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Resilience of Malaysian Public Sector Construction Industry to Supply Chain Disruptions

RESILIENCE OF MALAYSIAN PUBLIC SECTOR CONSTRUCTION INDUSTRY TO SUPPLY CHAIN DISRUPTIONS

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ABSTRACT

The uncertainty and complexity of the interdependent global economy have amplified collective exposure of supply chains to disruptive events. In the construction world, the fragmented nature of the temporary project teams and the uncertain operating environment make construction supply chains more vulnerable to these disruptive events. In Malaysia, the construction industry has become the focal point for development through the Government's "Malaysia Vision 2020" transformation programme, in the effort to become a developed country by the year 2020. However, despite good plans for the development of public projects, the Malaysian Auditor General Report 2014 identified several weaknesses in the delivery of construction projects that caused poor project performance. The dynamics and effects of interconnected risks among construction organisations tend to be overlooked across the Malaysian public project supply chains, making them highly vulnerable to supply chain disruptions. This calls for the need to go beyond the traditional silo approach of the risk management process. This research aims to investigate the Malaysian public sector supply chain's resilience capabilities and vulnerabilities in handling disruptions in the effort to build supply chain resilience against disruptions and improve the delivery of public projects.

A comprehensive questionnaire survey was conducted with 105 construction professionals from two groups of respondents, the public and private organisations in the public sector supply chain to identify their current vulnerabilities and capabilities. Data were analysed using descriptive statistics and compared using the Mann-Whitney U and Kruskal-Wallis tests. The findings revealed that the public organisations faced significantly higher political threats whilst the private organisations faced significant market pressures. Subsequent semi-structured interviews were conducted with 12 professionals in the field to identify the inherent pathogens that make the supply chain highly vulnerable in these critical areas. The emergent pathogenic influences include practice, circumstance, convention, organisation and behavior. Finally, a resilience response framework was developed based on the triangulation of these results. The framework allows the experts from the public sector supply chain to understand the critical vulnerabilities and pathogenic influences of their organisation and their supply chain members, along with the set of capabilities to reduce the disruptive impacts arising from these critical vulnerabilities.

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CHAPTER 1

INTRODUCTION TO THE STUDY

1.1 Research Background

The modern world has changed and it is now a highly interconnected one. With the innovation and growth and the interdependence of the global economy through worldwide communications and advanced technology, organisations from various regions are more interconnected than ever before. Countless benefits come along with these advances, including an unprecedentedly high level of international trade, lean supply chains that deliver low-cost consumer goods, and an improved standard of living in many developing countries (Kosansky and Taus, 2014). However, the uncertainty, complexity, and transparency of this interdependent global economy have also amplified collective exposure of supply chains to catastrophic events and disruptions.

Within a global context, risk can occur in many ways, including supply chain disruption, geopolitical risk, cyber risk, natural catastrophes, regulatory risk and unforeseen events. As an increasingly global marketplace brings greater complexity and risks for all players, it is not surprising that big organisations that were once listed as top-performing companies in the past, such as Lehman Brothers, General Motors and Worldcom, took a wrong turn and went bankrupt due to their inability to tackle risks in the global marketplace (see case studies in Swedberg, 2010; Monks and Minow, 2011). It is indeed a major shock to the global economy when big companies like this fail unexpectedly, as it sends cascading effects out into other industries in various regions. In some cases, events from completely unrelated sectors could also be the root cause of disruptions that occur in another industry, such as what the pharmaceutical industry faced a few years ago (see case study in Appendix A). This shows how interconnected risks have become in a global economy, and how these risks are beyond any single organisation's control.

Another example of interconnected risks can be seen in Figure 1.1, where the underlying connections between the recent global risks are highlighted based on a survey done by the World Economic Forum in 2014. It illustrates how risk can cascade from one point to another and how risks influence different sectors of the global economy. This goes to show how important it is for a supply chain to continue its function to supply the world's population with essential goods, regardless of any disruptive event, (Kosansky and Taus, 2014) in order to continue in the long run.

