cost certainty	223
owner's requirement for low maintenance cost	45	potential consultant's technical ability	104	**7.1 contractor capability**	164	certainty of final cost	224
3.PROJECT RISKS		innovation advice from consultants	105	materials availability	165	certainty of initial cost	225
unknown site risk factors	46	previous process used	106	nature and status of local construction industry	166	time certainty	226
site risk factors	47	enough experience to carry out the delivery option	107	allowance for competitive bidding	167	deliver on schedule	227
known site factors likely to cause problems	48	**5.3 stakeholder relationship**	108	industrial actions	168	control time growth	228
project technical uncertainty	49	specialisation and differentiation among participants	109	ease of application	169	schedule growth	229
potential for design changes during construction	50	collaboration among project participants	110	competitive tendering	170	client's requirement for on-time completion	230
risk management	51	designer contractor integration	111	protect confidentiality	171	**4.5 responsibility**	231
risk management improvement	52	degree of control	112	protect organisation interest	172	responsibility clarity	232
risk allocation	53	client's involvement	113	culture	173	single point responsibility	233
risk avoidance	54	client's trust towards other parities	114	safety	174	the clarity of delineation of responsibility	234
risk avoidance in cost	55	client's willingness to be involved	115	**8.3 client resources**	175	**4.6 disputes and arbitration**	235
risk avoidance in time	56	client's preference to control the project	116	client's business culture	176	dispute minimisation	236
shifting the risk to the contractor	57	owner involvement in project details	117	client's in-house capability	177	disputes	237
client's risk attitude	58	contractor and architect/engineer needs	118	client's in-house technical capability	178	claims and disputes between design and builder	238
client's willingness to take risks	59	consultant's staffing level to attend to contractor	119	client's management ability	179	conflict of interest	239

6.1.2.1 Risks

The qualitative analysis indicates 13 PSC related to risks. In addition to e*nvironmental risks, operational risks* and *financial risks* identified in previous studies, *reputational risks* were identified in the context of New Zealand roading infrastructure projects, and so this category was added into the database of PSC in the proposed framework.

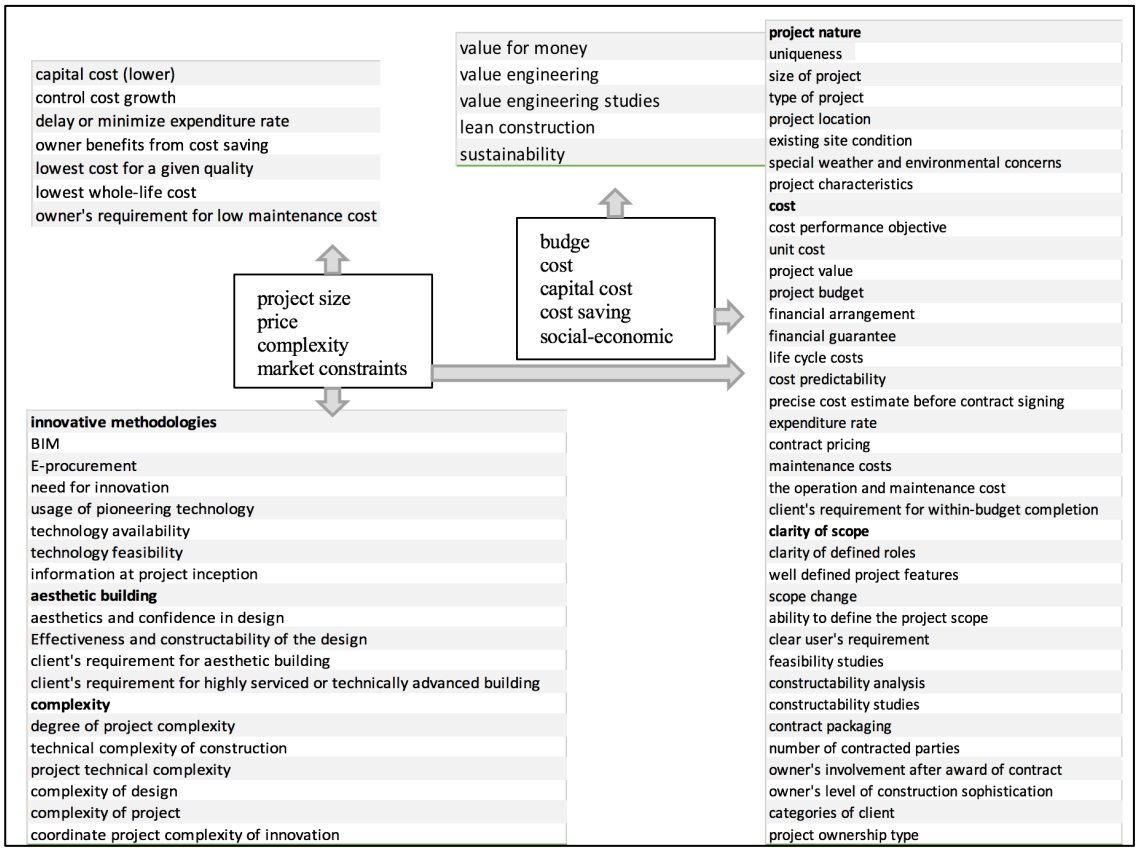
Figure 6.2 Comparative analysis of existing studies and the empirical studies (risks)



6.1.2.2 Price competition, complexity and best value

The three PS criteria price competition, complexity and best value identified in the qualitative analysis (interview data) are consistent with the criteria identified in the quantitative data (from the literature review). Figure 6.3 displays the detailed PSC related to price competition, complexity and best value.

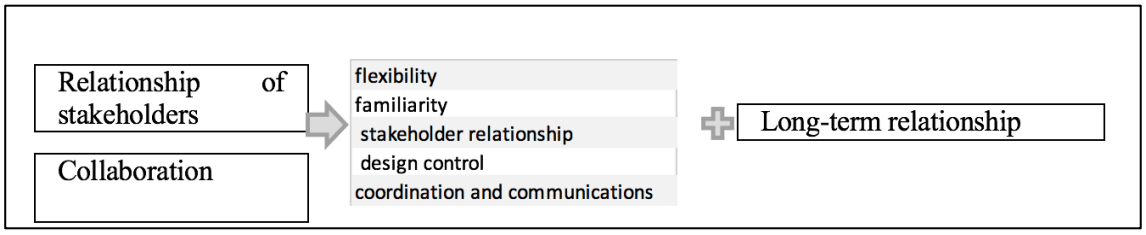
Figure 6.3 Comparative analysis of existing studies and the empirical studies (project size/complexity/best value)



6.1.2.3 Stakeholder integration

Relationship of stakeholders, *collaboration* and *long-term relationships* were explored in the qualitative study. The quantitative study examined *flexibility*, *familiarity*, *design control*, *coordination and communications*, and *stakeholder relationship*. *Long-term relationships* has not appeared in previous studies and so was added to the database, as shown in Figure 6.4.

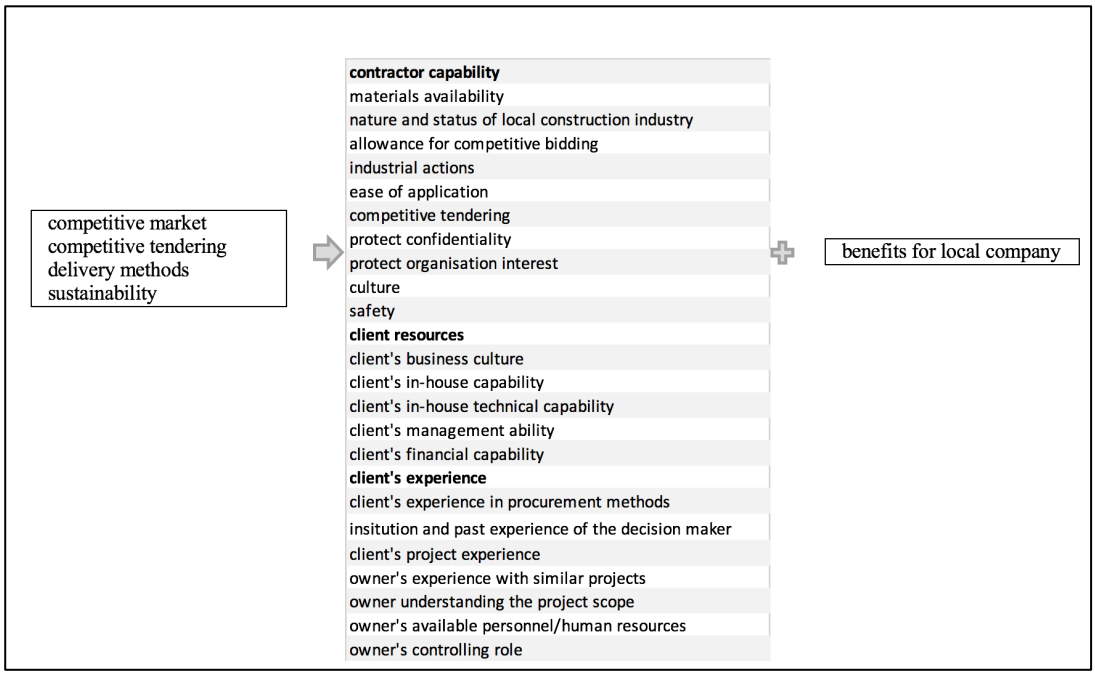
Figure 6.4 Comparative analysis of existing studies and the empirical studies (stakeholder integration)



6.1.2.4 Organisational considerations

As PSS involves many stages and multiple organisations, PSC need to be considered from the roles of organisations in the decision-making chain. The qualitative research identified that *competitive market*, *competitive tendering*, *various delivery methods*, and *substantiality* represent the main criteria of PSS. These PSC can also be found in the results from the literature review. One new criterion, *benefits for a local company*, was added to the database, as shown in Figure 6.5.

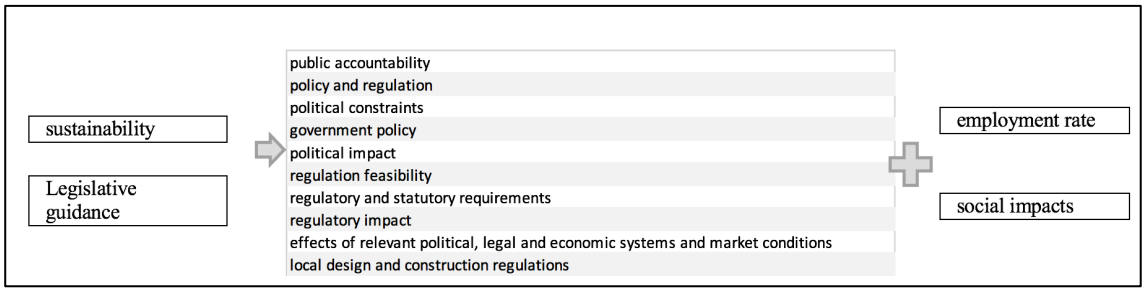
Figure 6.5 Comparative analysis of existing studies and the empirical studies (organisational considerations)



6.1.2.5 Political issues

The quantitative study found few extant studies discussing *political issues*. However, the qualitative research highlighted the importance of *political issues* in roading infrastructure projects. Apart from *legislative guidance* and *sustainability*, the analysis of the qualitative data also identified *employment rate* and *social impact* as the main PSC for PSS selection. As shown in Figure 6.6, these two PSC were not identified in the quantitative research data.

Figure 6.6 Comparative analysis of existing studies and the empirical studies (political issues)



6.1.2.6 Others

It is interesting that although analysis of the literature suggests that PSC have already started to evolve overseas to meet the changing requirements of the modern construction sector, few of those involved in New Zealand roading infrastructure projects identified widely used PSC during their interviews. Criteria such as *schedule, speed, quality, certainty and disputes* were not identified in the qualitative results – although this finding does not mean these PSC are less important or irrelevant to a project's success. It is important that the special characteristics of roading infrastructure projects are considered as PSC as the choice of the final PS is strongly influenced by the type of project being undertaken. In this framework, therefore, a comprehensive database of roading infrastructure PSC (nine groups) is identified, as shown in Figure 6.1.

6.1.3 Strategies for procurement system selection

Analysis of the interview data revealed that only two DSTs – MUV and AHP – are currently used in PSS for New Zealand roading infrastructure projects. Based on the current situation and issues identified from procurement activities in this context, three solutions are proposed to support PS decisions.

A transparent process with updated information techniques is critical for the decision-making process for roading infrastructure projects. The research findings highlight the lack of experience among practitioners and the need for expertise in roading infrastructure projects. The proposed

strategies aim at improving accuracy of information needed for quality PSS decision-making. Linden et al. (2017) noted that there is widespread agreement that tools need to be developed to support wide decision-making. Construction innovation literature has explored innovative approaches into building on experts' experiences. Traditionally, decision-supporting systems have been specific to a particular industry and/or method (Frada & Clyde, 2008). Decision-supporting systems align available knowledge and skills and embed them within an organisational entire-network relationship to pursue a win-win situation through sustaining superior performance (Li et al., 2015), achieving a social and/or economic goal (Rua & Alves, 2020), and improving positive relationships between stakeholders (Khalfan et al., 2007). In the construction context, process innovation comprises technology-based innovation, focusing on performance efficiency and effectiveness, and radical (organisational) design, focusing on the people's behaviours and mindsets (Akintoye et al., 2012). Those contribute to reducing risks and uncertainty by creating immature prototypes to more consolidated market resolutions or transforming emerging prototypes into articulated answers (van Winden & Carvalho, 2019). Therefore, the first purpose of the proposed framework is to produce an informed and transparent PSS process that enables the latest information from a roading infrastructure project to be represented and updated from the participants' experiences.

Quality decision-making around PSS for roading infrastructure projects is enhanced when knowledge is shared and visualised. Indeed, digital marketplaces and innovative tools have played meaningful roles in cultivating organisational innovation (Matthyssens, 2019). Building on a systematic procurement process, the chosen PS is based on the tenet that risks are minimised or eliminated when information is effectively used, or more precisely, shared. That is to say, the more information available and the better this information is utilised, the better the future can be predicted, with fewer reactive decisions having to be made (Bruno et al., 2018). The research findings emphasise the importance of sharing information by recording both individual and organisational knowledge. The interviewee data also revealed mistrust and misunderstanding in the PSS process in New Zealand roading infrastructure projects, which further highlights the need

for the proposed framework. By focusing on developing a shared platform to share communication of effective PSC and practices, and then visualising the knowledge and experience of procurement experts and the decisions of each step, the proposed framework will enable a transparent and fully informed PSS process. The framework's transparency and its combination of shared knowledge and experience can also be expected to reduce conflict, while its knowledge-sharing platform will enhance organisational knowledge.

The interviews with those who work on New Zealand roading infrastructure projects showed that industry practitioners are interested in using DSTs to select PSs although there are some challenges to the implementation of such techniques. Decision-making theory identifies conflicts of interest, asymmetric information and self-interest as barriers to quality decision making. Analysis of the interview data indicated that people working on New Zealand roading infrastructure projects are not familiar with DSTs, a finding that is consistent with the quantitative data from the literature review. These findings suggest that implementation of novel PSs is being hindered by a lack of knowledge about DSTs and the high costs of training decision-makers in these innovative techniques. Previous studies have also highlighted that most DSTs require the users to have a high-level knowledge of DSTs applications. This is a significant challenge in the New Zealand context because there are currently few project managers and procurement specialists who have experience in both roading infrastructure projects and theoretical decision-making techniques. Consequently, the proposed framework needs to allow for users who may have only basic knowledge about the capability of different PSs. It is also important that the framework is user-friendly as many of the decision-makers using the platform will be novel users of DSTs. A user-friendly platform will not only save cost and time but also improve the framework's usefulness in practice.

Policy and legislation are drivers for change in procurement-related systems (Wondimu et al., 2020). Some of those interviewed in the qualitative phase of this research claimed that the difficulty in PSS arose from legislative constraints, with some even going so far as to say a

suitable PS is not decided by its high-value or sustainable outcomes but by the legislation. Clearly, the interviewees believe that the guidance relating to roading infrastructure projects in New Zealand is not mature, and there is a need to select a suitable PS in an informed manner. PSS is complex and involves various stakeholders, with multiple decisions being made at different levels and stages by different groups. For this reason, the interviewees stated that variations and subjectivity appear throughout the process. For example, contractors interviewed as part of the qualitative phase of the research did not discuss sustainability as an essential criterion for PSS of government projects. Therefore, PSS should be designed into a dynamic process that considers the role of participants and the decisions made by different individuals. The Delphi method has been analysed by academics as a technique that surveys a panel of experts in order to reach a group decision; however, few projects use the Delphi method in practice. None of those involved in the interviews provided suggestions, guidance or solutions that might improve current PSS processes. From my personal experience, I agree that the procurement decisions are strongly influenced by the legislation and policy, and that the decisions made change continuously and dynamically, determined by various requirements. The proposed framework intends to offer a dynamic decision-making process that can guide and support informed rigorous decision-making in PSS for New Zealand roading infrastructure projects in the future.

6.2 Fundamentals of the framework

This section introduces the fundamentals for establishing the PSS decision-making framework. The framework will include three theoretical considerations: decision-making techniques, knowledge visualisation, and cognitive computing.

6.2.1 Decision support techniques

6.2.1.1 Decision-making for procurement system selection

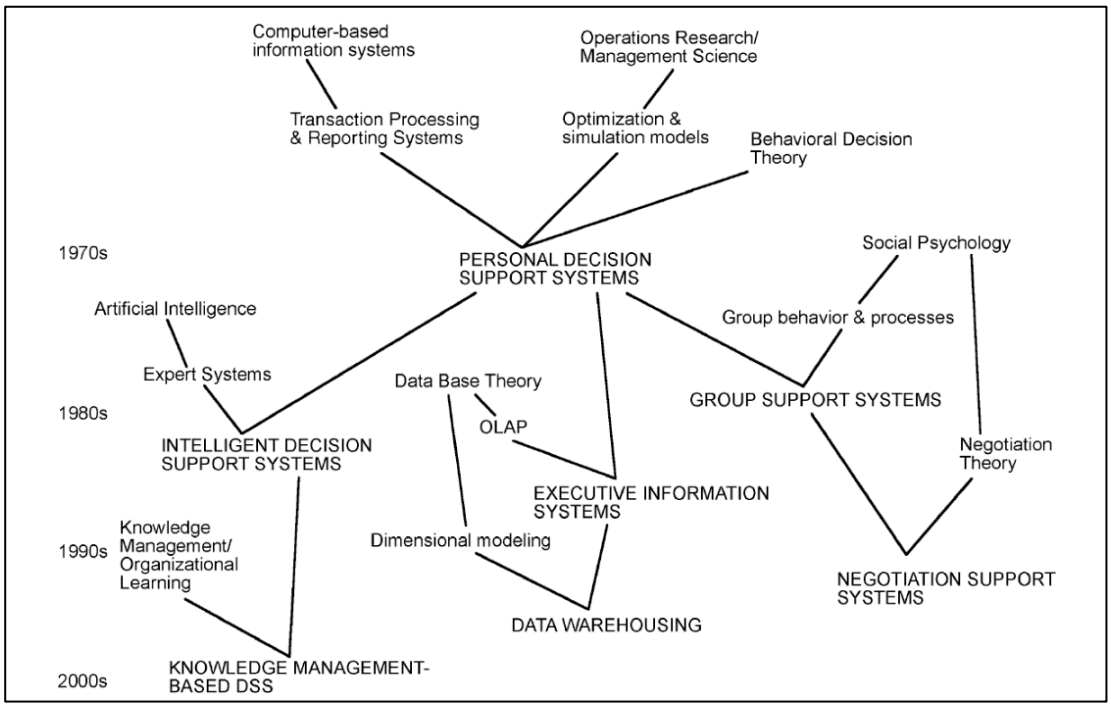
The overall purpose of the PSS process is to select a PS that satisfies the criteria of multiple stakeholders, both individuals and organisations. Infrastructure projects involve many more

participants than medium-sized and small construction projects do, and so the procurement process is multi-faceted and complex. Previous studies have tried to summarise a universal set of PSC, whereas the New Zealand practitioners interviewed in the qualitative part of this research said that PSC should consider the specifications and characteristics of the individual project. For example, overseas studies have listed *quality*, *schedule* and *speed* as important PSC for roading infrastructure projects, but the New Zealand participants in this research did not rate these three criteria as being very important. The mixed results probably indicate that there are multiple PSC, and different combinations of these would suit different projects. The findings also suggest that identifying a single set of PSC would not solve the challenge of subjective decision-making during the process of PSS. Furthermore, PSS in New Zealand roading infrastructure projects is neither an individual decision nor an optimally algorithmic process. The interview data revealed that PSs in New Zealand are often selected by a steering group that includes procurement specialists, project managers and technicians. Furthermore, the group members often change from the planning stage to the delivery stage. This finding highlights that both organisational and individual opinions influence the final stage of a project, and that the PSS process is dynamic and complex.

Every decision has hidden within it a guess about the future. As shown in Figure 6.7, DSTs have evolved since 2000, to reach the era of knowledge management-based systems. Considering the complexity in New Zealand roading infrastructure procurement selection, the proposed framework intends to provide a holistic picture of the procedure that mainly relies on the participants' knowledge. Frada and Clyde (2008) suggest that expertise depends not so much on the intrinsically stronger power of analysis as on a store of structured knowledge. Inspired by this, the framework with integrate the complex process of PSS decision-making with a systematic system for knowledge-building. It will include techniques and PSC that will help individuals to understand and analyse their decisions. Specifically, the framework will enable the participants to record their individual decisions about PSC and chosen weighting of their PSC, along with the

DSTs they employed. Thus, the framework will allow practitioners to draw on their individual knowledge gained from their work history and display their understanding of PSS.

Figure 6.7 The evolution of decision-supporting techniques



Source: Frada and Clyde (2008).

As there are multiple stages and stakeholders involved in roading infrastructure projects, a PS decision is made in a complex environment that encompasses a price model, a type of contract, the funding source and values-based desired outcomes. What typically happens is that a change works for short time but then the problem returns larger than before. For example, in the context of New Zealand roading infrastructure projects, the public agency practitioners might change the delivery method at the procurement stage because they lack experience implementing novel PSs . For this reason, this thesis intends to build up a process of a dynamic framework. As suggested by Cortez and Johnston (2019), the decision might be fittingly described by our existing vocabulary that needs a dynamical system setting into a stable procedure. Therefore, to determine a PS decision in an immature market, it is necessary to develop a dynamic decision-making process.

6.2.1.2 Techniques for PSS

For a roading infrastructure project, the quality of the PSC is extremely important. The qualitative study confirmed that roading infrastructure project PS in New Zealand is determined by a group. Given that the decision-making process can be vague, Delphi methods and fuzzy logic will be employed in the proposed framework. The literature review identified that fuzzy PSC functions are derived mostly from experts' judgements (Chan, 2007; Ng et al., 2002,), algorithms (Mostafavi & Karamouz, 2010), and chosen projects (Chao & Hsiao, 2012). Even though the PSS then is produced by a mathematical formula, the fuzzy (and/or rough) function memberships and Delphi method were approached in a compound and nonlinear process. As a qualitative process, these two approaches could assist participants to better understand the nature of the projects and opinions from their peers. This thesis has adopted MUV and AHP for analysis of PSC. As the weights of each PSC should be totally different from the others', the utility of each criterion must be identified case by case. In practice, the decision-makers will bring with them a diverse range of knowledge and experience. Therefore, this framework will provide a wide range of score bands (OR a wide-ranging score band) to assist participants to choose the relevant DSTs based on their preference.

6.2.1.3 The participants/users

When the decisions are made by people and not automatically generated by a machine, the users of the DSTs should be considered as human interaction may influence the PS decisions. Recognition of how users employ PSC as input for judging the most suitable PS during the procurement process has implications. Information quality is a multidimensional notion and concerns the understandings of the decision-makers who manage the information (Watts et al., 2009). Subsequently, the characteristics of the decision-makers will determine the choice of both the PSC and the DST. Nevertheless, there has been limited research into the end-users of DSTs in the construction sector However, comments made during the interviews clearly highlight the

importance of the participants to the decisions made during the PSS process, with the interview data indicating that the expertise of the practitioners and their individual methods will directly affect the final decision. In the context of New Zealand roading infrastructure participants, the end-users of DSTs have been categorised into various groups: strategic level and project level; experienced and inexperienced users; organisational level and individual level. This categories are linked with the research participants' organisations and their personal knowledge of PSS. For this reason, the framework enables the participants to clarify their roles in the PSS process in two ways: (1) the framework can record comprehensive information about PSS, and (2) the interviewees can view earlier decision-making processes via a transparent portal.

6.2.2 Knowledge visualisation

The qualitative study results indicate the need for knowledge visualisation when determining a suitable PS for roading infrastructure projects. Knowledge management has evolved as a body of knowledge following the expansion of the knowledge economy (Lee et al., 2016). As an organisational asset, knowledge applications enable an organisation to disseminate and use information to enhance the organisation's overall function (Lee et al., 2016). Information and knowledge can be presented in many ways. *Visualisation* is described as information communication using a computer-supported algorithm to create a graphic symbol that lets us gain knowledge and make decisions (Ursyn, 2014). It is generally accepted that visual representations promote the creation, integration and application of knowledge rather than data between individuals (Cañas et al., 2005). Visualisation allows the available thoughts and knowledge to repeated, changed and compared. Moreover, because visual science is driven by a combination of precise analysis and calculation, it enhances the likelihood of quality decisions being made (Ursyn, 2014). Knowledge visualisation empowers decision-makers to produce cognitive learning through verbal and nonverbal communication. Thus, a visualised knowledge and reasoning process heightens the participants' cognition, supports strategic decision-matching, and matches today's organisational requirements.

In the context of this thesis, the interviewees were seeking an effective way to communicate. Some of the contractors noted that mistrust in and misunderstanding of the decisions made might influence the project delivery. Visualised knowledge sharing at every step of the PSS will enable the stakeholders to view the "whole picture" of the decision-making process and consider PSC from different aspects. However, transparency and understanding of the PSS process requires knowledge visualised for multiple stakeholders along with information about the decision-making chain. Any group decision is complex because it involves many ideas from various perspectives. For this reason, knowledge and information visualisation should be a strategy for sharing and exchanging knowledge when determining a suitable PS.

6.2.3 Cognitive computing

No expert can understand all DSTs plus information and data around PSS can sometimes be vague (Luu et al., 2006). Recognising these challenges, the proposed framework, with the help of a proper DST, will provide a procedure for recording individuals' cognitive computing processes. Earlier studies have attempted to develop decision-supporting techniques to improve knowledge sharing and that are data-driven, thus objectively reducing human intervention. For example, Dzeng and Chang (2005) discussed the trend of investigating online information about construction procurement procedures and created a learning paradigm to assist inexperienced users in capturing such desired information. As noted earlier, different economies and organisations have their own guidelines, based on local laws and legislation, in order to normalise the procurement process. Similarly, DSTs have been recognised and formalised within the construction sector, together with perceptions of obligation and digitalisation (e.g. Abd Jamil & Fathi (2018)).

In the context of New Zealand roading infrastructure projects, this framework conducts a visualised procedure that attempts to provide step-by-step cognitive computing. Cognitive science, including thinking, visual cognition and action, is achieved by drawing on knowledge from the

fields of linguistics, artificial intelligence, philosophy and cognitive psychology (Glasersfeld, 1995). Accordingly, this framework aims to reduce cognitive biases from judgemental heuristics, such as determining PSC and linguistic rating by providing decision alternatives.

The framework employs *feedback loops*. Feedback loops allow the participants to understand the process and improve their individual understanding through multiple interactions. Individuals will actively learn from the other participants' knowledge and decisions and develop intuition and build judgment via a systematic and precise procedure.

6.3 Tools and techniques

The knowledge determines the accuracy of the decision and hence project performance. Tools and techniques are the bridge to connect the knowledge and the decision. For example, AHP is recognised as the conventional DST that need experts' judgements on each criterion. Likewise, MUV performs principal DSTs that use utility recognised by experts. Recently, Plantinga et al. (2019) produced a reasoning based on the expertise of the participants. Chan et al. (2001) highlighted that information solicited requires in-depth knowledge of and experience in adopting various PSs. Hybrid methods, such as the Delphi method, fuzzy logic and RA, should collect data from experienced participants to build the models (Khwaja et al., 2018; Li et al., 2015). DSTs enable us to make a knowledge-based decision systematically. As participant G1 said in their interview, "Techniques probably could help us to move away from intuition and subjective judgement. Importantly, it could record and review our thoughts."

6.3.1 Decision supporting techniques

6.3.1.1 Mean Utility Values (MUV)

Quantitative research shows that the overall utility of each criterion is multiply calculated by the experts. It strives to provide decision-makers with a custom set of utility factors to avoid biases in the selection process (Love et al., 1998). The priority of PSC and mean utility factors [$\mathcal{F}$] of

criterion i for PS_j is evaluated. The optimum PS is selected by a sum of the highest score $[H]$, which is expressed in the following equation:

$$[H] = \sum PSC_i\% * \mathcal{F}_{ij}\% \quad (1)$$

where:

$$\sum_{n}^{i} PSC_i\% = 1\,, i = 1,2,3 \cdots n.$$

6.3.1.2 Analytic hierarchy process (AHP)

Three steps are involved when using a *analytic hierarchy process* (AHP) to identify and analyse PSC: (1) building up a hierarchy structure, (2) setting up the pairwise comparisons matrix, and (3) assessing the priorities for each PS. The hierarchy structure produces a list of PSC that contains qualitative and quantitative factors in the procurement decision process. Of the 198 peer-reviewed articles analysed in the quantitative research part of this thesis, 33 (16.7%) had collected PSC based on empirical studies (for example, Mahdi and Alreshaid (2005)). Conversely, numerous articles recognised raw PSC based on previous research (for example, Chua et al. (2015)).

The second step is to create a pairwise comparison $[a_{ij}]$ of PSC that can be represented in the form of a matrix $[P]$, with the weight vector $[\omega]$. Suppose there are n PSC denoted by:

$$[P] = \begin{bmatrix} a_{11}, a_{12}, \dots a_{1n} \\ a_{21}, a_{22}, \dots a_{2n} \\ \vdots \\ a_{n1}, a_{n1} \dots a_{nn} \end{bmatrix} = \begin{bmatrix} \frac{\omega_1}{\omega_1}, \frac{\omega_1}{\omega_2}, \cdots \frac{\omega_1}{\omega_n} \\ \frac{\omega_2}{\omega_1}, \frac{\omega_2}{\omega_2}, \cdots \frac{\omega_2}{\omega_n} \\ \vdots \\ \frac{\omega_n}{\omega_1}, \frac{\omega_n}{\omega_2}, \dots \frac{\omega_n}{\omega_n} \end{bmatrix} \quad (2)$$

The average of all values of λ_{max} , which represents the largest eigenvalue of $[P]$, can be determined using the following equation:

$$\lambda_{max} = \sum_{j=1}^{n} a_{ij} * \frac{\omega_j}{\omega_i}_{i,j=1,2\cdots n} \quad (3)$$

In Saaty theories, the reliability of experts' judgements should be analysed through a ratio consistency index. The contribution of each criterion is determined by estimations made using eigenvectors and its priority of values.

The last step is to determine the importance of PSC for each PS. Of the 198 peer-reviewed articles analysed in the quantitative research part of this thesis, 33 (16.7%) had used MUV, 50 (25%) had used fuzzy logic, and 66 (33.3%) had used AHP to identify the importance of PSC in each PS.

6.3.1.3 Fuzzy set theory and rough set theory

Realising that the PSC chosen for PSS have not been very explicit, scholars have begun to utilise a fuzzy set or a rough set for modelling PSC involved in the PSS process. Fuzzy logic and rough set theory were developed to meet two challenges: (1) the absence of precise and incomplete information (Mostafavi & Karamouz, 2010), and (2) the uncertainties caused by experts' judgements Mafakheri et al., (2007). In this thesis, fuzzy logic and rough set theory underpins two basic approaches to establishing functions for the framework.

In the earlier studies, analysers such as Ng et al. (2002) applied fuzzy logic to adjust raw PSC through establishing fuzzy membership functions. The fuzzy triangular features are broadly used in PS decisions as they can resolve PSC certainty and are associate with linguistics terms. A matrix of values of alternatives $[Aj]$ concerning criterion could be indicated as:

$$[Aj] = max \begin{cases} A_{j\,(Low)}(PSC_i), A_{j\,(Medium)}\,(PSC_i) \\ A_{j\,(High)}\,(PSC_i) \end{cases} \quad (4)$$

In a similar way, Mafakheri et al. (2007) and Liu et al. (2015) introduced two approximations of lower and upper bounds as intervals to represent weights of PSC. Theoretically, a rough set model is designed to provide a pattern of a set of condition-decision rules for PS selection. The interval weight $[W_i] = [\overline{w_i} - \underline{w_i}]$ and the upper and lower bounds $[B]$ can be expressed as:

$$[B] = \begin{Bmatrix} Max\ \sum_i \left(\overline{w_i}\ - \underline{w_i}\right) \\ Min\ \sum_i \left(\overline{w_i}\ - \underline{w_i}\right) \end{Bmatrix} \quad (5)$$

(5)

where:

$i \in \mathcal{A} - \{j\}$

$\mathcal{A} = \{1, 2, 3, \cdots n\}$,

and the meaning of *i* and *j* is the same as in Equation (3).

6.3.1.4 The Delphi method

The Delphi method solicits the evaluations of experts through a series of designed questionnaires that are used to arrive at a group consensus in a decision. Multiple rounds of the Delphi method were delivered to clarify and refine related PSC accordingly. Khwaja et al. (2018) used the Delphi method to calculate utility factors, and Austin et al. (2016) used it to assess the weightings of PSC for further AHP analysis. It can be inferred from the application of the Delphi method in these studies that the method been embedded in the process of other DSTs as a data collection technique.

6.3.2 Computer programming

Analysis of the data collected from the literature review indicates that procurement decision-makers are not familiar with techniques that support decision-making. Likewise, the interview data indicate that DSTs are not widely adopted in New Zealand roading infrastructure projects. The quantitative data suggest this is probably because of decision-makers' lack of experience with DSTs, while the qualitative data suggest the high cost of training and a traditional mindset among industry practitioners both hinder the implementation of these techniques. To solve this challenge, the PSS procedure is represented by a computer program, and the functions of DSTs are designed in the framework through embedding the DSTs mentioned in section 6.3.1.

There are many computer programming languages, each with its own strengths and weaknesses. Thus, there is no single program that stands out at being the best for this research, and so two were considered: C++ would be the application of choice for a larger operating system, while MATLAB executes algorithms faster than C++ (Moore, 2018). In this framework, C++ was adopted to record and operate the group-decision process. As a well-known computer language, C++ can write and record a large number of programs, and it is easy and cheap to execute software written in C++. Based on the complexity of the PSS algorithm and the requirements of the decision-making process, C++ was adopted for the proposed framework for two reasons: (1) the C++ is one of the most influential programming languages used today and is compatible with many platforms, and (2) I am quite familiar with using C++ to write basic programming.

MATLAB is a matrix-based computer system designed to assist in scientific and engineering problem-solving (Hahn & Valentine, 2019). Based on the plan of the PSS process, MATLAB functions are elaborated in this framework to develop an algorithm to weight the decision attributes and select the preferred DSTs. It is widely agreed that MATLAB is optimised for matrix solutions as the process involves AHP, fuzzy set theory and WS. As a numerical method, MATLAB can be used in the proposed framework to write algorithms for numerical computation. Although MATLAB can solve various matrixes, and it is easier and faster for editing, the standard installation of the professional version and additional function toolboxes need to be purchased separately.

It is frustrating trying to find the right solution when users made a mistake. To solve this issue, the framework changes all academic languages to functional languages, meaning that all the algorithms have been described as a basic or normal language for the users.

This thesis presents algorithms in the form of a pseudo-code that is a mixture of simple computer programming interspersed with more general sentences to achieve human-readable commands. Figure 6.8 provides the format of an algorithm for computing using pseudo-code.

Figure 6.8 An example of pseudo-code format

Input:	A real value `x`
Output:	Square root of `x`
1	**if** $x \geq 0$
2	Print `sqrt( x )`
3	**else**
4	Print an error message

6.4 Framework establishment

The framework has been developed from different tools and concepts. The framework's initial role is to compute and analyse the knowledge delivered from the participants using a structural decision-making procedure. The techniques employed in the framework include AHP, fuzzy set theory, MUV and the Delphi method. The framework uses a systematic process through user-friendly briefs. This process ensures the practitioners will better understand the procedure and decide a preferred supporting technique for decision-making. Particularly relevant in visualisation are computer programming (e.g. MATLAB, C++) and dynamic dashboards. The programming has been designed to ensure the procedures will allow engagement by multiple participants and effectively produce big data analytics. The dynamic dashboards indicate cognitive computing by describing an amplification of the changes during each stage's process and decisions.

Compared with traditional PSS, the novel process of the framework will promote knowledge flows that centre on PSS and result in quality decision-making. The innovative process is a combination of intelligent techniques and organisational strategy. The various perspectives include attitudes on the decision-supporting techniques and the management of individual and corporate knowledge. Considering multiple criteria and imprecise conditions, the framework

establishes a structured algorithm for the calculating decisions. Nonetheless, the knowledge-supported system components must be viewed as the technology part of the framework, and it must also consider social and cultural factors (Frada & Clyde, 2008). In this case, the designed framework initially endeavours to integrate the participants' choices with the technical assessment. A visual mode of communication explains various organisational decisions to the individual decision-making participants, and in so doing, also contributes to their personal cognitive development. In the spirit of Schiuma et al. (2012), the framework will deliver the relationship between the participants' decisions and the final PS selection, reflecting how each individual decision is part of the whole PSS process.

Abu et al. (2016) suggested that construction organisations prefer to make decisions based on the experts' previous experiences. Decision-makers working on roading infrastructure projects in New Zealand need assessments from a diverse spectrum of specialists and then have to integrate that knowledge so they can select the best PS for a particular project. As a result, visualising and analysing the various ideas is essential before the final decisions are made. Eppler and Bresciani (2013) said that visualisation enables effective and seamless collaboration and so can improve communication. For this purpose, the framework implements a collaboration catalyst for communication through verbal representations and non-verbal methods (numbers and figures). Specifically, the framework can display a visualisation of the collaborative decisions made by individuals and groups. And by displaying individual feedback from participants and allowing dynamic interrelationships, the framework is transparent in how the final decision is reached.

6.4.1 Framework process

STEP I: Clarifying available procurement systems in New Zealand

Existing studies indicate that both traditional and alternative/novel PSs are used in New Zealand. Section 2.1.1 of the literature review explained how procurement systems can be categorised by contract administration types/laws, tendering methods, and various phases of the project life cycle.

To determine the best PS for a particular roading infrastructure project, first the PSs available in the New Zealand market need to be identified. The construction section practitioners who were interviewed in the qualitative phase of this research identified seven PSs being used in New Zealand roading infrastructure projects (see Table 6.1)

STEP II: Classifying the procurement selection criteria

Based on the results of the qualitative and quantitative phases of this research, PSC were classified into nine groups: megaproject characteristics, price competition, project risks, contract details, complexity, stakeholder integration, and political issues, organisational considerations and others. According to this classification, the PSC used in New Zealand roading infrastructure projects are displayed in Figure 6.1. There are also subsections within each of the nine groups. For example, project nature, cost and clarity of scope belong to PSC group 1: roading project characteristics.

STEP III: Linguistic rating for decision alternatives [v_{ij}]

A linguistic stage enhances the participants' ability to process, understand and generate a decision in a way that gives a superior outcome than if they had relied on their own cognitive processes alone (Li et al., 2019). Step III represents the individual judgements on the importance of the decision attributes for each alternative. Table 6.2 displays the linguistic term rating scale. According to this scale, the most crucial attribute regarding an alternative is scored 1 while the least-important attribute is scored 0. The interval scores support individuals to clarify and standardise their rating system. Furthermore, the scale stimulates participants to recognise the boundary and interrelationship of decision attributes between one another.

Table 6.2 Linguistic term rating scale

Scores	Linguistic term
0–0.2	Least important
0.2–0.4	Less important

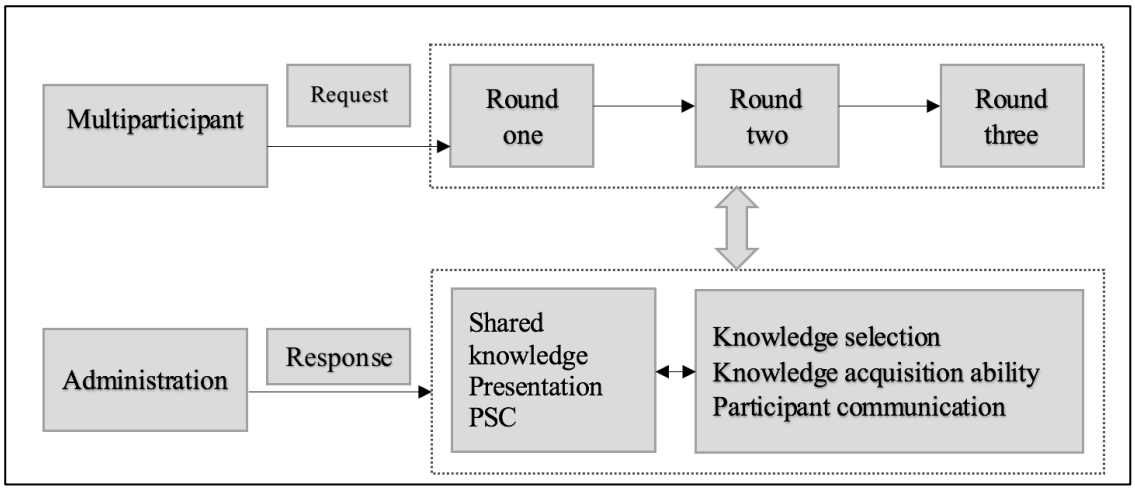
0.4–0.6	Important
0.6–0.8	Strongly important
0.8–1.0	Extremely important

Data from the qualitative interviews showed that industry practitioners find the diversity of project types and market circumstances challenging. As procurement for roading infrastructure projects involves updated PSC and novel PSs, the values $[v_{ij}]$ were defined by the participants. Thus, the framework enables personalised rating systems that reveal the importance of PSC for PS in the current market, instead of employing out-of-date rules.

STEP IV: A group decision for determining the decision attribute (PSC)

In the context of New Zealand roading infrastructure procurement, a list of PSC was displayed at STEP II. Inspired by the Delphi method, this step strives to distil and correlate preferences from the procurement panel. A group of experts (the panel) are asked to indicate the applicable significant PSC for a specific project. Meanwhile, the participants are permitted to create additional PSC for each round. Those additional PSC are excluded from the current PSC database. The frequency distribution and percentage of the preferred PSC would be confirmed once the decision has been progressed. In this way, the framework can support a change in preferred PSC once feedback has been given on the group decision. Figure 6.9 illustrates the group decision process.

Figure 6.9 The group decision process



When decisions are being made by a group, the size of the group is critical as more participants will increase the reliability of the result. However, there are no relevant studies on either the proper panel size when using the Delphi method or the appropriate number of rounds required (Alarabiat & Ramos, 2019). Austin et al. (2016) and Khwaja et al. (2018) looked at practical PS selection processes and suggested that 10 to 15 experts is sufficient for any type of construction project. Normally there are three sets of experts in the panel for New Zealand roading infrastructure projects: project managers (principal and senior), procurement specialists and designers (from the consultancy or contractor team). Therefore, we assume there are three main streams into the panel/group. Given a list of PSC from the database, the group would determine the most crucial PSC for a specific project. From the PSS angle, the process is based on the assumption that these experts understand the special characteristics of the project as well as the links between all its stakeholders.

STEP V: Determining the final choice

The procurement choice is determined based on the assumption that some of the initial PSC will be conceded and not included in the final analysis. Figure 6.10 presents the method for determining the weights of the chosen PSC (from STEP IV). Intuitively, a decision could be made if related factors are identified (Smith et al., 2004). However, a systematic approach is suggested

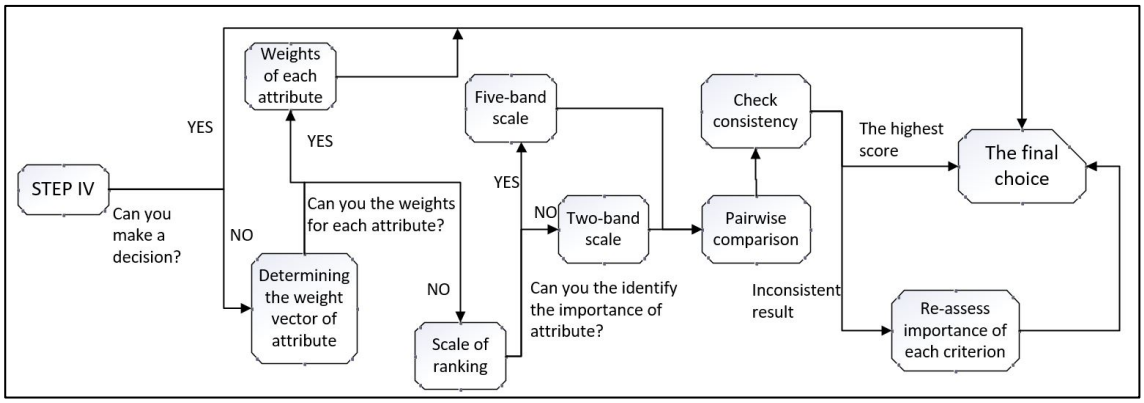
to examine the weight vector $[\omega]$ of each attribute for a specific project (Khwaja et al., 2018; Mafakheri et al., 2007). In this way, we assume that the decision would be made depending on a sum of the highest score $[H_i]$, which is expressed in the following equation:

$$[H_i] = \sum \omega_j * v_{ij} \tag{6}$$

where:

$$\sum_{n}^{j} \omega_j = 1 \, , i = 1,2,3 \cdots n.$$

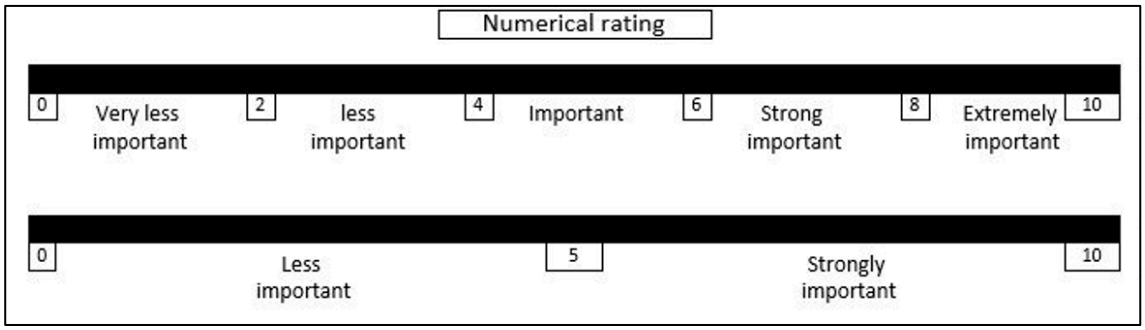
Figure 6.10 Method for determining the weight vector [ω] of attribute



The weight vector $[\omega]$ of each attribute is calculated by each of the experts, so the calculation is performed multiple times. Accordingly, $[\omega]$ is received from the judgements of participants. Extant studies argue that experienced participants can identify the weights, although it is a challenging task for inexperienced participants (Luu et al., 2006). Furthermore, data from the interviews conducted in the qualitative phase of this research show it is difficult for all participants to use one pathway to make the decision. To reduce this challenge and support decision-making, STEP V comprises an algorithm for cognitive computing based on AHP and fuzzy set theory. As illustrated in Figure 6.10, the participants are initially encouraged to adopt a traditional AHP method if they can give weights for each attribute. Otherwise, the framework provides a two-scale approach for ranking, comprising a five-band numerical rating and a two-band numerical rating (as shown in Figure 6.11). The five-band rating system is prioritised over the two-band as

it is expected the more granular scale will reduce the numbers of attributes for the pairwise comparisons. As individual practitioners will present with a wide range of knowledge and perspectives, several decision-making approaches are embedded in this stage to cater for individual needs.

Figure 6.11 Numerical rating for determining the weights of PSC



The next step is to create a pairwise comparison $[a_{ij}]$ of two attributes in each band that can be represented in the form of a matrix $[P]$, with the weight vector $[\omega]$. Suppose there are *n* attributes, then $[P]$ is denoted by:

$$[P] = \begin{bmatrix} a_{11}, a_{12}, \dots a_{1n} \\ a_{21}, a_{22}, \dots a_{2n} \\ \vdots \\ a_{n1}, a_{n1} \dots a_{nn} \end{bmatrix} = \begin{bmatrix} \frac{\omega_1}{\omega_1}, \frac{\omega_1}{\omega_2}, \cdots & \frac{\omega_1}{\omega_n} \\ \frac{\omega_2}{\omega_1}, \frac{\omega_2}{\omega_2}, \cdots & \frac{\omega_2}{\omega_n} \\ \vdots & \\ \frac{\omega_n}{\omega_1}, \frac{\omega_n}{\omega_2}, \cdots & \frac{\omega_n}{\omega_n} \end{bmatrix} \tag{7}$$

Therefore, $[\omega]$ could be determined using the following equation:

$$\omega_j = \frac{\frac{\omega_i}{\omega_j}}{i,j=1,2\cdots n\ (n>0)} / ((\sum_{j=1}^{n} \frac{\omega_i}{\omega_j})\ *\text{n}) \tag{8}$$

Considering the pairwise comparison, the scales take the values $^1/_9$, $^1/_8$, $^1/_7$, $^1/_6$, $^1/_5$, $^1/_4$, $^1/_3$, ½, 1, 2, 3, 4, 5, 6, 7, 8, 9. In Saaty theories, the reliability of experts' judgements should be analysed through a ratio consistency index. The contribution of each criterion is determined by estimations made using eigenvectors and its priority of values. To obtain a measurement of consistency, a

concordance analysis is applied that considers the largest eigenvalue and consistency index [CI]. The average of all values of λ_{max} , which represents the largest eigenvalue of [P], can be determined using the following equation:

$$\lambda_{max} = \sum_{j=1}^{n} a_{ij} * \frac{\omega_j}{\omega_i} \quad i,j=1,2\cdots n \tag{9}$$

We consider consistency ratio (CR):

$$[CR] = \frac{CI}{RI} \tag{10}$$

where:

RI (Ratio index) is defined by Saaty

the consistency index [CI] is defined as: (λ_{max} – n)/(n – 1), and

the consistency of a pairwise judgement is accepted when CR < 0.1.

Based on the participants' requirements, this subsection provides diverse pathways to to reach an agreed weighting for each of the identified PSC. If the results are still inconsistent, the participants are requested to re-assess their score with a levelless rating score.

6.4.2 Decision visualisation

The dashboards visualise the cognitive computing process for the final decision-makers by reporting the decisions made at each step. In real time, thus showing the participants how their knowledge sharing and exchange is reshaping the final decision. Based on the platform, the integration of knowledge from collaborative and individual choices of this project is created, structured, retrieved and recorded.

6.4.2.1 PS selection algorithm

The framework raises a cognitive computing process by combining classic decision-making techniques and dynamic dashboards. Figure 6.12, Figure 6.13, and Figure 6.14, display the decision-making algorithms with pseudo-code.

Algorithm 1 represents the detailed process of STEP III. Based on the empirical study's results (STEP I and STEP II), the programming offers the participants the opportunity to explore their rating system. The result would be recorded to connect with algorithm 3.

Figure 6.12 Algorithm 1 with pseudo-code

Input 233 PSC (T_{psc}=233) divided into 9 groups (NG_{psc}=9), predefined PS (N_{ps}=7) and participants (*papt*)
Output the values v_{ijp}
for *p*=1 to *papt* do
  for *i*=1 to NG_{psc} do
    for *j*=1 to N_{ps} do
      Assign a value: $v\ (i,j,p) = x$;
    end
  end
  if participant p has a different value for PSC_m in group i
    $v\ (i,j,p)_m\ = y$
  end
end

In algorithm 2, the programming clearly indicates how the PSC for a specific project would be selected. It aims to investigate multiple participants' choices under multiple criteria. The process follows STEP IV.

Figure 6.13 Algorithm 2 with pseudo-code

Input 233 PSC (T_{psc}=233) divided into 9 groups (NG_{psc}=9), predefined PS (N_{ps}=7) and participants (*papt*)
Output the selected psc_s_i *in descending according to* cnt_i (i=1,2,3,4)
1 initialise STEP=3
2 **for** $s = 1$ to STEP **do**
3 **if** $s = 1$
4 **for** j=1 to *papt* **do**
5 select n PSC out of T_{psc} PSC: $psc\_sel(j)_{s1}$=[$sel_{j1}, sel_{j2}, sel_{j3} \ldots sel_{jn}$] and $sel_{jx} \in [1,\ T_{psc}]$
6 **if** participant j has m extra PSC
7 $psc\_ext(j)_{s1}$=[$ext_{j1}, ext_{j2}, ext_{j3} \ldots ext_{jm}$] and $ext_{jx} \notin [1,\ T_{psc}]$
8 **end**
9 **end**
10 **end**
11 **for** each element e in psc_sel_{s1} and psc_ext_{s1}
12 count how many times it has been selected by all *papt:* cnt_e ++
13 **end**
14 sort *psc_s1= sum (*psc_sel_{s1} & psc_ext_{s1} *)*=[$e_1, e_2, e_3, \ldots e_{50}$] in dashboard
15 **if** $s = 2$
16 **for** t=*1 to papt* **do**
17 select n PSC from *psc_s1:* $psc\_sel(t)_{s2}$=[$sel_{t1}, sel_{t2}, sel_{t3} \ldots sel_{tn}$] and $sel_{tx} \in [e_1, e_2, e_3, \ldots e_{50}]$
18 **if** participant t has n extra PSC
19 $psc\_ext(t)_{s2}$=[$ext_{t1}, ext_{t2}, ext_{t3} \ldots ext_{tn}$] and $ext_{tx} \notin psc\_s1$
20 **end**
21 **end**
22 **end**
23 **for** each element f in psc_sel_{s2} and psc_ext_{s2}
24 count how many times it has been selected by all *papt:* cnt_f ++
25 **end**
26 **sort** psc_sel_{s2} and psc_ext_{s2}
27 *psc_s2*=[$f_1, f_2, \ldots f_{30}$] in dashboard
28 **if** $s = 3$
29 **for** r=*1 to papt* **do**
30 select p *PSC from psc_s2:*$psc\_sel(r)_{s3}$=[$sel_{r1}, sel_{r2}, \ldots sel_{rp}$] and $sel_{rx} \in [f_1, f_2, \ldots f_{30}]$
31 **if** participant r has q extra PSC
32 $psc\_ext(r)_{s3}$=[$ext_{r1}, ext_{r2}, ext_{r3} \ldots ext_{rq}$] and $ext_{rx} \notin psc\_s2$
33 **end**
34 **end**
35 **end**
36 **for** each element g in psc_sel_{s3} and psc_ext_{s3}
37 count how many times it has been selected by all *papt:* cnt_g ++
38 **end**
39 **sort** psc_sel_{s3} and psc_ext_{s3}
40 *psc_s3*=[$g_1, g_2, \ldots g_{20}$] in dashboard
41 display psc_s_z *in descending according to* cnt_z and z=1,2,3 in dashboard
42 **end**
43 **end**

Finally, algorithm 3 represents the process of STEP V which allows the participants to use preferred DST according to their experiences and understanding of a specific mega infrastructure

project. This stage provides the participants a user-friendly pathway to determine the weights of PSC.

Figure 6.14 Algorithm 3 with pseudo-code

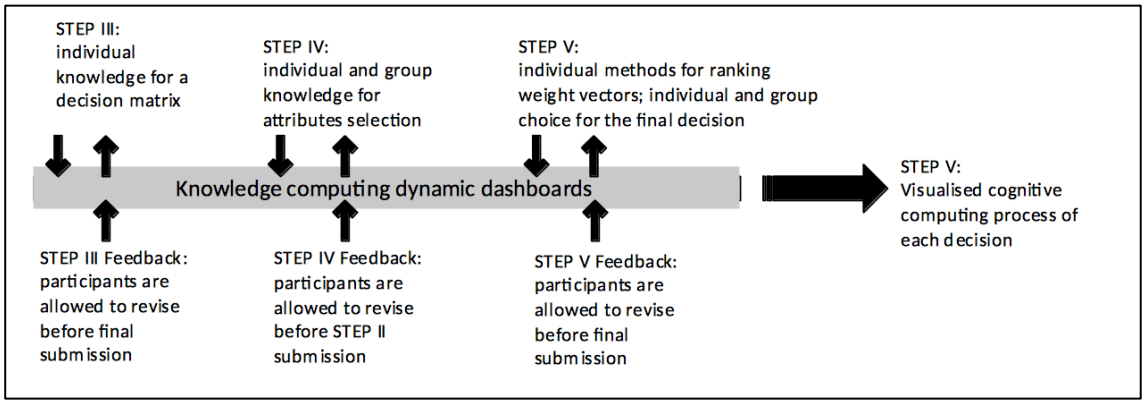
```
Input: a selection for app_sel (p)
Output: a selected case for each participant papt; a selected PS ps for each participant papt
for p=1 to papt do
  switch app_sel(p)
    case 1:
      ps(p)=user p select a ps from 1,2,... N_ps;
    case 2:
      for i=1 to length (psc_sel) do
       weight vector ω_i =user p input a value between [0,1] and sum (ω)=1
     case 3:
       weight vector ω_i =AHP (psc_sel)// according to equation (7.2), equation (7.3)
       calculate λ_max // according to equation (7.4)
       if CRs>0.1
          weight vector ω_i =user p input a value between [0,1] and sum (ω)=1
       end
     end
  end
  calculate H_ps according to equation (7.1) and ps(p)= max H_ps
  end
end
   for each papt select app_sel(p)
     count how many papt for each case
   end
   display the decisions (ps) of each papt
   end
end
```

6.4.2.2 Cognitive computing visualisation

Using dynamic dashboards means step-by-step data can be automatically updated in real time. Furthermore, an algorithm-based process means that the participants can be notified of any live decisions concerning the findings or records. This feature empowers participants by enhancing their understanding of their own decision-making process as well as that of the continuously

developing set of PSC. The framework also enables the analysis of how participants' knowledge and choices have influenced the final decision (as shown in Figure 6.15). While values $[v_{ij}]$ of PS against PSC are diverse, considering different participants, they can be adopted to all situations of various projects. In this context, the feedback of the visualised decision matrix in STEP III targets the focus of procurement selection initiatives. It describes and documents individual knowledge in the framework.

Figure 6.15 The cognitive computing process



In addition, the framework purposes to compute the collaborative human thoughts and cognition through managerial determination by participants. The second phase centres on preferred PSC for a specific project. During the selection process, the participants' weightings (the group weighting?) of each criterion, shown as a percentage, is displayed at the end of this round. The participants then have an opportunity to review their individual decisions. This iterative manner of communication is designed to give the participants a sense of involvement in and ownership of the project. The decision visualisations also help the participants to analyse their choices. A key advantage of the Delphi method, which is used in the framework, is that it facilitates experts to reach a consensus over an important agreement (Alarabiat & Ramos, 2019). For this reason, the dashboard visualises an exploratory result from each round in this phase. The dashboard is created to inspire participants to exploit the shared knowledge and experience by identifying and clarifying the significance of the proposed PSC.

Furthermore, inspired by Herbert Simon Noble, the research explored the cognitive limitations of the human capacity to calculate a choice from alternatives. A group decision is the result of human interaction and so is likely to differ from individual choices (Frada & Clyde, 2008). Also, because innovative PSs are still in their early years, organisations need to develop their strategic innovation capacity through dynamic cognitive computing such as value creation and having an organisational culture that embraces experimentation and is open to information exchange. Institutionalised agreements and structural process can also constrain proactive techniques (Matthyssens, 2019), so companies that wish to engage in proactive techniques will need to examine these. The last dashboard displays a record of each step's core information, so linking the final choice back to the decision-making process. The purpose of this is not only to display the final choice, but to create value by giving the participants an opportunity to improve their knowledge and understanding of the process and organisations a record of the data and the process. Specifically, the dashboard presents the results of STEP III, before and after revision with the bar chart of selected PSC and the pie chart of individual decisions of a PS, and the pathways of their decision-making approaches.

Overall, the first dashboard presents the relative weightings of the PSC for each PS. Figure 6.16 represents the decision matrix that allows participants to realise their understanding of PSC and PS relationships. For instance, STEP II shows the current PSC categorises, based on empirical studies and the researcher's experience. This step displays the algorithm 1 outputs which enable the participants to set up a personalised rating system. Furthermore, it prompts participants to examine the categorises regarding personal knowledge. It enables the participants to reason and make decisions based on the shared information and their own knowledge and experience. This step also leads the decision-makers to acknowledge world knowledge (e.g. current policies) about the PS and PSC.

Figure 6.16 Determining values of procurement selection criteria against seven procurement systems

	PS1	PS2	PS3	PS4	PS5	PS6	PS7
Megaproject characteristic	v_{11}	v_{12}	v_{13}	v_{14}	v_{15}	v_{16}	v_{17}
Complexity	v_{21}	v_{22}	v_{23}	v_{24}	v_{25}	v_{26}	v_{27}
Price competition	v_{31}	v_{32}	v_{33}	v_{34}	v_{35}	v_{36}	v_{37}
Stakeholder integration	v_{41}	v_{42}	v_{43}	v_{44}	v_{45}	v_{46}	v_{47}
Project risks	v_{51}	v_{52}	v_{53}	v_{54}	v_{55}	v_{56}	v_{57}
Political issues	v_{61}	v_{62}	v_{63}	v_{64}	v_{65}	v_{66}	v_{67}
Organisational considerations	v_{71}	v_{72}	v_{73}	v_{74}	v_{75}	v_{76}	v_{77}
Best Value	v_{81}	v_{82}	v_{83}	v_{84}	v_{85}	v_{86}	v_{87}
Others	v_{91}	v_{92}	v_{93}	v_{94}	v_{95}	v_{96}	v_{97}
The weights for altered PSC							
Altered PSC_x	v_{x1}	v_{x2}	v_{x3}	v_{x4}	v_{x5}	v_{x6}	v_{x7}

The dashboards presented at the second step support each panel member to compare their individual knowledge and decisions with the group decision. It contains two functions: (1) the dashboard initially focuses on self-preference. The preferences hold the information related to the participant's objectives, which correspond to agreeable alternatives that the participant might receive at any point of the decision-making process; (2) it shows the information related to the other participants' public preferences. To some extent, this step is used to measure the participants' preferences verify their cognitions in PSC and provide the chance to consider which PSC are more suitable to be chosen throughout the decision-making process. Figure 6.17 shows the representations of each step of algorithm 2. A communication board is available, which provides the participants with a place where they can discuss the selected PSC. As suggested by Carneiro et al. (2019), a communication board can assist the participants to exchange ideas about their preferences for each considered criterion.

Figure 6.17 Selection process of a set of procurement selection criteria for a specific project

Round one	percent(%)		Round two	percent(%)		Round three	percent(%)
psc-s1-1	*s1-1%*		*psc-s2-1*	*s2-1%*		*psc-s3-1*	*s3-1%*
psc-s1-2	*s1-2%*	⇒	*psc-s2-2*	*s2-2%*	⇒	*psc-s3-2*	*s3-2%*
⋮			⋮			⋮	
psc-s1-50	*s1-50%*		*psc-s2-30*	*s2-30%*		*psc-s3-20*	*s3-20%*

The final dashboard displays the whole picture of the decisions taken at each step of the PSS process. Clearly, the participants will have a range of attitudes about and experiences with DSTs. To satisfy all the participants' preferences, STEP V is designed to provide three pathways so that the participants can assess the optimal PS using an approach they are familiar with. For example, experienced participants might identify a suitable PS without analysing each criterion's weights vector, whereas less-experience participants might like to make their decisions while using the structural process for support. The three main pathways in the framework (see Figure 6.10) in STEP V. The final dashboard presents the cognitive processes from the STEP I to STEP V as well as world knowledge (the PSC classification, and PSs in the market), self-knowledge (personal favourites) and "Other" knowledge (group decision and information related to the public preferences) for a specific project. It displays the selected PSC (the results of algorithm 2), the pattern of DSTs pathways the decision-makers used, and the distribution of preferences for the final suggested PSs.

Overall, the quantitative study in Chapter Four provided the fundamental information needed for the construction of the PSS, while the qualitative study in Chapter Five showed the current PSS situation in New Zealand roading infrastructure projects. The proposed framework is based on and developed from an integration of these qualitative and quantitative research results.

7. CHAPTER SEVEN: FRAMEWORK VALIDATION

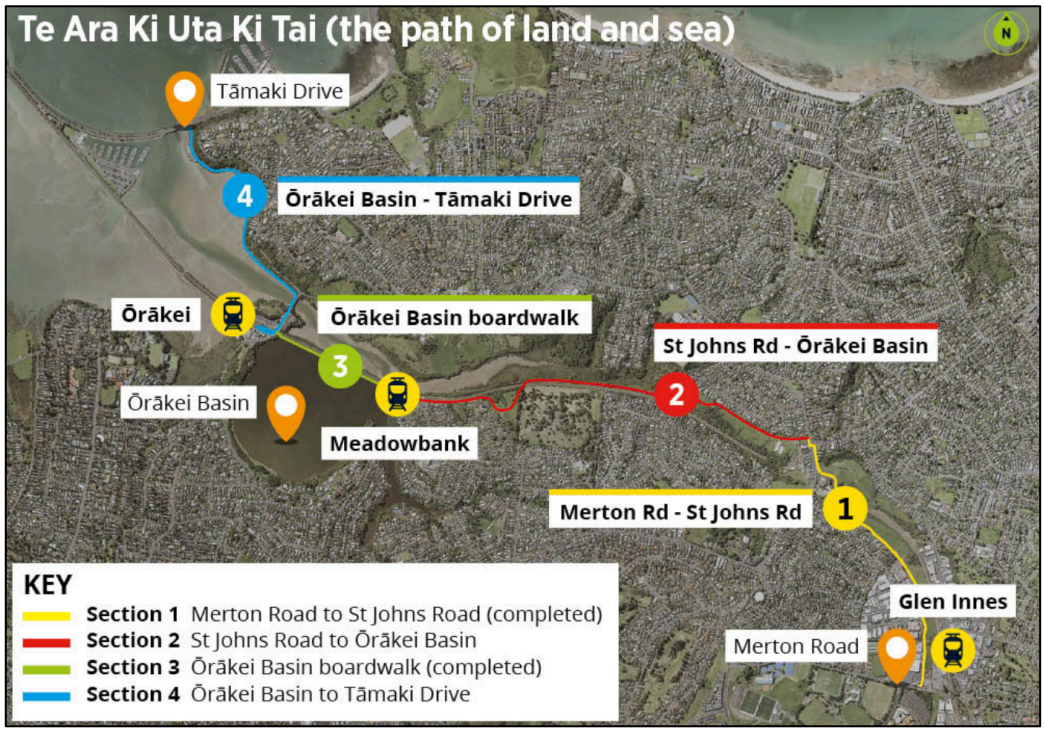
Chapter Six and Chapter Seven address RO3: To develop and validate a procurement system selection framework. The proposed framework was presented in Chapter Six, and this chapter focuses on validation of the framework. Based on the case study, the framework was revised so that it can better support PSS in New Zealand roading infrastructure projects.

7.1 Case study background

The case study is Te Ara Ki Uta Ki Tai. The purpose of this project is to connect with and expand the Auckland Cycle Network. The project is aligned with the long-term vision of the NZTA, Auckland Transport and Auckland Council to build a world-class cycling infrastructure that promotes cycling as a safe and convenient transport choice. The project construction started on 9 December 2016, and at the time this thesis was being written up (February 2021), had not yet been completed. The walking and cycling project will contribute approximately 7 km of shared-use path to the Auckland Cycle Network, providing a link between Glen Innes Town Centre and Tāmaki Drive. Figure 7.1 shows the route map of the project. It comprises four sections: (1) Merton Road to St John's Road (completed), (2) St John's Road to Ōrakei Basin, (3) Ōrakei Basin boardwalk (completed), and (4) Ōrakei Basin to Tāmaki Drive.

To validate the framework the case study discussed roading infrastructure project a pathway from St John's Road to Ōrakei Basin. The path traverses land within the Meadowbank Pony Club, behind Selwyn College and Purewa Cemetery before crossing the North Island Main Trunk line via an overbridge at Tahapa Reserve and traversing Tahapa Reserve. It then runs alongside the rail line to connect with section 3 at the Meadowbank Train Station. The case study focused on section two of the project: a shared-use pathway (walking and cycling) 4 meters wide and 2.7 km long from St John's Road to Ōrakei Basin. Figure 7.2 displays the completed construction plan for this case.

Figure 7.1 Glen Innes to Tāmaki Drive Shared Path route



The purpose of the procurement stage is to confirm the suitable procurement system, including the contract type (delivery model), value management, price model and funding source. Traditionally, the procurement plan for the delivery method is decided after funding for a project is approved. For this case, the project is funded by AT and NZTA. Therefore, the traditional PSS, in this case, could only determine the delivery model for the procurement plan.

7.2 Research administration

The case study is about the procurement of services for and delivery of a specific roading infrastructure project in New Zealand. Two types of organisations were involved in this case study: a public agency and the contractor. Project managers and procurement specialists, as the primary decision-makers, were invited to test the proposed framework.

Figure 7.2 Construction plan of Section 2 of the Te Ara Ki Uta Ki Tai project: St John's Rd to Ōrākei Basin

The case study contained two phases: phase one was testing the model and phase two was non-structural interviews. Key stakeholders from the public agency involved in the project were invited to decide a PS through the framework process at phase one. Then, all the participants were encouraged to express their opinions about the proposed framework. The questions were aimed to obtain feedback on the proposed framework.

Three participants (T1, T2, T3) attended the framework test and five interviews were conducted between February 2021 and March 2021. The framework test lasted seven days, and the interviews were between 15 and 45 minutes long. The participants' backgrounds can be seen in Table 7.1.

Table 7.1 The research participants' backgrounds

Participants	Organisation type	Code
Senior project manager	Public agency	T1
Project manager	Public agency	T2
Procurement specialist	Public agency	T3
Project manager	Contractor	T4
Project manager	Contractor	T5

7.3 Framework validation

7.3.1 Process illustration

The framework is applied as a decision-supporting process to assist key people who make the decisions about the PSC and preferred PS. Table 7.2 presents the seven PSs in the context of roading infrastructure projects in New Zealand.

Table 7.2 Procurement systems of New Zealand roading infrastructure projects

Procurement System	
PS1	All-in-one + Measure and value + publicly funded
PS2	All-in-one + Measure and value + privately funded
PS3	Design and construct + Measure and value + publicly funded
PS4	Design and construct + Measure and value + privately funded
PS5	Early contractor involvement + Measure and value + publicly funded
PS6	Early contractor involvement + Measure and value + privately funded
PS7	Alliance + privately funded

The PSC were categorised into nine groups according to the integrated results of the quantitative and qualitative research presented in Chapters Four and Five of this thesis. With support by MATLAB, the first dynamic dashboard presented the values of the PSC for each PS. Figure 7.3 gives an example of the decision matrix. The matrix allows participant T1 to realise his understanding of PSC and PS relationships. For instance, participant 1 believes the importance ratio of PSC1 for PS1 is 0.1; PSC2 for PS1 is 0.2, etc. The first left column lists the nine PSC groups from Figure 6.1 with index numbers from 1 to 9. This stage prompts the participants to examine the categories from their personal experience. Take participant T1's results, for example: the dashboard shows that participant T1 did not see the criterion "size of project" to have the same importance as other criteria classified into Group 1. Alternatively, participant T1 provided a new string of "size of project" values for each PS (altered weights). In this way, a dynamic evaluation process was established person by person. In this case, participant T1 provided the weights for the altered PSC and did not change the matrix before submitting the results in STEP V. As a result, the final weighing system of PSC-PS for participant T1 is shown in Figure 7.3.

Figure 7.3 Participant one–Dashboard one (Linguistic rating for decision alternatives)

PSC groups	PS1	PS2	PS3	PS4	PS5	PS6	PS7
1.MEGAPROJECT CHARATERISTICS	0.1	0.1	0.2	0.4	0.4	0.2	0.2
2.PRICE COMPETITION	0.2	0.3	0.3	0.5	0.6	0.4	0.4
3.PROJECT RISKS	0.1	0.2	0.3	0.1	0.2	0.2	0.2
4.COMPLEXITY	0.1	0.2	0.1	0.4	0.3	0.5	0.5
5.STAKEHOLDER INTEGRATION	0.8	0.9	0.9	0.5	0.3	0.5	0.5
6.POLITICAL ISSUES	0.6	0.6	0.6	0.5	0.5	0.7	0.7
7.ORGANISATIONAL CONSIDERATIONS	0	0	0	0	0.5	0	0
8.BEST VALUE	0.6	0.6	0.6	0.8	0.9	0.6	0.6
9.OTHERS	0.6	0.6	0.5	0.4	0.3	0.4	0.4
The weights for altered PSC							
Size of project	0.8	0.9	0.9	1	1	0.9	0.9

The dynamic dashboard presented at the second stage (Figure 7.4) supported the panel members (all the participants) to select the most important PSC for this case. First, each participant was asked to select a maximum of 50, 30 and 20 applicable PSC from a set of 233 criteria in the database. The second stage comprised three iterations. For the first iteration, each participant was asked to select a maximum of 50 PSC from a set of 233 criteria in the database. Every participants' selections were then combined to generate the top 36 PSC for the group. The list of these 36 PSC, in descending order, was shown to the participants. The same process was repeated twice more, with 18 group PSC being identified from a maximum selection of top 30 PSC (the result from round one) from each participant in the second iteration, and a final group selection of 11 PSC having been identified from 18 PSC from each individual in the third iteration.

Figure 7.4 Procurement selection criteria identified for the case

Round 1	Percent (%)
Size of project	100
Categories of client	100
Contract packaging	100
Project value	100
Project budget	100
Clients's willing to take risks	100
Risk allocation	67
Risk management	67
Clear user's requirement	67
Cents's involvement	67
Complexity	67
Owner's experience with similar projects	67
Client's management ability	67
Innovative methodologies	67
Sustainability	67
Value for money	67
Cost certainty	67
Cost	67
Control cost growth	33
Quality	33
High quality for a given cost	33
Delivery speed	33
Contractor capability	33
Well defined project features	33
Contractor's reputation	33
Project location	33
Regulation feasibility	33
Design control	33
Schedule growth	33
Disputes	33
Competitive tendering	33
Early completion	33
Shifting the risk to the contractor	33
Ease change incorporation	33
Knowledge of the strategy	33
Construction duration	33

Round 2	Percent(%)
Size of project	100
Categories of client	100
Contract packaging	100
Value for money	67
Project budget	67
High quality for a given cost	67
Clients's willing to take risks	67
Risk allocation	67
Clear user's requirement	67
Cents's involvement	67
Complexity	67
Owner's experience with similar projects	67
Risk management	33
Client's management ability	33
Cost certainty	33
Cost	33
Well defined project features	33
Contractor's reputation	33

Communication board:
1. additional PSC--personal experience of delivering projects
2. clarify the meaning of "project value and project size" & the scope of "cost"

Round 3	Percent (%)
Size of project	100
Categories of client	100
Risk allocation	100
Complexity	100
Well defined project features	67
Contractor's reputation	67
Value for money	67
Clear user's requirement	67
Personal experience of delivering projects	67
Contractor's reputation	67
Owner's experience with similar projects	33

The participants were allowed to leave messages on the communication board and provide suggestions for additional PSC that were not in the database. For example, Figure 7.4 shows one participant suggesting "personal experience of delivering projects" as an additional criterion at the end of round two, and another wanted the meaning of "project value and project size" and "cost" to be clarified. The framework testing participants were able to view the communication board after the third iteration began. At the end of this stage, the participants as a group has agreed on a set of 11 key PSC: "size of project", "categories of client", "risk allocation", "complexity", "well-defined project features", "contractor's reputation", "value for money", "clear user's requirement", "personal experience of delivering projects", "contractor's reputation", and "owner's experience with similar projects."

To assess the optimal PS, the framework required the participants to evaluate the weighting of selected PSC weights. At this stage, the participants could choose their preferred routes to reach their final decision. For example, experienced participants knew PS1 without without needing to

analyse the weights vector for each criterion, whereas less-experienced participants filled in their choices step-by-step with programming support. The diverse knowledge in the framework is depicted in Figure 7.5. This dashboard describes the frequency distribution of methods in choosing a PS and the panel members' final suggestions to determine the optimal PS. As shown in the final dashboard, early contractor involvement + measure and value + public-funded remains the highest score.

7.3.2 The usefulness of the framework

The framework is able to support the decision-maker by having a visualised and dynamic decision-making process while, at the same time, displaying a cognitive computing process.

First, the framework helps the final decision-maker to identify essential information and exploit complex information during the PSS process. As the framework is required to record and represent the decision-making process, it can save in-putted knowledge and information for future projects. T5 stated, "A clear decision-making process could show more important and precise information for the next stage [of the] project [Section 3]." At the same time, the recorded information enables the participants to consider and re-think the knowledge and pattern of similar projects. As T1 stated, "We always say we need procurement methodologies, strategies and experience working within a collaborative procurement team. This framework shows a way to record the streamlined portfolios of procurement activities." As a result of its high level of information recording and transparent process, the framework enables the clear transfer and exchange of information during the construction stage.

Figure 7.5 Final dashboard visualised for the framework

**********	**Final output**
**********	**Selected PSC** Percent (%)
The above tables print the final selected criteria after 3 rounds.	Size of project 100
percent for selection of pathway 1: 0	Categories of client 100
the involved participants are: **********	Risk allocation 100
percent for selection of pathway 2: 66.66%,	Complexity 100
the involved participants are: 1,3 **********	Well defined project features 67
percent for selection of pathway 3: 33.33%,	Contractor's reputation 67
the involved participants are: 2,	Value for money 67
**********	Clear user's requirement 67
**********	Personal experience of delivering projects 67
percent for All-in-one + Measure and value + public-funded: 0.00%,	Contractor's reputation 67
percent for All-in-one + Measure and value + private-funded : 00.0%,	Owner's experience with similar projects 33
percent for Design and Construct + Measure and value + public-funded: 33.33%,	**********
percent for Design and Construct + Measure and value + private-funded: 0.00%,	
percent for Early contractor involvement + Measure and value + public-funded: 66.67%,	**Suggested procurement system**
percent for Early contractor involvement + Measure and value + private-funded: 0.00%,	Design and Construct + Measure and value + public-funded: 66.67%,
percent for Alliance + private-funded: 00.00%,	Early contractor involvement + Measure and value + public-funded: 33.33%
**********	
**********	
pathways 1: for user direct select; pathway 2: for input weights by users; pathway 3: for AHP	

Moreover, the framework comprehensively records the PSC that are influencing contemporary PS for roading infrastructure projects. PSC have not been updated globally since 2016, and no relevant PSC have been found in New Zealand studies. As T3 highlighted, “Plans sourcing and delivering of goods and services to support roading infrastructure is not easy. Alliance and PPP are probably the main strategies in the future. We do need to consider the criteria about innovation and sustainability in the fast-paced environment.” Indeed, the framework consists of a systematic and rigorous decision-making process that could be used as a tool to monitor progress and report on the PSC that are relevant to construction PSs in modern times.

Furthermore, the framework assists decision-makers to understand the procurement activities from a broader point of view. T1 pointed out: “I can find the key points for improving the existing contract packages.” As a procurement decision, the selected PS determined a specific contract type. In this case, T4 and T5 read the dashboards and decision-making process reports. They confirmed the usefulness of improved information transparency and agreed that the process could reduce mistrust and misunderstanding during the decision-making process. T4 said, “We can receive the procurement decision and we can see how the procurement decision comes from. All project decisions will impact the tender programme and result in the upcoming construction session.”

Furthermore, both participants who work for public agencies and those who are contractors indicated that knowledge visualisation helps to improve the procurement decision quality, particularly for inexperienced practitioners. T1 said, “It is good for our people who are not strong communicators and who are lacking experiences.” It is not common for a consultant to be engaged for the whole procurement process, but the framework means that their expertise regarding design knowledge, construction expectations and procurement decisions is retained within the model, even after they are no longer involved. Thus, the framework offers a platform representing the consultants’ knowledge of a specific project, while at the same time, systematically reviews the decision-makers’ understanding of the PSs. The framework’s visualised knowledge can also

benefit downstream stakeholders, such as contractors. Furthermore, infrastructure projects are complex with many stages and involve multiple stakeholders, so there is significant risk that information can be missed and that some of the players will lack experience in collaborative relationships. But the transparent and knowledge-based nature of the framework means that it can potentially remove some of the bias created by the complex nature of these projects.

Finally, the framework recognises that many of the players in infrastructure projects bring with them significant knowledge and decision-making skills and promotes their expertise. Indeed, it is expected that participants will be involved in the process of developing the framework model. The case study confirmed that the framework allows participants to review their own opinions and also showed how the participants deepened their own understanding about the PSS process by looking at the input from the other participants. Interestingly, the participants felt the current contractor selection method, which probably indicated the DSTs adoption might impact the traditional mindset within PSS. T1 said, "When I started to choose the values for each criterion, I wonder if we need to change our price-quality method." As noted earlier in this thesis, contractor selection methods in New Zealand include non-price attributes, and each attribute has a weight derived from the project manager's personal experiences. The case study results suggest the framework could potentially change mindsets about the decision-making process for the whole procurement chain.

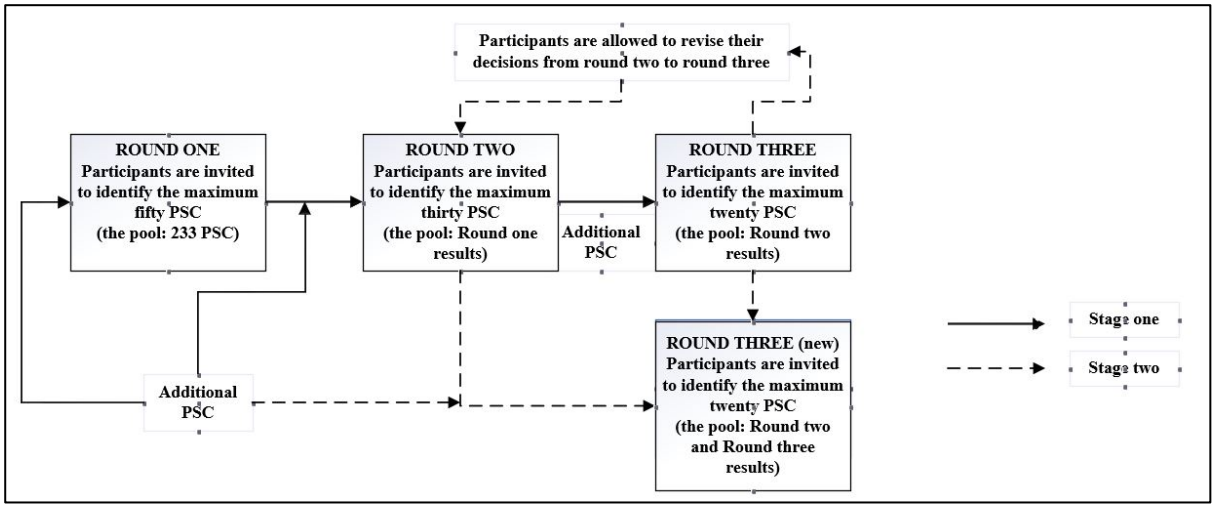
7.3.3 The improvement for the current framework

7.3.3.1 Group decisions and individual decisions

T2 and T3 highlighted how individual decisions were influenced by group decisions. T2 stated: "In round three, I would choose the most important criteria in round two." Chan et al. (2001) discussed the challenges of adopting the Delphi method, as it is such as complex process. To improve the quality of the PSC selected, the revised process contains two phases within three selection rounds. The dashboard of phase one depicts a random-order list of chosen PSC. It is

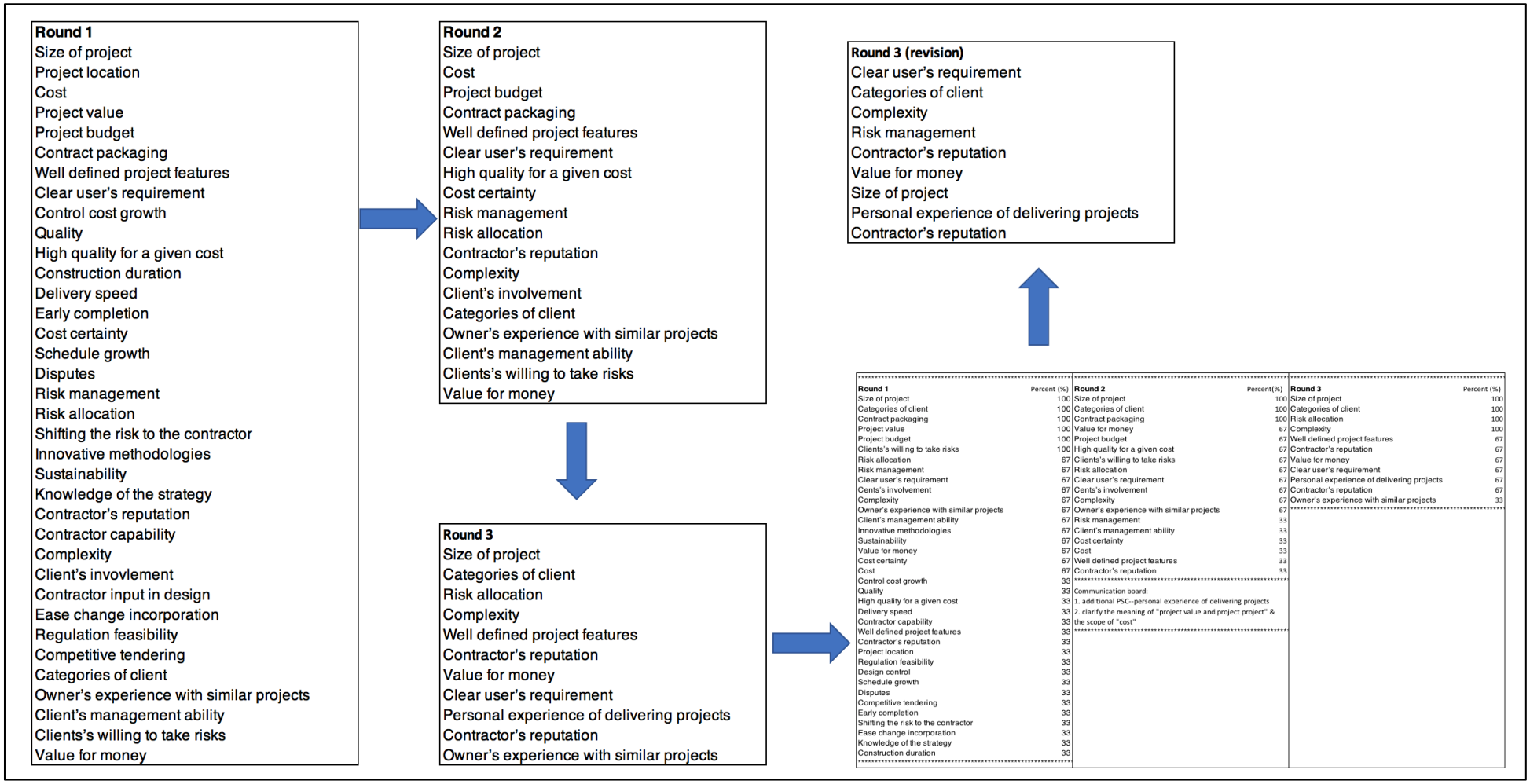
intended to focus on the individuals' decisions. After that, phase two begins to list PSC in descending order according to each round's counted numbers. At this point, the participants are allowed to edit their preferences within a few days (5 days, for example). Figure 7.6 details the representations of each step that follows algorithm 2 above. The dashboard records the cognitive computing process and not only displays self-expertise throughout the structured procedure, but also allows the participants to recognise a trend and decide whether to change their individual decision or not.

Figure 7.6 Re-statement of STEP IV



The participants were then invited to revise STEP IV. The dashboard (Figure 7.7) represents different decisions made before and after showing the other participants' opinions. Although this framework does not focus on the factors influencing collaborative decision-making, the cognitive computing process infers that individuals change their mindsets during the procedure. Specifically, there is a difference between the initial and revised third round. STEP V adopts Round 3 (revision) for further analysis. However, it is still valuable to show the whole decision-making process. T1 and T3 believed this stage contributes to mindset development, with T1 stating that "it is interesting to explore the factors' influence on our decision. It probably shows our learning process of using new procurement strategies."

Figure 7.7 Revised dashboard (STEP IV)



7.3.3.2 Visualised final report

The final dashboard presents the whole picture of the decision-making process. The first part of the dashboard reports the weights of each criterion against each PS. Figure 7.8 shows an example of T2's final report. The individual report represents each panel member's personal opinions and knowledge regarding the relationships between PSC and PS. As suggested by the participants, the final output dashboard contains three sections: the PSC, the techniques selected, and the final decision. Specifically, this dashboard describes the key PSC of individual and collaborative decisions (before and after reading the distribution of selected PSC), the frequency distribution of methods used in choosing a PS, and the panel members' final suggestions to determine the optimal PS. As suggested in the final dashboard, the framework sought the most suitable PS based on the decisions of the panel members, all of whom have had experience working on infrastructure projects.

In the case study, the selected PSC before revision were size of project, categories of client, risk allocation, complexity, well-defined project features, contractor's reputation, value for money, clear user's requirement, personal experience of delivery projects, contractor's reputation and owner's experience. Section 7.3.3.1 discussed the revised process of STEP IV. Therefore, the revised PSC for this specific project have been identified as *clear user's requirement, categories of client, complexity, risk management, contractor's reputation, value for money, size of project, personal experience of delivering projects* and *contractor's reputation*. The dashboard orders the PSC based on how often each criterion was selected by the participants. For example, all the participants selected *complexity* as an important PS criterion, whereas only 67% of participants agreed that *the contractor's reputation* was a criterion for this project.

Figure 7.8 Revised dashboard (final report)

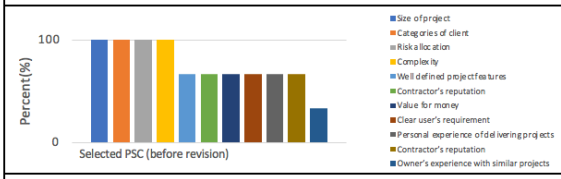
Individual report

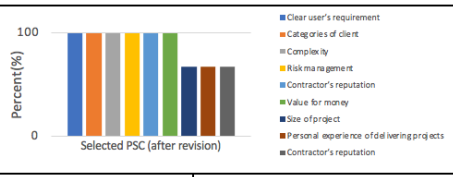
PSC groups	PS1	PS2	PS3	PS4	PS5	PS6	PS7
1.MEGAPROJECT CHARATERISTICS	0.1	0.1	0.2	0.4	0.4	0.2	0.2
2.PRICE COMPETITION	0.2	0.3	0.3	0.5	0.6	0.4	0.4
3.PROJECT RISKS	0.1	0.2	0.3	0.1	0.2	0.2	0.2
4.COMPLEXITY	0.1	0.2	0.1	0.4	0.3	0.5	0.5
5.STAKEHOLDER INTEGRATION	0.8	0.9	0.9	0.5	0.3	0.5	0.5
6.POLITICAL ISSUES	0.6	0.6	0.6	0.5	0.5	0.7	0.7
7.ORGANISATIONAL CONSIDERATIONS	0	0	0	0	0.5	0	0
8.BEST VALUE	0.6	0.6	0.6	0.8	0.9	0.6	0.6
9.OTHERS	0.6	0.6	0.5	0.4	0.3	0.4	0.4
The weights for altered PSC							
Size of project	0.8	0.9	0.9	1	1	0.9	0.9

Final output

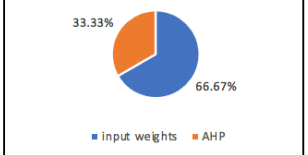
Selected PSC (before revision)	Percent (%)
Size of project	100
Categories of client	100
Risk allocation	100
Complexity	100
Well defined project features	67
Contractor's reputation	67
Value for money	67
Clear user's requirement	67
Personal experience of delivering projects	67
Contractor's reputation	67
Owner's experience with similar projects	33
**********	

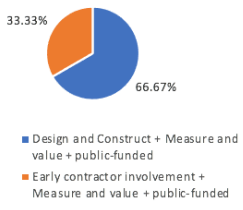
Selected PSC (after revision)	Percent (%)
Clear user's requirement	100
Categories of client	100
Complexity	100
Risk management	100
Contractor's reputation	100
Value for money	100
Size of project	67
Personal experience of delivering projects	67
Contractor's reputation	67
**********	





****
****
The above tables print the final selected criteria after 3 rounds.
percent for selection of pathway 1: 0
the involved participants are: **********
percent for selection of pathway 2: 66.66%,
the involved participants are: 1,3 **********
percent for selection of pathway 3: 33.33%,
the involved participants are: 2,
****
****
percent for All-in-one + Measure and value + public-funded: 0.00%,
percent for All-in-one + Measure and value + private-funded : 00.0%,
percent for Design and Construct + Measure and value + public-funded: 66.67%,
percent for Design and Construct + Measure and value + private-funded: 0.00%,
percent for Early contractor involvement + Measure and value + public-funded: 33.33%,
percent for Early contractor involvement + Measure and value + private-funded: 0.00%,
percent for Alliance + private-funded: 00.00%,
****
****
pathways 1: for user direct select; pathway 2: for input weights by users; pathway 3: for AHP





Suggested procurement system	**Final decision:**
Design and Construct + Measure and value + public-funded: 66.67% Early contractor involvement + Measure and value + public-funded: 33.33%	Design and Construct + Measure and value + public-funded

As suggested by T3 and T4, the framework should provide charts and graphs to display the results. The figures could be automatically shown according to the STEP IV and STEP V findings with support by MATLAB. Graphic presentation is better able to directly display the distribution of the participants' knowledge within the same organisation and the same project than a text

description can. The framework and dashboard can provide a procurement panel with comprehensive information on the decision-making process. As T4 explained, “It looks like a new communication approach, and I am expected to view the whole from the beginning to the end.” Considering the feedback from the panel members who participated in the case study, the revised framework included an additional step, STEP VI, which displayed a dashboard that reported the cognitive computing process as well as the final decision based on the analysis.

8.CHAPTER EIGHT: CONCLUSION

The research aimed to improve the quality of the decision-making process for procurement system selection in roading infrastructure projects**.** Chapter Eight is the conclusion of this thesis and reflects on how well the research has achieved its primary research aim. The chapter comprises three subsections: section 8.1 discusses how each research objective has been achieved, section 8.2 demonstrates the theoretical and practical implications of the research findings, and section 8.3 lists the limitations of the research and provides future research directions that would extend the current research.

8.1 The three research objectives

This research employed a pragmatic stance that believes "research methods should be integrated or mixed building on their complementary strengths and non-overlapping weaknesses" (Plano Clark & Ivankova, 2016). Therefore, a mixed-methods approach was utilised to address the research objectives. The following sections summarise how the objectives have been achieved.

8.1.1 The key components of procurement system decision-making process

- *Research objective one: To investigate the key components of procurement system decision-making processes***.**

The research addressed the first objective by posing two sub-questions:

(1) What are the key themes in the procurement system decision-making process?

(2) What is the significance of these key themes to the procurement system decision-making process?

The questions have been answered in Chapter Four through a quantitative research method; namely, a literature review. A secondary data collection technique was used to identify all bibliographic studies related to PSS. Based on a systematic process, the peer-reviewed journal

articles were descriptively analysed. Supported by the bibliometric analysis software *VOSviewer*, three themes were identified that showed the key components in selecting a suitable PS in the construction sector.

8.1.1.1 Procurement system

To develop a decision-making framework for procurement system selection, the first step must be to clarify what a *procurement system* is. The results from the quantitative analysis show that only 5% of the peer-reviewed articles that looked at construction procurement provided a clear definition of PS. It is evident that a shared understanding of PS concepts is lacking in the academic literature. Extant studies have examined PS at multiple levels; some at the macro-level, others at the project level and some at different stages of the project chain. As a result, the studies have had different foci – for example, contract types, contractor selection, supplier selection – and hence show different understandings of PSS. The findings from the literature review highlighted the need to consider and focus on a clear definition of PSs during the qualitative interviews, as well as a need to explore the similarities and differences between different PSs.

8.1.1.2 Procurement system selection criteria

Data from quantitative analysis indicate that there is a holistic view of the PSC in the construction sector, and this finding could contribute to the construction of the PS decision-making process in terms of a PSC database. The research confirmed the pivotal role of PSC and centres on the necessity of considering PSC in terms of both project performance and the implementation process. Nonetheless, it was observed that there is no universal set of PSC and there is no clear classification of the identified PSC. A total of 256 PSC have been identified in the construction sector, and these criteria make up the list of PSC for the proposed framework.

8.1.1.3 Decision-supporting techniques

DSTs have been recognised as one of the core elements in the decision-making process. The literature review identified that the research scope into PSS has extended into chain management and the operations field, indicating that DSTs have been developed for informed decision-making. Novel decision-supporting techniques have been found helpful in information collection and analysis Overall, 62 articles were identified from the existing studies that mentioned DSTs, including 13 that focused specifically DSTs. Table 4.6 displays the characteristics, and benefits and limitations of adopting these techniques, while Figure 4.10 illustrates how different DSTs have been applied to support decision-making during PSS. The results from both the quantitative and qualitative phases of this research confirmed the selected PS would be more reliable if DSTs were adopted because these techniques focus on systematic and objective decision-making to achieve accurate results.

But although the results highlight the potential benefit of employing DSTs in the proposed framework, further analysis of DSTs is needed, given the recent evolution of PSC and PSs as well as the ongoing development of ever-more-powerful technology platforms.

8.1.2 NZ roading infrastructure projects context

- *Research objective two: To discover the current procurement system selection processes being used in New Zealand roading infrastructure projects.*

The research examined New Zealand infrastructure procurement decisions to determine the fundamentals of PSS. At the same time, it examined the challenges of implementing the current PSS processes and provides suggestions for potential improvements. This thesis employed qualitative research to addressed RO2, and the findings were presented in Chapter Five.

8.1.2.1 New Zealand roading infrastructure projects procurement system

A *procurement system* consists of four components: *value management*, *contract types*, *price models*, and *funding*. In the context of New Zealand roading infrastructure projects, there are seven *procurement systems*, as shown in Table 7.2.

7.3.1.3 The factors that influence the procurement system decision

The key stakeholders in New Zealand roading infrastructure projects identified six groups of factors that influence the procurement system decision: *project risks, complexity, price competition, best value, political issues,* and *organisational considerations*. The sub-categories of each group are shown in Figure 5.2. These factors are considered as the criteria for the PSS decision-making process. Just as was found in the quantitative phase of the research, the participants interviewed in the qualitative phase had no shared consensus on a universal set of PSC.

8.1.2.3 The techniques used for procurement system selection

The interview data show that DSTs support decision-makers to analyse their decisions and extract information. Decision-supporting techniques such as AHP, MUV, RA can be applied to analyse PSC based on experts' knowledge. The interviewees confirmed there is a need for better information management during the PSS process, as it is rarely applied in the current market.

8.1.2.4 The challenges of and potential improvements to the current roading infrastructure project procurement system selection process

The challenges in the roading infrastructure project PSS process were discussed from four perspectives. A summary of the key findings is presented below:

1. Strategic-level issues
    - The practitioners lack experience in delivering various PSs and making a wise decision for a suitable PS.

- There is no rigour guidance to support PSS.
- Organisational knowledge is lost if the experts relocate, resign or retire.

2. Project-level issues
    - Uncertainty and delay often happen under the current PS decision-making process.
    - There is asymmetric information between different stakeholders.
    - The practitioners misunderstand the decision-making process and mistrust is common between stakeholders.
3. Organisational-level issues
    - The organisations lack a radical mindset and are reluctant to adopt novel PSs and novel DSTs.
    - Self-interest leads to different stakeholders having different goals.
4. Individual-level issues
    - It is still very limited for many who are making PSS decisions in the construction sector.
    - Unexpected consequences can add additional requirements of the practitioners

The interview data provide two suggestions for PSS improvements:

1. Shared and visualised knowledge should be provided for all participants in the PSS chain.
2. Transparent and updated information is required to aid the participants to gain experience and to achieve symmetric information.

The practitioners also warned that adoption of DSTs would only happen if they proved to be time- and cost-effective.

8.1.3 Procurement system selection framework

- *Research objective three: To develop and validate a procurement system selection framework.*

Based on the critical components identified in the PSS decision-making process and potential improvements to address the current challenges, this research developed a framework to support PSS decision-making for New Zealand roading infrastructure projects. A case study was then employed to validate the proposed framework.

The framework was established based on the integration of the findings from the quantitative and qualitative research phases. The case study validates the proposed framework, and also identified ways to improve the applicability of the framework. A summary revised process for the procurement system selection for roading infrastructure projects is presented in Figure 8.1. Overall, the framework contains six steps.

STEP I – Identifying procurement systems for New Zealand roading infrastructure projects

There is no universally agreed definition or description of PSs using in New Zealand roading infrastructure projects. Based on the quantitative and qualitative data (that is, data from the documents and interviews, respectively) PSs can classified into seven categories: (1) All-in-one + Measure and value + publicly funded, (2) All-in-one + Measure and value + privately funded, (3) Design and Construct + Measure and value + publicly funded, (4) Design and Construct + Measure and value + privately funded, (5) Early contractor involvement + Measure and value + publicly funded, (6) Early contractor involvement + Measure and value + privately funded, and (7) Alliance + privately funded (see Table 6.1).

STEP II – Clarifying procurement selection criteria

A systematic literature review identified 256 PSC. Considering the characteristics of roading infrastructure projects in New Zealand, the interview data show that the PSC comprise roading

project characteristics, risks, best value, price competition, complexity, stakeholder integration, political considerations, organisational considerations and others. Combining the findings from the literature review and the interviews, the 233 PSC relevant to roading infrastructure projects in New Zealand can be seen in Figure 6.1.

STEP III – Linguistic rating for decision alternatives

STEP III allows each participant to display their individual opinions on decision alternatives based on a five-part rating score, from 0 = least important to 1.0 = extremely important (see Table 6.2).

At this step, each participant has a chance to review their personal understanding of those procurement activities. This step also provides the participants with an opportunity to change the classifications of the PSC determined in STEP II. It is understandable that different participants will categorise PSC in different ways. For this reason, the framework empowers the participants to consider the specific requirements of roading project procurement. For example*, size of project* was identified as *weights for altered PSC* in the case study, indicating that T2 had disagreed with *size of project* belonging in PSC group one. Meanwhile, a suitable set of weights for *size of project* against each PS was provided.

STEP IV – Group decision for determining the decision attribute

STEP IV is when the group decision is made, which means that all the participants need to have identified a shared list of PSC for a roading infrastructure project. Over several rounds, the number of PSC is narrowed down to a maximum of 20 for the project in question. Specifically, STEP IV comprises two stages: in stage one, the participants select the core PSC through a three-round Delphi process, and in stage two, participants have a chance to revise their decisions by repeating rounds two and three.

STEP V – Determining the optimal decision

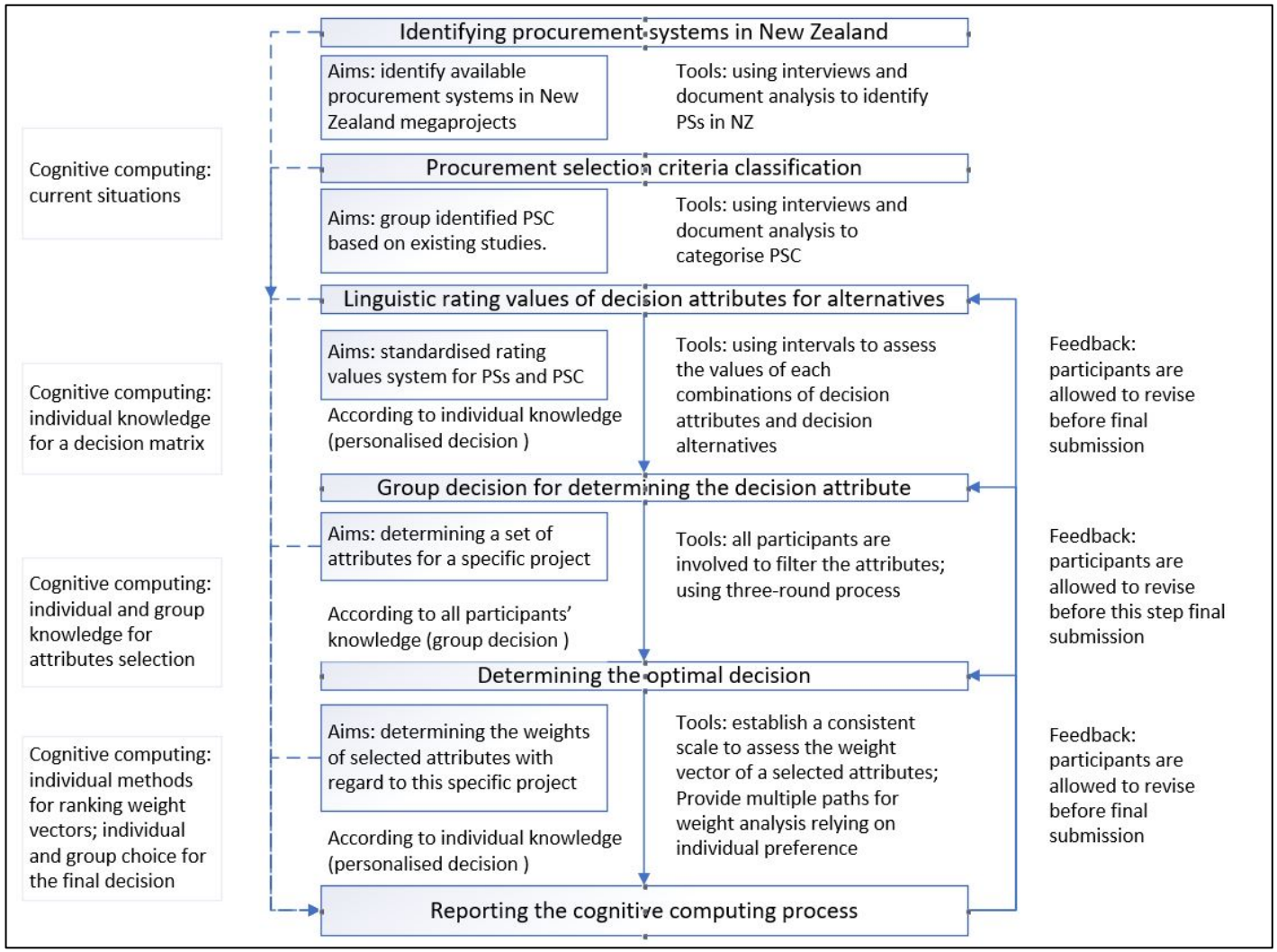
Participants are encouraged to select their preferred approach to analysing PSC. As all participants come with diverse backgrounds and experiences in delivering roading infrastructure projects, they are likely to choose different decision-supporting techniques. For example, experienced practitioners might directly provide PSC values, while inexperienced decision-makers might need a systematic and heuristic process to support and guide them to make a wise decision.

STEP VI – Reporting the cognitive computing process

The cognitive computing process is reported in three phases:

1. An individual understanding of PSC-PS relationships can present the basic understanding of PSS.
2. A combination of group and individual decisions regarding PSC enable the participants to realise and revise a list of PSC suitable for their specific project.
3. A preferred DST would be adopted based on each participant's experience in roading infrastructure projects. The participants' mindsets might be influenced by the results displayed on the dynamic dashboard and other people's knowledge displayed on the communication board. Through feedback loops and dynamic dashboards, the participants' knowledge can be visualised and shared.

Figure 0.1 A framework for roading infrastructure procurement system selection



8.2 Theoretical and practical implications

This research makes two significant research contributions to the construction procurement management body of knowledge. The following is a list of specific contributions from two aspects.

Initially, the framework uses artificial intelligence algorithms to visualise expert knowledge through a step-by-step process. Even though those algorithms have been explored in many engineering decision system studies, they have not often been used to combine individual and group techniques in a whole decision-making procedure. In the existing studies, many decision-supporting charts are followed by data collection and data analysis procedures without considering the practical difficulties such as the technique's acceptability, users' cognitive capabilities and linguistic errors. Subsequently, I believe this study provides a valuable guideline for academia interested in better understanding the applications of DSTs in the construction procurement field. Furthermore, the framework gives practitioners an experience of the decision-making process through visualised dashboards. And last but certainly not least, this research has developed a platform where individual experts' and organisations' knowledge can be shared within the context of a systematic decision-making process.

The framework also provides dynamic displays of the decisions made at each step and can record knowledge and information. It sheds light on the methodological benefits of expert and intelligent systems of collaborative decision-making in general and highlights the fundamental cognitive aspects of construction procurement decisions in particular. Rather than just ending at organisational choices, the participants' cognitive process is also central in this framework and the participants play a vital role in the visualised decision process. Their previous experience, domain knowledge in this area, and cognitive capabilities would be computing that perhaps promote the individual cognitive functioning. Analysis of the different steps of the framework will open researchers' eyes about how group decisions influence individual behaviours and how cognitive learning can be achieved. The visual dashboard reveals the overall group decisions,

which are then confirmed or changed, perhaps through direct interaction between individuals in the group over the communication board. Feedback from the participants can potentially lead to clarification of the dashboard information. The framework gives new and practical insights into how knowledge can be shared and exchanged through visualised dynamics of a structured procedure. In this case, the participants' engagement brings a holistic understanding of the effects of their attitudes towards strategic decisions and their knowledge of construction procurement. It is also important that organisations work with experts who comprehensively understand the decision-making process through well-designed knowledge visualisation and high-level human cognitive computing.

8.3 Limitations and future research

Although mixed methods research is straightforward, challenges were encountered during the research. The proposed framework encompasses diverse disciplines, and research into a cross-discipline real-world issue can be complicated and challenging for a young researcher. The research required analysis and integration of data from the literature review, secondary documents and qualitative interviews. Logistically, comparing and contrasting these different forms of data throughout the research meant continuous clarification and refinement of the research strategies; for example, deciding which method should be assigned priority in the framework.

There were three COVID-19 lockdowns during the research period, making it difficult to adhere to the original schedule. For example, face-to-face interviews became a challenging task. Also, I had planned to employ a focus group to validate the framework, but had to change this to a case study. Although the case study successfully confirmed the validity of the proposed framework and also identified ways to improve it, future research should include a focus group for a more extensive expert examination. Furthermore, there were some unexpected results from the quantitative study. For example, the literature review was unable to clearly identify PSS stakeholders in the context of roading infrastructure projects, so a pilot study was needed to

explore and identify stakeholders who could be interviewed for the qualitative study. Furthermore, many concepts around the PSS decision-making process are still unclear. For example, future research could examine how much time and resourcing is needed for effective PSS decision-making, and an exploration of the meanings of the sub-themes for each procurement system would also be useful.

This thesis sheds light on future research that could cultivate intelligence in the construction sector through the use of DSTs in procurement practice. It has provided an innovative view of the PSS process, including identification of the most influential DSTs and PSC. Meanwhile, other methods (e.g. regression analysis, neural network) could also be used to promote wise decision-making. Furthermore, many other DSTs have recently been developed in other sectors to cope with uncertainty and measure the weight of criteria, such as VIsekriterijumska optimizacija i KOmpromisno Resenje (VOIKR) (Yurdakul et al., 2020), in vitro fertilization (Louis et al., 2021), and probabilistic linguistic term sets (PLTS) (Wang et al., 2021). Those techniques could be given more attention in future research on construction procurement decisions alongside the ones covered in this thesis.

Feedback given during the case study has provided interesting insights into the influence of interactions on collaborative and individual decisions. To the best of my knowledge, this is the first research to reveal the role of knowledge visualisation in supporting construction procurement decision-making. Based on the existing epistemologies in the construction field, future research is recommended to investigate the effects of knowledge sharing on the quality of construction PS decisions.

The framework presented in this thesis has been based on and developed from a sound theory of techniques and fundamental innovative processes. It has focused explicitly, however, on knowledge visualisation for New Zealand roading infrastructure procurement. Future research could, therefore, consider various sectors with diverse variables across different industries.

Recruiting participants from different countries and organisations would also be an extension worth exploring.

REFERENCES

Abd Jamil, A. H., & Fathi, M. S. (2018). Contractual challenges for BIM-based construction projects: A systematic review. *Built Environment Project and Asset Management, 8*(4), 372–385. http://dx.doi.org/10.1108/BEPAM-12-2017-0131

Abu, H., Mohamad, N. Y., Muhammad Asim, T., & Wiwied, V. (2016). Effect of knowledge management on growth performance in construction industry. *Management Decision, 54*(3), 735–749. https://doi.org/10.1108/MD-01-2015-0006

Agbesi, K., Fugar, F. D., & Adjei-Kumi, T. (2018). Modelling the adoption of sustainable procurement in construction organisations. Built Environment Project and Asset Management, 8(5), 461–476. https://doi.org/10.1108/BEPAM-10-2017-0108

Akbiyikli, R., Eaton, D,. & Dikmen, S. U. (2012). Achieving sustainable construction within private finance initiative (Pfi) road projects in the UK. *Technological and Economic Development of Economy, 18*(2), 207–229. https://doi.org/10.3846/20294913.2012.677586

Akintoye, A. (1994). Design and build: A survey of construction contractors' views. *Construction Management and Economics, 122*(2), 155–163. https://doi.org/10.1080/01446199400000021

Akintoye, A., Goulding, J., & Zawdie, G. (2012). *Construction innovation and process improvement*, Wiley-Blackwell. https://doi.org/10.1016/j.jclepro.2015.11.057

Aktin, T., & Gergin, Z. (2016). Mathematical modelling of sustainable procurement strategies: three case studies. *Journal of Cleaner Production, 113*(1), 767–780. https://doi.org/10.1016/j.jclepro.2015.11.057

Al Khalil, M. I. (2002). Selecting the appropriate project delivery method using AHP. *International Journal of Project Management, 20*(6), 469–474. https://doi.org/10.1016/s0263-7863(01)00032-1

Alarabiat, A., & Ramos, I. (2019). The Delphi Method in information systems research (2004–2017). *Electronic Journal of Business Research Methods, 17*(2), 86–99. https://doi.org/10.34190/JBRM.17.2.04

Alhazmi, T., & Mccaffer, R. (2000). Project procurement system selection model. *Journal of Construction Engineering and Management-Asce, 126*(3), 176–184. https://doi.org/10.1061/(asce)0733-9364(2000)126:3(176)

Ansah, R. H., & Sorooshian, S. (2018). 4P delays in project management. *Engineering Construction & Architectural Management, 25*(1), 62–76. https://doi.org/

Arnott, D., & Gao, S. (2019). Behavioral economics for decision support systems researchers. *Decision Support Systems, 122*(2), 113063. https://doi.org/10.1016/j.dss.2019.05.003

Auckland Council. (2021). Procurement strategy, policy, and sustainable framework. https://www.aucklandcouncil.govt.nz/plans-projects-policies-reports-bylaws/our-policies/Pages/procurement-strategy-policy.aspx

Auckland University. (2020). Procurement strategy. https://cdn.auckland.ac.nz/assets/auckland/about-us/the-university/procurement/procurement-strategy.pdf

Austin, R. B., Pishdad-Bozorgi, P., & De La Garza, J. M. (2016). Identifying and prioritizing best practices to achieve flash track projects. *Journal of Construction Engineering and Management, 142*(2). https://doi.org/10.1061/(ASCE)CO.1943-7862.0001061

Baiden, B. K., Price, A. D. F., & Dainty, A. R. J. (2006). The extent of team integration within construction projects. *International Journal of Project Management, 24*(1), 13–23. https://doi.org/10.1016/j.ijproman.2005.05.001

Bazerman, M. H., & Moore, D. A. (2009). *Judgment in managerial decision making*, John Wiley & Sons. https://search.ebscohost.com/login.aspx?direct=true&db=cat05020a&AN=aut.b11388158&site=eds-live.

Béhague, D., & Storeng, K. (2013). Pragmatic politics and epistemological diversity: The contested and authoritative uses of historical evidence in the Safe Motherhood Initiative. *Evidence & Policy: A Journal of Research, Debate & Practice, 9*(1), 65–85. https://doi.org/10.1332/174426413X663724

Berghman, L., Matthyssens, P., Streukens, S., & Vandenbempt, K. (2013). Deliberate learning mechanisms for stimulating strategic innovation capacity. *Long Range Planning,* 46(1-2), 39–71. https://doi.org/10.1016/j.lrp.2012.11.003

Bolanos, L., Transue, M., Wheeler, P., & Gifford, J. (2019). US surface transportation public-private partnerships: Objectives and evidence-extended findings. *Transportation Research Record, 2673*(1), 290–300. https://doi.org/10.1177%2F0361198119858280

Braun, V., & Clarke, V. (2013). *Successful qualitative research: A practical guide for beginners.* SAGE. https://search.ebscohost.com/login.aspx?direct=true&db=cat05020a&AN=aut.b12878121&site=eds-live.

Brockmann, C. (2021). *Advanced construction management: The complexity of megaprojects.* Wiley-Blackwell. http://ebookcentral.proquest.com/lib/AUT/detail.action?docID=6426888.

Bruno, T., Gelderman, C. J., Lambrechts, W., & Semeijn, J. (2018). The promise of Best Value Procurement: Governance and (in)stability of specifications within an innovative biogas project. *Journal of Cleaner Production, 172*(4), 1465–1475. https://doi.org/doi:10.1016/j.jclepro.2017.10.251

Bryman, A. (2006). *Mixed methods.* SAGE. SAGE. https://search.ebscohost.com/login.aspx?direct=true&db=cat05020a&AN=aut.b11307407&site=eds-live.

Cañas, A. J., Carff, R., Hill, G., Carvalho, M., Arguedas, M., Eskridge, T. C., Lott, J., & Carvajal, R. (2005). *Concept maps: Integrating knowledge and information visualization*, Springer Verlag. Retrieved from https://ezproxy.aut.ac.nz/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=edselc&AN=edselc.2-52.0-36849066332&site=eds-live.

Carneiro, J., Martinho, D., Marreiros, G. & Novais, P. (2019). How cognitive and affective aspects can influence the outcome of the group decision-making process. *Expert Systems*, *36*(3), 18-46. https://doi.org/10.1111/exsy.12257

Carlin, A. P., & Kim, Y. H. (2019). Teaching qualitative research: Versions of grounded theory. *Grounded Theory Review*, 18(1), 29–43.

Chan, A. P. C., Yung, E. H. K., Lam, P. T. I., Tam, C. M., & Cheung, S. O. (2001). Application of Delphi method in selection of procurement systems for construction projects. *Construction Management and Economics, 19*(7), 699–718. https://doi.org/10.1080/01446190110066128

Chan, C. T. W. (2007). Fuzzy procurement selection model for construction projects. *Construction Management and Economics, 25*(6), 611–618. https://doi.org/10.1080/01446190701209933

Chang, C.-Y., & Ive, G. (2002). Rethinking the multi-attribute utility approach based procurement route selection technique. *Construction Management and Economics, 20*(3), 275–284. http://doi/org/10.1080/01446190110117608

Chao, L. C., & Hsiao, C. S. (2012). Fuzzy model for predicting project performance based on procurement experiences. *Automation in Construction, 28*(5), 71–81. https://doi.org/10.1016/j.autcon.2012.07.003

Chen, C.-Y. (2011). Managing projects from a client perspective: The concept of the meetings-flow approach. *International Journal of Project Management, 29*(6), 671–686. https://doi.org/10.1016/j.eswa.2010.10.008

Chen, L., Manley, K., Lewis, J., Helfer, F., & Widen, K. (2018). Procurement and governance choices for collaborative infrastructure projects. *Journal of Construction Engineering and Management, 144*(8), 10-15. https://doi.org/10.1061/%28ASCE%29CO.1943-7862.0001525

Chen, Q., Jin, Z. G., Xia, B., Wu, P., & Skitmore, M. (2016). Time and cost performance of design-build projects. *Journal of Construction Engineering and Management, 142*(2), 04015074 1-7. http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0001056

Chen, Y. Q., Liu, J. Y., Li, B. G., & Lin, B. S. (2011). Project delivery system selection of construction projects in China. *Expert Systems with Applications, 38*(5), 5456–5462. https://doi.org/doi:10.1016/j.eswa.2010.10.008

Cheung, S. O., Lam, T. I., Leung, M. Y., & Wang, Y. W. (2001). An analytical hierarchy process based procurement selection method. *Construction Management and Economics, 19*(4), 427–437. https://doi.org/doi:10.1061/(asce)0742-597x(2001)17:3(132)

Cheung, S. O., Lam, T. I., Wan, Y. W., & Lam, K. C. (2001). Improving objectivity in procurement selection. *Journal of Management in Engineering, 17*(3), 132–139. https://doi.org/10.1061/(asce)0742-597x(2001)17:3(132)

Chua, S. J. L., Ali, A. S. & Bin Alias, A. (2015). Analytic hierarchy process decision-making framework for procurement strategy selection in building maintenance work. *Journal of Performance of Constructed Facilities, 29*(2), 13. http://dx.doi.org/10.1061/(ASCE)CF.1943-5509.0000529

Cobo, M. J., López-Herrera, A. G., Herrera-Viedma, E. & Herrera, F. (2011). Science mapping software tools: Review, analysis and cooperative study among tools. Journal of the American Society for Information Science and Technology, 62(7), 1382–1402. https://doi.org/10.1002/asi.21525

Corbin, J. M., & Strauss, A. L. (2008). *Basics of qualitative research: Techniques and procedures for developing grounded theory.* Sage Publications. Retrieved from https://ezproxy.aut.ac.nz/login?url=https://methods.sagepub.com/book/basics-of-qualitative-research.

Cortez, R. M. & Wesley, J. J. (2019). Cultivating organizational wisdom for value innovation. *Journal of Business & Industrial Marketing, 34*(6)**,** 1171–1182. https://doi.org/10.1108/JBIM-11-2017-0292

Creswell, J. W. (2005). *Collecting data in mixed methods research.* Pearson Education.

Creswell, J. W. (2013). *Qualitative inquiry & research design: Choosing among five approaches.* SAGE. https://search.ebscohost.com/login.aspx?direct=true&db=cat05020a&AN=aut.b12523665&site=eds-live.

Creswell, J. W,. & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches.* SAGE. https://search.ebscohost.com/login.aspx?direct=true&db=cat05020a&AN=aut.b24601627&site=eds-live.

Crotty, M. (1998). *The foundations of social research: Meaning and perspective in the research process*. Sage.

Dada, J. O. (2017). An appraisal of paradigm shifts required of competence of the Nigerian quantity surveyors. *Engineering, Construction and Architectural Management, 24*(6)**,** 1269–1280. http://doi.org/10.1108/ECAM-02-2016-0038

Davies, C., & Fisher, M. (2018). Understanding research paradigms. *Journal of the Australasian Rehabilitation Nurses Association, 21*(3)**,** 21–25. https://ezproxy.aut.ac.nz/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=anh&AN=134014168&site=eds-live

Davis, P. R., Jefferies, M., & Ke, Y. (2017). Psychological contracts: Framework for relationships in construction procurement. *Journal of Construction Engineering and Management, 143*(8), 04017028. http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0001327

Deb, D., Balas, V. E., & Dey, R. (2019). *Engineering research methodology: A practical insight for researchers.* Springer. https://ezproxy.aut.ac.nz/login?url=https://link.springer.com/10.1007/978-981-13-2947-0.

Delgado, L., Shealy, T., Garvin, M., & Pearce, A. (2018). Framing energy efficiency with payback period: Empirical study to increase energy consideration during facility procurement processes. *Journal of Construction Engineering and Management, 144*(5). http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0001464

Denzin, N. K. & Lincoln, Y. S. (2008). *Collecting and interpreting qualitative materials*. Sage Publications.

Dictionary. (2011). *Oxford Dictionary*. Available: https://www-oed-com.ezproxy.aut.ac.nz

Doloi, H. (2013). Empirical analysis of traditional contracting and relationship agreements for procuring partners in construction projects. *Journal of Management in Engineering, 29*(3)**,** 224–235. http://dx.doi.org/10.1061/(ASCE)ME.1943-5479.0000141

Dzeng, R.-J., & Chang, S.-Y. (2005). Learning search keywords for construction procurement. *Automation in Construction, 14*(1)**,** 45–58. https://doi.org/10.1016/j.autcon.2004.06.003

Eadie, R., & Mccavigan, M. (2016). Random selection: Winning the lottery in construction contracts. *International Journal of Procurement Management, 9*(2), 185–205. https://doi.org/10.1504/IJPM.2016.075264

Eastman, C. (2018). *Researching organizational coaching using a pilot study.* SAGE. https://methods.sagepub.com/case/researching-organizational-coaching-using-a-pilot-study.

Eck, N. J. V., & Waltman, L. 2010. Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics, 84*(2), 523–538. https://doi.org/ 10.1007/s11192-009-0146-3

Edirisinghe, R. (2019). Digital skin of the construction site: Smart sensor technologies towards the future smart construction site. *Engineering Construction & Architectural Management, 26*(2), 184–223. https://doi.org/10.1108/ECAM-06-2016-0139

Edler, J., & Georghiou, L. (2007). Public procurement and innovation – Resurrecting the demand side. *Research Policy, 36*(7), 949–963. https://doi.org/10.1016/j.respol.2007.03.003

Edmonds, W. A., & Thomas, D. K. (2017). *An applied guide to research designs: Quantitative, qualitative, and mixed methods.* SAGE. https://doi.org/10.4135/9781071802779

Egan, J. (1998). *Rethinking construction –The Egan report.* https://constructingexcellence.org.uk/wp-content/uploads/2014/10/rethinking_construction_report.pdf

Ekanayake, E. M. A. C., Shen, G., & Kumaraswamy, M. M. (2019). Mapping the knowledge domains of value management: A bibliometric approach. *Engineering, Construction and Architectural Management, 26*(3), 499–514. https://doi.org/10.1108/ECAM-06-2018-0252

El Wardani, M. A., Messner, J. I., & Horman, M. J. (2006). Comparing procurement methods for design-build projects. *Journal of Construction Engineering and Management, 132*(3), 230–238. https://doi.org/doi:10.1061/(asce)0733-9364(2006)132:3(230)

Eppler, M. J., & Bresciani, S. (2013). Visualization in management: From communication to collaboration. A response to Zhang. *Journal of Visual Languages and Computing, 24*(3), 146–149. https://doi.org/10.1016/j.jvlc.2012.11.003

Eriksson, P. E., Dickinson, M., & Khalfan, M. M. A. (2007). The influence of partnering and procurement on subcontractor involvement and innovation. *Facilities, 25*(5-6), 203–214. http://doi.org/10.1108/jfmpc-05-2016-0018

Eriksson, P. E., Lingegard, S., Borg, L., & Nystrom, J. (2017). Procurement of railway infrastructure projects – a European benchmarking study. *Civil Engineering Journal – Tehran, 3*, 199–213. https://doi.org/10.28991/cej-2017-00000086

Eriksson, P. E., Volker, L., Kadefors, A., Lingegard, S., Larsson, J., & Rosander, L. (2019). Collaborative procurement strategies for infrastructure projects: A multiple-case study. *Proceedings of the Institution of Civil Engineers – Management Procurement and Law, 172*, 197–20. http://doi.org/10.1680/jmapl.19.00016

Eugenia, S.-T., Nataliia, M., Olena, K., & Piet, K. (2018). Mapping and visualization: Selected examples of international research networks. *Journal of Information, Communication and Ethics in Society, 16*(4), 381–400. https://doi.org/10.1108/JICES-03-2018-0028

Fellows, R., & Liu, A. (2015). *Research methods for construction*. John Wiley & Sons. http://ebookcentral.proquest.com/lib/AUT/detail.action?docID=1895747.

Ferme, L., Zuo, J., & Rameezdeen, R. (2018). Improving collaboration among stakeholders in green building projects: Role of early contractor involvement. *Journal of Legal Affairs*

and Dispute Resolution in Engineering and Construction, 10(4), 04518020. http://dx.doi.org/10.1061/(ASCE)LA.1943-4170.0000278

Fielder, A., Panaousis, E., Malacaria, P., Hankin, C., & Smeraldi, F. (2016). Decision support approaches for cyber security investment. *Decision Support Systems, 86*(4)**,** 13–23. https://doi.org/10.1016/j.dss.2016.02.012

Frada, B., & Clyde, W. H.(2008). *Handbook on decision support systems 1: Basic themes.* Springer. https://search.ebscohost.com/login.aspx?direct=true&db=edsebk&AN=255937&site=eds-live.

Glasersfeld, E. V. (1995). *Radical constructivism: A way of knowing and learning.* Falmer Press. https://search.ebscohost.com/login.aspx?direct=true&db=cat05020a&AN=aut.b11243648&site=eds-live.

Hahn, B. D., & Valentine, D. T. (2019). *Essential MATLAB for engineers and scientists.* Academic Press. https://ezproxy.aut.ac.nz/login?url=https://www.sciencedirect.com/science/book/9780081029978

Harden, A., & Thomas, J. (2010). Mixed methods and systematic reviews: Examples and emerging issues. In A. Tashakkori & C. Teddlie (Eds.), *SAGE handbook of mixed methods in social and behavioral research.* SAGE.

Haynes, L., & Roden, N. (1999). Commercialising the management and maintenance of trunk roads in the United Kingdom. *Transportation, 26*(1)**,** 31–54. https://doi.org/10.1023/a:1005180621490

He, B., Huang, H., & Yuan, K. F. (2016). Managing supply disruption through procurement strategy and price competition. *International Journal of Production Research, 54*(7)**,** 1980–1999. https://doi.org/10.1080/00207543.2015.1074297

Hesse-Biber, S. N.(2010). *Mixed methods research: Merging theory with practice*. Guilford Press. http://ebookcentral.proquest.com/lib/AUT/detail.action?docID=471119.

Heyvaet, M., Hannes, K,. & Onghena, P. (2017). *Using mixed methods reseerch synthesis for literature reviews.* SAGE.

Hu, X., Xia, B., Skitmore, M., & Chen, Q. (2016). The application of case-based reasoning in construction management research: An overview. *Automation in Construction, 72*(2), 65–74. https://doi.org/10.1016/j.autcon.2016.08.023

Humble, Á., & Radina, M. (2019). *How qualitative data analysis happens: Moving beyond "Themes emerged"*. Routledge. https://search.ebscohost.com/login.aspx?direct=true&db=cat05020a&AN=aut.b26863315&site=eds-live.

Ibbs, W., & Chih, Y. Y. (2011). Alternative methods for choosing an appropriate project delivery system (PDS). *Facilities, 29*(13)**,** 527–541. https://doi.org/10.1108/02632771111178418

Ibrahim, C., Costello, S. B., Wilkinson, S., & Walker, D. (2017). Innovation in alliancing for improved delivery of road infrastructure projects. *International Journal of Managing Projects in Business, 10*(4)**,** 700–720. https://doi.org/10.1108/ijmpb-11-2016-0088

Issa, R., & Mutis, I. (2015). *Ontology in the AEC industry: A decade of research and development in architecture, engineering, and construction.* American Society of Civil Engineers. http://ebookcentral.proquest.com/lib/AUT/detail.action?docID=3425651.

Ivankova, N. V., Creswell, J. W., & Stick, S. L. (2006). Using mixed-methods sequential explanatory design: From theory to practice. *Field Methods, 18*(1), 3–20. https://doi.org/10.1177/1525822X05282260

Ive, G., & Chang, C. Y. (2007). The principle of inconsistent trinity in the selection of procurement systems. *Construction Management and Economics, 25*(7), 677–690. https://doi.org/10.1080/01446190601164089

Jeong, Y. K., Song, M., & Ding, Y. (2014). Content-based author co-citation analysis. *Journal of Informetrics, 8*(1), 197–211. https://doi.org/10.1016/j.joi.2013.12.001

Jin, R., Zou, Y., Gidado, K., Ashton, P., & Painting, N. (2019). Scientometric analysis of BIM-based research in construction engineering and management. *Engineering, Construction and Architectural Management, 26*(8), 1750–1776. https://doi.org/10.1108/ECAM-08-2018-0350

Kaka, A. P., & Khosrowshahi, F. (1996). Effect of different procurement routes on contractors' cash flows. *Engineering Construction & Architectural Management, 3*(3), 133–145. https://doi.org/10.1109/MPOT.2014.2313072

Kandhway, K. (2015). Finding a research problem: Tips for new Ph.D. students. *IEEE Potentials, 34*(3), 25–29. https://doi.org/10.1109/MPOT.2014.2313072

Khalfan, M. M. A., Mcdermott, P., & Swan, W. (2007). Building trust in construction projects. *Supply Chain Management-an International Journal, 12*(6), 385–391. https://doi.org/10.1108/13598540710826308

Khwaja, N., O'Brien, W. J., Martinez, M., Sankaran, B., O'connor, J. T., & Hale, W. (2018). Innovations in project delivery method selection approach in the Texas Department of Transportation. *Journal of Management in Engineering, 34*(6). https://doi.org/10.1061/%28ASCE%29ME.1943-5479.0000645

Kleber, D. M.-S., & Volkova, T. (2016). Value innovation frameworks for delivering superior customer responsiveness. *Journal of Business Management*, 34–45. https://doi.org/10.1111/128993435453

Konchar, M., & Sanvido, V. (1998). Comparison of U.S. project delivery systems. *Journal of Construction Engineering and Management, 124*(6), 435–444. https://doi.org/10.1061/(asce)0733-9364(1998)124:6(435)

Koppinen, T., & Lahdenpera, P. (2007). Realized economic efficiency of road project delivery systems. *Journal of Infrastructure Systems, 13*(4), 321–329. https://doi.org/10.1061/(asce)1076-0342(2007)13:4(321)

Korom, P. (2019). A bibliometric visualization of the economics and sociology of wealth inequality: A world apart? *Scientometrics, 118*(3), 849–868. https://doi.org/10.1007/s11192-018-03000-z

Kumar, R. (2019). *Research methodology: A step-by-step guide for beginners.* SAGE. https://search.ebscohost.com/login.aspx?direct=true&db=cat05020a&AN=aut.b26576995&site=eds-live.

Kumaraswamy, M., Wong, K., & Chung, J. (2017). Focusing megaproject strategies on sustainable best value of stakeholders. *Built Environment Project and Asset Management, 7*(4), 441–455. https://doi.org/10.1108/BEPAM-01-2017-0003

Kumaraswamy, M. M., & Dissanayaka, S. M. (1998). Linking procurement systems to project priorities. *Building Research and Information, 26*(4)**,** 223–238. https://doi.org/10.1080/096132198369832

Kumaraswamy, M. M., & Dissanayaka, S. M. (2001). Developing a decision support system for building project procurement. *Building and Environment, 36*(4)**,** 337–349. https://doi.org/10.1080/096132198369832

Lædre, O., Austeng, K., Haugen, T. I., & Klakegg, O. J. (2006). Procurement routes in public building and construction projects. *Journal of Construction Engineering and Management, 132*(7)**,** 689–696. https://doi.org/10.1061/(ASCE)0733-9364(2006)132:7(689)

Laryea, S. (2019). Procurement strategy and outcomes of a new universities project in South Africa. *Engineering, Construction & Architectural Management, 26*(2). http://dx.doi.org/10.1108/ECAM-04-2018-0154

Latham, M. (1994). *Constructing the Team.* Her Majesty's Stationery Office.

Lee, M. C. Y. (2019). *Experiential learning from a pilot study of insider research: Interviewing international doctoral students.* SAGE. https://methods.sagepub.com/case/experiential-learning-from-insider-research-international-doctoral-students

Lee, V. H., Foo, A. T. L., Leong, L. Y., & Ooi, K. B. (2016). Can competitive advantage be achieved through knowledge management? A case study on SMEs. *Expert Systems with Applications, 65*(1)**,** 136–151. https://doi.org/10.1016/j.eswa.2016.08.042

Li, B., Akintoye, A., Edwards, P. J., & Hardcastle, C. (2005). Critical success factors for PPP/PFI projects in the UK construction industry. *Construction Management and Economics, 23*(5)**,** 459–471. https://doi.org/10.1080/01446190500041537

Li, D. (2013). *Values of our times: Contemporary axiological research in China*. Springer. https://link.springer.com/10.1007/978-3-642-38259-8.

Li, H. M., Cao, Y. C., Su, L. M., & Xia, Q. (2019). An interval Pythagorean fuzzy multi-criteria decision making method based on similarity measures and connection numbers. *Information, 10*(2), 80. http://dx.doi.org/10.3390/info10020080

Li, H. M., Qin, K. L., & Li, P. (2015). Selection of project delivery approach with unascertained model. *Kybernetes, 44*(2)**,** 238–252. https://doi.org/10.1108/k-01-2014-0012

Li, X., Wu, Q., & Holsapple, C. W. (2015). Best-value supply chains and firms' competitive performance: Empirical studies of their linkage. *International Jounral of Operations and Production Management, 35*(12), 1688–1709. https://doi.org/10.1108/IJOPM-01-2014-0014

Lindblad, H. (2019). Black boxing BIM: The public client's strategy in BIM implementation. *Construction Management and Economics, 37*(1)**,** 1–12. https://doi.org/10.1080/01446193.2018.1472385

Linden, I., Liu, S., & Colot, C. (2017). Decision support systems VII. Data, information and knowledge visualization in decision support system. In *Proceedings of the Third International Conference, ICDSST 2017, Namur, Belgium, May 29–31, 2017.* Springer. https://link.springer.com/10.1007/978-3-319-57487-5.

Ling, F. Y. Y., Chan, S. L., Chong, E. & Ee, L. P. (2004). Predicting performance of design-build and design-bid-build projects. *Journal of Construction Engineering & Management, 130*(1)**,** 75–83. https://doi.org/10.1061/(ASCE)0733-9364(2004)130:1(75)

Liu, B., Huo, T., Shen, Q., Yang, Z., Meng, J., & Xue, B. (2015) Which owner characteristics are key factors affecting project delivery system decision making? Empirical analysis based on the rough set theory. *Journal of Management in Engineering, 31*(4), [5014018]. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000298

Liu, T., & Wilkinson, S. (2011). Adopting innovative procurement techniques : Obstacles and drivers for adopting public private partnerships in New Zealand. *Construction Innovation, 11*(1)**,** 452–469. https://doi.org/10.1108/14714171111175918

Lo, H. W., Liou, J. J. H., Wang, H. S., & Tsai, Y. S. (2018). An integrated model for solving problems in green supplier selection and order allocation. *Journal of Cleaner Production, 190*(2)**,** 339–352. https://doi.org/10.1016/j.jclepro.2018.04.105

Loosemore, M. (2016). Social procurement in UK construction projects. *International Journal of Project Management, 34*(2)**,** 133–144. https://doi.org/10.1016/j.ijproman.2015.10.005

Louis, C. M., Erwin, A., Handayani, N., Polim, A. A., Boediono, A., & Sini, I. (2021). Review of computer vision application in in vitro fertilization: the application of deep learning-based computer vision technology in the world of IVF. *Journal of assisted reproduction and genetics*, https://doi.org/10.1007/s10815-021-02123-2

Love, P. E. D., Davis, P. R., Edwards, D. J. & Baccarini, D. (2008). Uncertainty avoidance: Public sector clients and procurement selection. *International Journal of Public Sector Management, 21*(7)**,** 753–776. https://doi.org/10.1108/09513550810904550

Love, P. E. D., Edwards, D. J., Irani, Z., & Sharif, A. (2012). Participatory action research approach to public sector procurement selection. *Journal of Construction Engineering and Management, 138***,** 311–322. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000440

Love, P. E. D., Skitmore, M., & Earl, G. (1998). Selecting a suitable procurement method for a building project. *Construction Management and Economics, 16*(2)**,** 221–233. https://doi.org/10.1080/014461998372501

Love, P. E. D., Zhou, J., Matthews, J., Sing, M. C. P., & Edwards, D. J. (2017). System information modelling in practice: Analysis of tender documentation quality in a mining mega-project. *Automation in Construction,* 84**,** 176–183. http://dx.doi.org/10.1016/j.autcon.2017.08.034

Lu, W., Hua, Y., & Zhang, S. (2017). Logistic regression analysis for factors influencing cost performance of design-bid-build and design-build projects. *Engineering, Construction and Architectural Management, 24*(1)**,** 118–132. https://doi.org/10.1108/ECAM-07-2015-0119

Luu, D. T., Chen, S. E., & Ng, S. T. (2003). Parameters governing the selection of procurement system – An empirical survey. *Engineering, Construction and Architectural Management, 10*(3)**,** 209–218. https://doi.org/10.1108/09699980310478458

Luu, D. T., Ng, S. T., & Chen, S. E. (2005). Formulating procurement selection criteria through case-based reasoning approach. *Journal of Computing in Civil Engineering, 19*(3)**,** 269–276. https://doi.org/10.1061/(asce)0887-3801(2005)19:3(269)

Luu, D. T., Ng, S. T., Chen, S. E., & Jefferies, M. (2006). A strategy for evaluating a fuzzy case-based construction procurement selection system. *Advances in Engineering Software, 37*(3)**,** 159–171. https://doi.org/10.1016/j.advengsoft.2005.05.004

Mafakheri, F., Dai, L., Slezak, D., & Nasiri, F. (2007). Project delivery system selection under uncertainty: Multicriteria multilevel decision aid model. *Journal of Management on Engineering, 23***,** 200–206. https://doi.org/10.1061/(ASCE)0742-597X(2007)23:4(200)

Mahdi, I. M., & Alreshaid, K. (2005). Decision support system for selecting the proper project delivery method using analytical hierarchy process (AHP). *International Journal of Project Management, 23*(3)**,** 564–572. https://doi.org/10.1061/(ASCE)0742-597X(2007)23:4(200)

Masterman, J. W. E. (1992). *An introduction to building procurement systems.* E & FN Spon.

Matthyssens, P. (2019). Reconceptualizing value innovation for Industry 4.0 and the industrial Internet of Things. *Journal of Business & Industrial Marketing, 34*(6)**,** 1203–1209. https://doi.org/10.1108/JBIM-11-2018-0348

Ministry of Business, Innovation & Employment (MBIE). (2019). *Government Procurement Rules for sustainable and inclusive procurement*. Accessed https://www.procurement.govt.nz/procurement/principles-charter-and-rules/government-procurement-rules/

Ministry of Business, Innovation & Employment (MBIE). (2020). *Annual procurement plan.* https://www.procurement.govt.nz/search/?keyword=procurement+system&action=Search

Merriam, S. B. (2009). *Qualitative research : a guide to design and implementation*, Jossey-Bass. https://search.ebscohost.com/login.aspx?direct=true&db=cat05020a&AN=aut.b11452006&site=eds-live

Miller, J. B., Garvin, M. J., Ibbs, C. W., & Mahoney, S. E. (2000). Toward a new paradigm: Simultaneous use of multiple project delivery methods. *Journal of Management in Engineering, 16***,** 58–67. https://doi.org/10.1061/(ASCE)0742-597X(2000)16:3(58)

Mills, J., & Birks, M. (2014). *Qualitative methodology: A practical guide.* Sage. https://methods.sagepub.com/book/qualitative-methodology-a-practical-guide

Mohan, K., Kelwin Kar Wai, W., & Jacky, C. (2017). Focusing megaproject strategies on sustainable best value of stakeholders. *Built Environment Project and Asset Management, 7*(4)**,** 441–455. https://doi.org/10.1108/BEPAM-01-2017-0003

Mohsini, R. A. (1993). Knowledge-based design of project-procurement process. *Journal of Computing in Civil Engineering, 7***,** 107–122. https://doi.org/10.1061/(ASCE)0887-3801(1993)7:1(107)

Molenaar, K. R., & Songer, A. D. (1998). Model for public sector design-build project Selection. *Journal Of Construction Engineering And Management-Asce, 124*(6)**,** 467–479. https://doi.org/10.1061/(asce)0733-9364(1998)124:6(467)

Molenaar, K. R., Songer, A. D., & Barash, M. (1999). Public-sector design/build evolution and performance. *Journal of Management in Engineering, 15*(2)**,** 54–62. https://doi.org/10.1061/(asce)0742-597x(1999)15:2(54)

Moore, H. (2018). *MATLAB for Engineers* (Global ed.) Pearson Education. http://ebookcentral.proquest.com/lib/AUT/detail.action?docID=5573755.

Morgan, D. L. (2007). Paradigms lost and pragmatism regained: Methodological implications of combining qualitative and quantitative methods. *Journal of Mixed Methods Research, 1*, 48–76. http://dx.doi.org.ezproxy.aut.ac.nz/10.1177/1558689806292462

Mostafavi, A., & Karamouz, M. (2010). Selecting appropriate project delivery system: Fuzzy approach with risk analysis. *Journal of Construction Engineering & Management, 136*(8), 923–930. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000190

Murphy, M., & Eadie, R. (2019). Socially responsible procurement: A service innovation for generating employment in construction. *Built Environment Project and Asset Management, 9*, 138–152. https://doi.org/10.1108/BEPAM-02-2018-0049

Naoum, S. G., & Egbu, C. (2016). Modern selection criteria for procurement methods in construction: A state-of-the-art literature review and a survey. *International Journal of Managing Projects in Business, 9*(2), 309–336. https://doi.org/10.1108/IJMPB-09-2015-0094

National Infrastructure Unit (NIU). (2011). *National Infrastructure Plan 2011.* New Zealand Treasury. https://www.treasury.govt.nz/publications/infrastructure-plan/national-infrastructure-plan-2011

National Economic Development Office (NEDO). (1985). Thinking about Building. *Building EDC.*

New Zealand Council for Infrastructure Development (NZCID). (2009). *Policy priorities for advancing economic infrastructure development in New Zealand.* https://www.infrastructure.org.nz/resources/Documents/Reports/NZCID%20Policy%20Recomendations%20for%20Advancing%20Economic%20Infrastructure.pdf

New Zealand Council for Infrastructure Development (NZCID). (2009). *Policy priorities for advancing economic infrastructure development in New Zealand*. http://www.infrastructure.govt.nz/plan/2011/nip-jul11.pdf.

New Zealand Government Procurement. (2019). *Government procurement rules.* https://www.procurement.govt.nz/assets/procurement-property/documents/government-procurement-rules.pdf

New Zealand Legislation Website (NZLW). (2005). Public procurement in New Zealand*. New Zealand Law Journal, 323*.

New Zealand Transport Agency (NZTA). 2013. *ŌTAKI to north of Levin SH1–SH57 Connection Scoping Report.* https://www.nzta.govt.nz/assets/projects/otaki-to-north-of-levin/docs/sh1-sh57-scoping-report.pdf

New Zealand Transport Agency (NZTA). 2014. *Transmission Gully PPP -Lessons Learnt Review-FINAL REPORT.* https://www.nzta.govt.nz/assets/projects/transmission-gully/docs/transmission-gully-ppp-lessons-learnt-review-dec-2014.pdf

New Zealand Treasury. (2021). *Consulting on New Zealand's long-term fiscal challenges*. https://www.treasury.govt.nz/publications/consultation/long-term-fiscal-2021

Ng, S. T., Duc Thanh, L., Swee Eng, C. & Ka Chi, L. (2002). Fuzzy membership functions of procurement selection criteria. *Construction Management and Economics, 20*(3)**,** 285–296. https://doi.org/10.1080/01446190210121288

Nguyen, P. H. D., Lines, B. C. & Tran, D. Q. (2018). Best-value procurement in design-bid-build construction projects: Empirical analysis of selection outcomes. *Journal of Construction Engineering and Management, 144*(10), 126–136 . http://dx.doi.org/10.1061/9780784481271.013

Novikov, A. M. & Novikov, D. A. (2013). *Research methodology: From philosophy of science to research design.* CRC Press/Balkema. http://ebookcentral.proquest.com/lib/AUT/detail.action?docID=1177216.

O'Leary, Z. (2004). *The essential guide to doing research.* SAGE. https://search.ebscohost.com/login.aspx?direct=true&db=cat05020a&AN=aut.b1090055x&site=eds-live.

Ojo, S. O., Aina, O., & Adeyemi, A. Y. (2011). A comparative analysis of the performance of traditional contracting and design-build procurements on client objectives in Nigeria. *Journal of Civil Engineering and Management, 17*(2)**,** 227–233. https://doi.org/10.3846/13923730.2011.574449

Oraee, M., Hosseini, M. R., Palliyaguru, R., Papadonikolaki, E. & Arashpour, M. (2017). Collaboration in BIM-based construction networks: A bibliometric-qualitative literature review. *International Journal of Project Management, 35*(7)**,** 1288–1301. https://doi.org/10.1016/j.ijproman.2017.07.001

Oyegoke, A. S., & Kiiras, J. (2009). Development and application of the specialist task organization procurement approach. *Journal of Management in Engineering, 25***,** 131–142(3). https://doi.org/10.1108/17538370910971018

Palaneeswaran, E., Kumaraswamy, M., & Ng, T. (2003). Targeting optimum value in public sector projects through "best value"-focused contractor selection. *Engineering, Construction and Architectural Management, 10*(6)**,** 418–431. https://doi.org/10.1108/09699980310509390

Pan, Y., & Zhang, L. (2021). Roles of artificial intelligence in construction engineering and management: A critical review and future trends. *Automation in Construction, 122***,** 103517. http://dx.doi.org/10.1016/j.autcon.2020.103517

Patterson, R. E., Blaha, L. M., Liggett, K. K., Havig, P. R., Grinstein, G. G., Sheldon, K. C., Kaveney, D. E., & Moore, J. A. (2014). A human cognition framework for information visualization. *Computers and Graphics, 42*(1)**,** 42–58. https://doi.org/10.1016/j.cag.2014.03.002

Penyalver, D., Turro, M., & Williamson, J. B. (2019). Measuring the value for money of transport infrastructure procurement: An intergenerational approach. *Transportation Research Part A – Policy and Practice, 119***,** 238–254. https://doi.org/10.1016/j.tra.2018.11.013

Perng, Y.-H., & Chang, C.-L. (2004). How does Government Procurement Law affect bidding price competition in Taiwan? *Building Research & Information: The International Journal of Research, Development and Demonstration, 32*(6)**,** 497–509. https://doi.org/10.1080/0961321042000269410

Petticrew, M., & Roberts, H. (2008). Why do we need systematic reviews? In M. Petticrew & H. Roberts (Eds.), *Systematic reviews in the ocial sciences: a practical guide.* Blackwell.

Piramuthu, S., Kapoor, G., Zhou, W., & Mauw, S. (2012). Input online review data and related bias in recommender systems. *Decision Support Systems, 53*(3)**,** 418–424. https://doi.org/10.1016/j.dss.2012.02.006

Plano Clark, V. L., & Ivankova, N. V. (2016). *Mixed methods research: A guide to the field*. SAGE. https://methods.sagepub.com/book/mixed-methods-research-a-guide-to-the-field.

Plantinga, H., Voordijk, H. ,& Doree, A. (2019). The reasoning behind infrastructure manager's choice of procurement instruments. *Engineering Construction & Architectural Management, 26*(2)**,** 303–320. https://doi.org/10.1108/ECAM-02-2018-0068

Plowright, D. (2011. *Using mixed methods: Frameworks for an integrated methodology*. SAGE. https://search.ebscohost.com/login.aspx?direct=true&db=cat05020a&AN=aut.b11918597&site=eds-live.

Pritchard, D. (2016). *Epistemology.* Palgrave Macmillan. http://ebookcentral.proquest.com/lib/AUT/detail.action?docID=4770117.

Qiang, M., Wen, Q., Jiang, H. C., & Yuan, S. N. (2015). Factors governing construction project delivery selection: A content analysis. *International Journal of Project Management, 33*(8)**,** 1780–1794. https://doi.org/10.1016/j.ijproman.2015.07.001

Quinn, J. B., Anderson, P., & Finkelstein, S. (1996). Leveraging intellect. *Academy of Management Executive, 10*(3)**,** 7–27. https://doi.org/10.5465/AME.1996.9704111471

Rahmani, F., Maqsood, T,. & Khalfan, M. (2017). An overview of construction procurement methods in Australia. *Engineering Construction & Architectural Management, 24*(4)**,** 593–609. https://doi.org/10.1108/ECAM-4276805

Rajeh, M., Tookey, J. E., & Rotimi, J. O. B. (2015a). Estimating transaction costs in the New Zealand construction procurement: A structural equation modelling methodology. *Engineering Construction and Architectural Management, 22*(2)**,** 242–267. https://doi.org/10.1108/ecam-10-2014-0130

Rajeh, M. A., Tookey, J. E. & Rotimi, J. O. B. (2015b). Developing a procurement path determination chart SEM-based approach. *Construction Management and Economics, 33*(10-11)**,** 921–941. https://doi.org/10.1080/01446193.2016.1151538

Ramkumar, M. (2016). A modified ANP and fuzzy inference system based approach for risk assessment of in-house and third party e-procurement systems. *Strategic Outsourcing, 9*(2)**,** 159–188. https://doi.org/10.1108/so-12-2015-0030

Ren, Z., Kwaw, P., & Yang, F. (2012). Ghana's public procurement reform and the continuous use of the traditional procurement system. *Built Environment Project and Asset Management, 2*(1)**,** 56–69. https://doi.org/10.1108/20441241211235053

Rowlinson, S. (2017). Building information modelling, integrated project delivery and all that. *Construction Innovation: Information Process Management, 17*(1)**,** 45–49. https://doi.org/10.1108/CI-05-2016-0025

Rowlinson, S., & Yates, D. (2003). nDCAD: A virtual change agent for professions and procurement systems? *Construction Management and Economics, 21*(8)**,** 849–857. https://doi.org/10.1080/0144619032000174530

Rua, O. L., & Alves, H. (2020). Linking municipal Best Value and market performance: the Portuguese experience. *Public Money and Management, 40***,** 113–121. https://doi.org/10.1080/09540962.2019.1651036

Schiuma, G., Carlucci, D., & Sole, F. (2012). Applying a systems thinking framework to assess knowledge assets dynamics for business performance improvement. *Expert Systems with Applications, 39*(9)**,** 8044–8050. https://doi.org/10.1016/j.eswa.2012.01.139

Seifert, R. W., Thonemann, U. W., & Hausman, W. H. (2004). Optimal procurement strategies for online spot markets. *European Journal of Operational Research, 152*(3)**,** 781–799. https://doi.org/10.1016/s0377-2217(02)00754-3

Shalaby, A., & Hassanein, A. (2019). A decision support system (DSS) for facilitating the scenario selection process of the renegotiation of PPP contracts. *Engineering Construction and Architectural Management, 26*(6)**,** 1004–1023. https://doi.org/10.1108/ecam-01-2018-0010

Simon, H. A. (1997). *Administrative behavior: A study of decision-making processes in administrative organizations.* Free Press.

Skitmore, M., & Marsden, D. (1988). Which procurement system? Towards a universal procurement selection technique. *Construction Management and Economics, 6*(1)**,** 71–89. https://doi.org/10.1080/01446198800000008

Sloot, R. N. F., Voordijk, J. T. & Heutink, A. (2019). Assessing usefulness of 4D BIM tools in risk mitigation strategies. *Automation in Construction, 106*(11), 102881. http://dx.doi.org/10.1016/j.autcon.2019.102881

Smith, J., Zheng, B., Love, P. E. D. & Edwards, D. J. (2004). Procurement of construction facilities in Guangdong Province, China: Factors influencing the choice of procurement method. *Facilities, 22***,** 141–148. https://doi.org/10.1108/02632770410540351

Songer, A. D., & Molenaar, K. R. (1996). Selecting design-build: Public and private sector owner attitudes. *Journal of Management in Engineering, 12*(6)**,** 47–53. https://doi.org/10.1061/(asce)0742-597x(1996)12:6(47)

Sosa, E. 2017. *Epistemology.* Princeton University Press.

Stats NZ. (2017). *Economy grows 0.8 percent.* https://www.stats.govt.nz/news/economy-grows-0-8-percent

Stats NZ. (2020). *Which industries contributed to New Zealand's GDP?* https://www.stats.govt.nz/tools/which-industries-contributed-to-new-zealands-gdp#top-10

Teo, P., & Bridge, A. J. (2017). Crafting an efficient bundle of property rights to determine the suitability of a public-private partnership: A new theoretical framework. *International Journal of Project Management, 35*(3)**,** 269–279. https://doi.org/10.1016/j.ijproman.2016.10.008

Tergan, S.-O., & Keller, T. (2005). *Knowledge and information visualization: Searching for synergies.* Springer. https://link.springer.com/10.1007/b138081.

Tesar, M. (2020). “Philosophy as a method”: Tracing the histories of intersections of “philosophy,” “methodology,” and “education”. *Qualitative Inquiry, 27*(5), 107780042093414 . https://doi.org/10.1177%2F1077800420934144

Tookey, J. E., Murray, M., Hardcastle, C., & Langford, D. (2001). Construction procurement routes: re-defining the contours of construction procurement. Engineering, Construction and Architectural Management, 8(1), 20–30. https://doi.org/10.1046/j.1365-232x.2001.00174.x

Tran, D. Q., Molenaar, K. R., & Kolli, B. (2017). Implementation of best-value procurement for highway design and construction in the USA. *Engineering Construction and Architectural Management, 24*(5)**,** 774–787. https://doi.org/10.1108/ecam-03-2016-0073

Tucker, S.N. & Ambrose, M.D. (1998). Innovation and evaluation in process improvement. Symposium Conducted at The Meeting of The 14th Annual ARCOM Conference, 9-11 September, University of Reading, London.

Turri, J. (2014). *Epistemology: A guide.* Wiley. http://ebookcentral.proquest.com/lib/AUT/detail.action?docID=1434098.

Ursyn, A. (2014). *Perceptions of knowledge visualization: Explaining concepts through meaningful images.* IGI Global. https://services.igi-global.com/resolvedoi/resolve.aspx?doi=10.4018/978-1-4666-4703-9.

van Manen, M. (2016). *Researching lived experience: Human science for an action sensitive pedagogy*. Routledge. http://ebookcentral.proquest.com/lib/AUT/detail.action?docID=4558596.

van Winden, W., & Carvalho, L. (2019). Intermediation in public procurement of innovation: How Amsterdam’s startup-in-residence programme connects startups to urban challenges. *Reasearch Policy, 48*(9), 103789. http://dx.doi.org/10.1016/j.respol.2019.04.013

Walder, K., & Molineux, M. (2020). Listening to the client voice – A constructivist grounded theory study of the experiences of client-centred practice after stroke. *Australian Occupational Therapy Journal, 67*(2)**,** 100–109. https://doi.org/10.1111/1440-1630.12627

Walker, D. H. T., Davis, P. R., & Stevenson, A. (2017). Coping with uncertainty and ambiguity through team collaboration in infrastructure projects. *International Journal of Project Management, 35***,** 180–190. https://doi.org/10.1016/j.ijproman.2016.11.001

Wang, Y., Tian, L., & Wu, Z. (2021). Trust modelling based on probabilistic linguistic term sets and the MULTIMOORA method. *Expert Systems with Applications*, *165*(7), 111–117. http://doi.org/10.1016/j.eswa.2020.113817

Warszawski, A. (1996). Strategic planning in construction companies. *Journal of Construction Engineering and Management-Asce, 122*(2)**,** 133–140. https://doi.org/10.1061/(asce)0733-9364(1996)122:2(133)

Watts, S., Shankaranarayanan, G., & Even, A. (2009). Data quality assessment in context: A cognitive perspective. *Decision Support Systems, 48*(1)**,** 202–211. https://doi.org/10.1016/j.dss.2009.07.012

Williams, M. (2016). *Key concepts in the philosophy of social research*, SAGE. http://ebookcentral.proquest.com/lib/AUT/detail.action?docID=5601759.

Wimalasena, N. N., & Gunatilake, S. (2018). The readiness of construction contractors and consultants to adopt e-tendering: The case of Sri Lanka. *Construction Innovation: Information Process Management, 18*, 350–370. https://doi.org/10.1108/CI-03-2017-0025

Wondimu, P. A., Klakegg, O. J., Lohne, J., & Laedre, O. (2020). Experiences with best-value procurement in Norway and the Netherlands. *Journal of Construction Engineering and Management, 146*(5), 13. https://doi.org/10.1061/(asce)co.1943-7862.0001814

Wright, J. N. & Fergusson, W. (2009). Benefits of the NEC ECC form of contract: A New Zealand case study. *International Journal of Project Management*, *27*(3), 243-249. http://doi.org/10.1016/j.ijproman.2008.03.005

Xu, Z. (2016). *Natural theology reconfigured : Confucian axiology and American pragmatism*, Routledge. http://ebookcentral.proquest.com/lib/AUT/detail.action?docID=4456147.

Yi, Y., Luo, J. & Wübbenhorst, M. (2020). Research on political instability, uncertainty and risk during 1953–2019: A scientometric review. *Scientometrics*, 123, 1–26. http://dx.doi.org/10.1007/s11192-020-03416-6

Yik, F. W. H., Lai, J. H. K., Chan, K. T., & Yiu, E. C. Y. (2006). Problems with specialist subcontracting in the construction industry. *Building Services Engineering Research & Technology, 27*(3), 183–193. https://doi.org/10.1191/0143624406bse160oa

Yin, R. K. (2009). *Case study research: Design and methods*. Sage Publications.

Yin, R. K. (2014). *Case study research: Design and methods*. SAGE.

Yu, W.-D., & Wang, K.-W. (2012). Best value or lowest bid? A quantitative perspective. *Journal of Construction Engineering and Management, 138*, 128–134. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000414.

Yurdakul, M., Balci, A., & Ic, Y. T. (2020). A knowledge-based material selection system for interactive pressure vessel design. *International Journal on Interactive Design and Manufacturing*, *14*(1), 323–343. http://doi.org/10.1007/s12008-020-00652-1

Zhao, N., & Ying, F. (2019). Method selection: A conceptual framework for public sector PPP selection. *Built Environment Project and Asset Management, 9*(2), 214–232. https://doi.org/10.1108/bepam-01-2018-0018

Zhong, B., Wu, H., Li, H., Sepasgozar, S., Luo, H., & He, L. (2019). A scientometric analysis and critical review of construction related ontology research. Automation in Construction, 101, 17–31. https://doi.org/10.1016/j.autcon.2018.12.013

Appendix A: procurement system selection key themes

Research themes	Research sub-themes	Papers
PSS and performance	Project prediction	Molenaar and Songer (1998); Ling et al. (2004); (Ling et al., 2004), Chao and Hsiao (2012); Chou et al. (2015); Cao and So (2016); Eriksson et al. (2017)
	Performance measurements	Paek et al. (1992); Kumaraswamy and Dissanayaka (1998); Molenaar and Songer (1998); Sterner (2002); Cachon and Zhang (2007); Williams (2007); Farahvash and Altiok (2008); Murray (2009); Elyamany and Abdelrahman (2010); Emuze and Smallwood (2013); Li (2013); Eriksson (2017); Walker et al. (2017); Zhang and Wang (2019); Lam (2019).
	Performance information	e-procurement (Cheung et al. (2004); Kauffman and Mohtadi (2004); Pan et al. (2007); Chang et al. (2008); Aboelmaged (2010); Leach (2009); Aboelmaged (2010); Schoenherr and Mabert (2011a); Gupta and Narain (2015); Ramkumar (2016)) decision techniques (Degraeve et al. (2005); Degraeve et al. (2005); Lædre et al. (2006); Huang et al. (2013); Khamjan et al. (2013); Puranam and Katehakis (2014); Xing et al. (2014); Leu et al. (2015); Manley and Chen (2015); Tan and Lee (2015).)
	Decision making factors/ Critical success factors	Ghingold and Johnson (1997); Rowlinson and Yates (2003); Li et al. (2005); Dzeng and Chang (2005); Zhang et al. (2010); Li et al. (2010); Chan et al. (2011); Schoenherr and Mabert (2011b); Cheaitou et al. (2014); Ashuri and Mostaan (2015); Merzifonluoglu (2015); Strahorn et al. (2015); Aktin and Gergin (2016); He et al. (2016); Aghimien et al. (2017); Berrios and McKinney (2017); Obi et al. (2017); Hasanzadeh et al. (2018); Biazzin and Carvalho (2019); Cholette et al. (2019); Eriksson et al. (2019); Penyalver et al. (2019); Elhag et al. (2020).
PS development	Variables	project types (Wilson and Sharpe (1988);); value creation (Akintoye et al. (2003); Hallikas et al. (2014)); culture (Moore and Dainty (2001);); sustainability (Alnaser and Flanagan (2007); Akbiyikli et al. (2012)); cost/time/quality (Wirtz et al. (2009); Ojo et al. (2011); organizational views (Chong and Preece (2014)); communications (Kwofie et al. (2019))
	Understanding of PS	DB (Akintoye (1994); Songer and Molenaar (1996); Warszawski (1996); Molenaar et al. (1999); Lam et al. (2008); de Albuquerque et al. (2015); Chen et al. (2016a); Ramsey et al. (2016) BOT/PFI/DBFO/PPP/Partnering/BVP/alliance (Haynes and Roden (1999); Koppinen and Lahdenpera (2007); Weisheng et al. (2013); Adekilekun and Gan (2015); Oliveira et al. (2016); Rahmani et al. (2016); Rahmani et al. (2017) Ibrahim et al. (2017); Tran et al. (2017); Bruno et al. (2018); Bolanos et al. (2019); Dabarera et al. (2019); Wondimu et al. (2020))

PSS process	Sub-elements Tendering stage (Supplier selection Contractor selection Design team selection); Contracts	Supplier selection(Chen (2007); Liu et al. (2011); Gurnani et al. (2012); Hu et al. (2012); Bag (2016); Li (2017); Lo et al. (2018); Phochanikorn and Tan (2019), Jaskowski et al. (2014); Chowdhury et al. (2020).) Contracts (Shen et al. (1999); Lambropoulos (2007); Mandell and Brunes (2014); Chen et al. (2016b); Eadie and McCavigan (2016) Contractor (sub-contractor) selection (Palaneeswaran and Kumaraswamy (2000); Tserng and Lin (2002); El Wardani et al. (2006); Yik et al. (2006); Abdelrahman et al. (2008); Walraven and de Vries (2009); Alleman et al. (2017); Nazari et al. (2017); Hasanzadeh et al. (2018); Lines and Kumar (2018); van der Walt et al. (2019)) Decision techniques (Sundarraj and Mok (2011); Ibem and Laryea (2014); Abd Jamil and Fathi (2018); Goncalo and Morais (2019); Shalaby and Hassanein (2019); Zhao and Ying (2019); Aghajani and Torabi (2020))
	Stakeholders relationships/conflicts	O'Keeffe (2000); Greenwood (2001); Kang et al. (2007); Alaez-Aller and Longas-Garcia (2010); Obonyo et al. (2005); Doloi (2013); Paez-Perez and Sanchez-Silva (2016); Akinkunmi et al. (2018); Dey et al. (2019)
	Changes/trends	Macmanus (1992); Hampton (1994); Ngowi (1998); Jakes (1999); Tookey et al. (2001); Eadie et al. (2015); Ohashi (2009); Lu et al. (2013); Brezovnik et al. (2015); Chen et al. (2018); Ferme et al. (2018); Kumaraswamy et al. (2018)
PS and PSC	Selection approaches	Evlaution techqniues (Skitmore. R.M. and Marsden (1988); Griffith and Headley (1997); Luu et al. (2003); Mahdi and Alreshaid (2005); Ive and Chang (2007); Chua et al. (2015b); Rowlinson (2017); Khwaja et al. (2018)) Selection methods (Chan et al. (2001); Cheung et al. (2001b); Chang and Ive (2002); Deng et al. (2014); Teo and Bridge (2017b);
	PSC	Love et al. (1998); Chan et al. (2001); Ng et al. (2002); Luu et al. (2005), Smith et al. (2004); Rweiamila and Edries (2007); Love et al. (2008); Liu et al. (2015); Qiang et al. (2015); Jimoh et al. (2016); Naoum and Egbu (2016)
	Procurement decision system/model	Kumaraswamy and Dissanayaka (1998); Alhazmi and McCaffer (2000); Cheung et al. (2001a); Kumaraswamy and Dissanayaka (2001); Al Khalil (2002); Kashiwagi and Byfield (2002); Luu et al. (2006); Oyetunji and Anderson (2006); Chan (2007); Mafakheri et al. (2007a); Ye and Liu (2008); Chen et al. (2010); Mostafavi and Karamouz (2010a); Chen et al. (2010); Chen et al. (2011); Love et al. (2012); Chua et al. (2015a); Li et al. (2015); Rajeh et al. (2015a); Rajeh et al. (2015b); Jin Lin et al. (2015); El Sawalhi and El Agha (2017); Sackey and Kim (2018a); Salem et al. (2018); Wang et al. (2018); Li et al. (2019); Su et al. (2019); Plantinga et al. (2019)

Appendix B: Ethic Approval

Consent-form

APPENDIX E: CONSENT AND ASSENT FORM EXEMPLARS

Instructions for use:

1. This section is provided to assist you in the effective use of these exemplars.
2. Comprehensive information about AUT's ethics approval processes may be found online at http://www.aut.ac.nz/researchethics and especially section 2 Informed and Voluntary Consent of *Applying for Ethics Approval: Guidelines and Procedures* to guide your use of these exemplars. It will also assist if you read the information in the Glossary on the distinction between Assent and Consent** as well as the Frequently Asked Questions section. If your research requires ethics approval by a Health and Disability Ethics Committee (HDEC), please ensure that your Consent Form conforms to the template given in the quick links section of the HDEC website (http://ethics.health.govt.nz/)
3. The format of these Consent and Assent Forms is AUTEC's preferred format. You may choose to format it differently, in which case you will need to provide a reason for this in the appropriate section of the application form and you also need to know that the following content is compulsory and must be incorporated into your Consent Form:
    a. The AUT brand and logo;
    b. The Consent or Assent statements;
    c. The AUTEC approval details (Note that the date of approval is the date of the memo from the Executive Secretary giving final ethics approval, not the date of the AUTEC meeting).
4. Do rewrite sections to better reflect your research and the contents of your Information Sheet.
5. Do make additional provision for the signatures of parents or guardians where the participant is aged between 16 and 20 and legally able to give consent and when parental agreement is appropriate**.
6. Do delete sections that are not applicable to your research.
7. Do adjust the header and footer sections.
8. This is a Consent Form for participants, which will be used under the auspices of the University – please use language appropriate to the potential participants involved, be friendly and encourage the reader to participate in your research, and ***ensure that your grammar and spelling are of a high quality.***
9. If you will be using an anonymous questionnaire as your research instrument, then a Consent Form may not be required. Please refer to the Frequently Asked Questions section of the Ethics Knowledge Base (see above).
10. When you have drafted your Consent Form, and **before** you submit it with your application, delete this instruction section and any instructions (usually in coloured font) in the exemplars.

***You have understood the difference between assent and consent, haven't you?*

Before submitting this with your application, please note the following:

- ***Incomplete or incorrectly formatted applications will not be considered by AUTEC;***
- ***Please check online for the most recent version of this exemplar before submitting your application;***

This Consent Form needs to be submitted, along with the application and all associated documents as follows:

- ***In printed form;***
- ***With the required signatures in sections A.8 and A.9;***
- ***Single sided;***
- ***Using clips rather than staples;***
- ***By 4 pm on the agenda closing date at:***

The AUTEC Secretariat
Room WU406, WU Building, 46 Wakefield Street, City Campus.

- ***The Internal Mail Code is D-88. If sending applications by Internal Mail, please ensure that they are posted at least two days earlier to allow for any delay that may occur.***

Consent Form

Project title: ***Developing a framework for mega infrastructure projects procurement system selection***

Project Supervisor: ***Dr. Fei Ying and Professor John Tookey***

Researcher: ***Nan Zhao***

- I have read and understood the information provided about this research project in the Information Sheet.
- I have had an opportunity to ask questions and to have them answered.
- I understand that notes will be taken during the interviews and that they will also be audio-taped and transcribed.
- I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time without being disadvantaged in any way.
- I understand that if I withdraw from the study then I will be offered the choice between having any data that is identifiable as belonging to me removed or allowing it to continue to be used. However, once the findings have been produced, removal of my data may not be possible.
- I agree to take part in this research.
- I wish to receive a summary of the research findings (please tick one): Yes○ No○

Participant's signature: .....

Participant's name: .....

Participant's Contact Details (if appropriate):

.....

.....

.....

.....

Date:

Approved by the Auckland University of Technology Ethics Committee on type the date on which the final approval was granted AUTEC Reference number type the AUTEC reference number

Note: The Participant should retain a copy of this form.

Participant information sheet

Participant Information Sheet: Interview

Date Information Sheet Produced:

10TH January 2019

Project Title

Developing a framework for infrastructure projects procurement system selection

An Invitation

My name is Nan Zhao, and I am a PhD candidate at AUT University. I invite you to participate in this research on developing a decision supporting system for procurement system selection. This research will form the basis of my research project. Your participation in this research is voluntary and you may withdraw from this research at any time, without providing an explanation and this will not affect you in any way.

What is the purpose of this research?

This research aims to improve the quality of decision-making process for roading infrastructure procurement. It will first review and analysis the current procurement system practice and identify existing challenges in the practice. Based on that, a deeper understanding of the complexities involved at the operational level is expected so that the issues can be approached properly in order to unlock possibilities for effective improvement of procurement decisions. The results of this study will contribute to the body of knowledge regarding the procurement management and infrastructure (particularly the roading infrastructure sector), and about how best procurement selection process can be achieved. The outcome of this research would be used for conference, journal publications, and PhD thesis.

How was I identified and why am I being invited to participate in this research?

You have been identified by the job title on the public websites, or been recruited by other people.

The participants in this research are procurement managers, senior project managers, policy advisors, and government officials. You have been invited to participate in this research as one of the aforementioned participants.

How do I agree to participate in this research?

If you agree to participant in this research, please fill out the attached consent form, sign it and sent it back to me.

What will happen in this research?

You have choice to take a "face to face" interview, or pass through a "Skype/phone" interview. If you agree to participate in this project, I will invite you to participate in this interview, and it will take you approximately 45 minutes to complete. The research will ask questions on your opinions on the procurement method selection.

What are the discomforts and risks?

New Zealand market is quite small and there are only few people will be considered as decision makers in roading project procurement system selection process. The targeted participants are procurement managers, policy advisors, senior project managers in public agencies, or/and government officials. Because of limited field of interviewees, your opinions might be recognised by your peers. Some questions may be about work practise that could affect bally on you.

How will these discomforts and risks be alleviated?

The snowball recruitment procedures have been carefully reviewed within a professional research team by recognised professionals in their field. Each participant will be coded, and none of your personal information will be disclosed to any third parties or in any part of this research output (Journal, conference papers, and thesis). Every effort will be made to maintain our confidentiality in matters outside the scope of research.

You are able to withdraw from the study at any time. If you choose to withdraw from the study, then you will be offered the choice between having any data that is identifiable as belonging to you removed or allowing it to continue to be used. However, once the findings have been produced, removal of your data may not be possible.

What are the benefits?

There is probably no benefit in participating. However, the findings of the research may provide some benefits for you. The proposed framework will assist decision makers/public clients in choosing a right type procurement method in their projects and then enhance the possibility of project success. The summary of procurement method selection process will provide a general knowledge of project management for all participants within procurement stage.

How will my privacy be protected?

The research team want to know the challenges related current procurement method selection process towards yourself and others in order to reveal the truth and then improve the current policy or/and procurement selection process. Because of the limited field of interviewees, the research team will know who are the participants, also those potential participants could be identified by their peers. Instead of making an unconditional guarantee of confidentiality, the information they provided will be confidential within limits. The research team will tell the participant who have been involved, and who may be participated in this research. But all information (opinions, personal information, etc.) collected from participants will be kept strictly confidential. The interview transcript and your consent form will be scanned and downloaded to an external hard drive and securely stored. Only the researcher team have access to them. None of your personal information will be disclosed to any third parties or in any part of this research output (Journal, conference papers, and thesis). Each participant will be coded, and none of their personal information will be disclosed to any third parties or in any part of this research output (Journal, conference papers, and thesis).

What are the costs of participating in this research?

There is no financial cost involved in participating in this research. The only cost of participating is the time given to answer the questions.

What opportunity do I have to consider this invitation?

If you do decide to take part you will be given this information sheet to keep and be requested to send back the signed consent form within ONE month.

Will I receive feedback on the results of this research?

All participants are entitled to feedback from this study. A summary of research findings will be provided by email. I will also inform any imminent publications concerning the findings of the project.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to primary research,

Nan Zhao (email: nan.zhao@aut.ac.nz or mobile: 0211758848)

Or the Project Supervisors, Dr. Fei Ying (email:fei.ying@aut.ac.nz or office telephone: 09 9219999 ext. 6635), Prof. John Tookey (email: john.tookey@aut.ac.nz or telephone: 09 9219999 ext. 9512).

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, Kate O'Connor, ethics@aut.ac.nz, 921 9999 ext 6038.

Whom do I contact for further information about this research?

Please keep this Information Sheet and a copy of the Consent Form for your future reference. You are also able to contact the research team as follows:

Researcher Contact Details:

Nan Zhao (email: nan.zhao@aut.ac.nz or mobile: 0211758848)

Dr. Fei Ying (email: fei.ying@aut.ac.nz or office telephone: 09 9219999 ext. 6635).

Prof. John Tookey (email: john.tookey@aut.ac.nz or telephone: 09 9219999 ext. 9512)

Approved by the Auckland University of Technology Ethics Committee on *type the date final ethics approval was granted*, AUTEC Reference number *type the reference number*.

Appendix C: Pseudo-code

Knowledge Visualization Alogorithm

Input: 233 PSCs (T_{PSC}=233) divided into 9 groups (NG_{PSC}=9), 7 predefined PS (N_{PS}=7) and *papt* participants
Output: A selected PS *ps* for each participant *papt*

for *i*=1 to *papt* **do**
  for *j*=1 to NG_{PSC} **do**
    for *k*=1 to N_{PS} **do**
      Assign a weight: *wt(i,j,k)=x*;
    end
  end
  if participant *i* has a different value for PSC *m* in group *j*
    $wt(i,j,k)_m=y$;
  end
end
Initialize STEP=3
for *s*=1 to STEP **do**
  if *s*==1
    for *j*=1 to *papt* **do**
      select *n* PSC out of T_{PSC} PSCs: $psc\_sel(j)_{s1}=[sel_{j1}, sel_{j2}, \ldots, sel_{jn}]$ and $sel_{jx} \in [1, T_{PSC}]$
      if participant *j* has *m* extra PSCs
        $psc\_ext(j)_{s1}=[ext_{j1}, ext_{j2}, \ldots, ext_{jm}]$ and $ext_{jx} \notin [1, T_{PSC}]$
      end
    end
  end
  for each element *e* in psc_sel_{s1} and psc_ext_{s1}
    count how many times it has been selected by all *papt*: cnt_e++
  end
  sort psc_sel_{s1} and psc_ext_{s1} in descending according to cnt_e
  $psc\_s1=[e_1, e_2, \ldots, e_{50}]$
  if *s*==2
    for *t*=1 to *papt* **do**
      select *n* PSC from *psc_s1*: $psc\_sel(t)_{s2}=[sel_{t1}, sel_{t2}, \ldots, sel_{tn}]$ and $sel_{tx} \in [e_1, e_2, \ldots, e_{50}]$
      if participant *t* has *n* extra PSCs
        $psc\_ext(j)_{s2}=[ext_{t1}, ext_{t2}, \ldots, ext_{tn}]$ and $ext_{tx} \subset psc\_s1$
      end
    end
  end
  for each element *f* in psc_sel_{s2} and psc_ext_{s2}
    count how many times it has been selected by all papt: cnt_f++
  end
  sort psc_sel_{s2} and psc_ext_{s2} in descending according to cnt_f
  $psc\_s2=[f_1, f_2, \ldots, f_{30}]$
  if *s*==3
    for *r*=1 to *papt* **do**
      select *p* PSC from *psc_s2*: $psc\_sel(r)_{s3}=[sel_{r1}, sel_{r2}, \ldots, sel_{rp}]$
    end
  end
  for each element *g* in psc_sel_{s3}
    count how many times it has been selected by all papt: cnt_g++
  end
  sort psc_sel_{s3} in descending according to cnt_g
  $psc\_s3=[g_1, g_2, \ldots, g_{20}]$
end
psc_sel=psc_s3;

for *p*=1 to *papt* **do**
  input a selection for *app_sel(p)*
  switch *app_sel(p)*
    case 1:
      ps(p)=user *p* select a PS from *1,2, …, N_{PS};*
    case 2:
      for *i*=1 to **length**(*psc_sel*) **do**
        val(*i*)=user *p* input a value between [0,1] and sum(*val*)=1;
      end
      $val\_sum(v) = \sum_{i=1}^{NG_{PSC}} wt_i val_i$
      $ps(p) = \arg\max_{v \in 1,2,\ldots,N_{ps}} val\_sum(v)$
    case 3:
      ps(p)=**AHP**(*psc_sel*);
  end
end