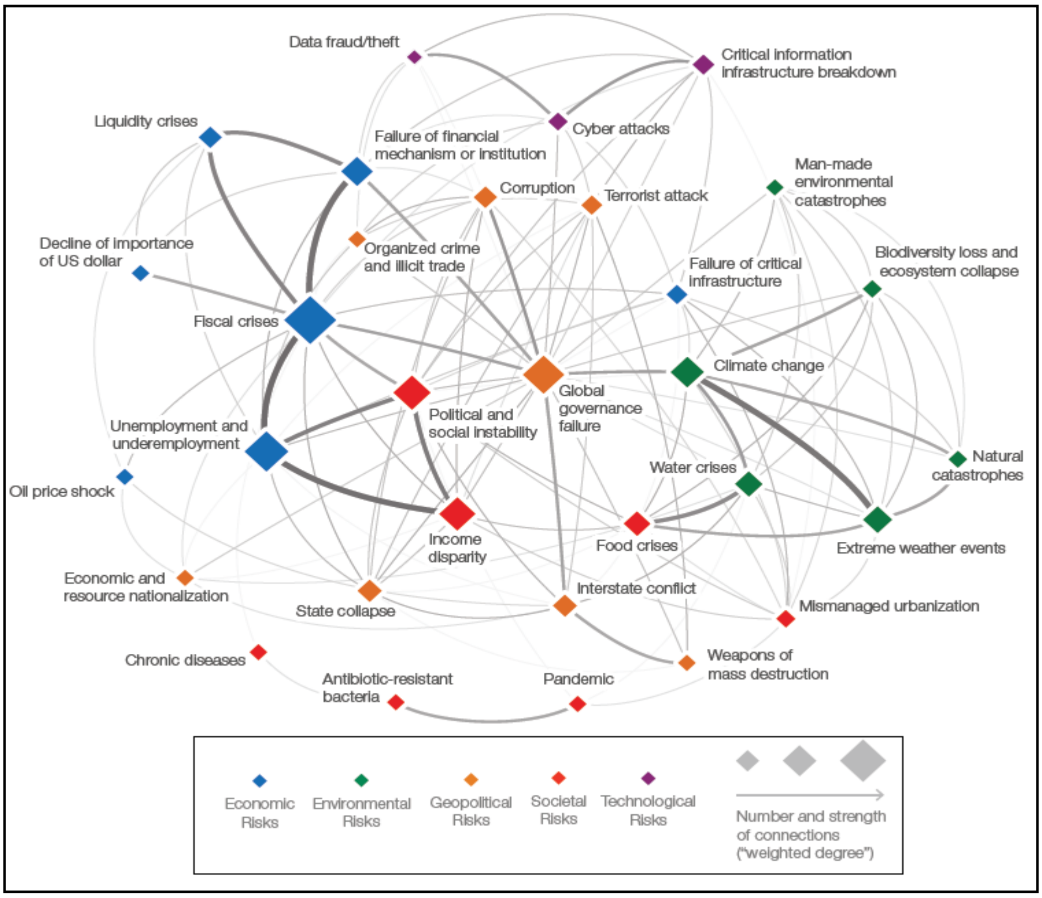

Figure 1.1: The global risks 2014 interconnections map (World Economic Forum, 2014)

One of the industries driven by supply chains and affected by interconnected risk of disruptions is the construction industry. In the construction world, this logic of interdependence can be seen through the diverse set of project team members (i.e. project manager, architects, consultants, contractors, suppliers) involved from initiation to the completion of the project. As in other industries, supply chains in construction also face disruptions that cause poor project performance and deviations from project objectives. Studies conducted on performance in construction often identify delays and cost overruns as affecting project outcomes (Mehdi-Riazi et al., 2011; Joshi, 2009; Le-Hoai et al., 2008). The factors that cause these delays and cost overruns suggest that they are contextually dependent, although some commonalities could be identified from country to country. Whilst these studies add value to the existing body of knowledge in improving performance, they hardly concentrate on the modern day complexities related to supply chain risks and to risks which are interdependent across the construction supply chain dominant in many countries. The interdependencies of the supply chain in the construction industry differ from those in other industries, such as the retail and manufacturing sectors, as construction involves a project-based supply chain that is transient in nature with overlapping risks that are wider than their immediate contractual responsibilities (Loosemore, 2000). Project team members come from different disciplines and are involved at different stages of the project (planning, design, tender, construction). Each of these groups has their own objectives as they participate in the project, and the team arrangement may change as the project progresses. This level of segmentation, especially in complex supply chains of large-scale projects, makes construction supply chains more vulnerable to disruptive events. Construction projects also often feature multiple overlapping risks that include commercial, design, project, quality and safety issues that have to be dealt with at the same time (Zurich, 2014). This is evident not just in the developed countries, but also in various developing countries.

One of the developing countries facing disruption to construction activities across supply chains due to interconnected risks is Malaysia. Research conducted by Joshi (2009), Abdul-Rahman et al. (2006) and Pratt (2000) reveals that large local construction projects have frequently ended up being delivered late, with cost overruns. The recent National Audit Department Report also points out the non-performance of some key engineering projects at several scales that led to catastrophic outcomes to the client and other public and private organisations (National Audit Department, 2014). Poor performance of the supply chain results in the Government not obtaining the best value for money on the expenditure incurred, thus affecting the public's perception of the Government's credibility in managing public sector projects. The Government is therefore calling for improvements in handling disruptions to improve public project performance. This is vital as numerous public projects are to be implemented under the Tenth and Eleventh Malaysian Plans, under the provision of the "Malaysia Vision 2020" transformation programme, with the aim of becoming a developed country by the year 2020.

In this case, although risk management is widely practised in Malaysia, it can be seen that as the nature of the supply chain becomes more complex, it is difficult for the associated risks to be mitigated by individual participants in the supply chain. Furthermore, as the project progresses from one phase to another, its associated risks also shift among the general contractors, sub-contractors, suppliers and other parties in the supply chain. This level of exposure and vulnerability to risk show how vital it is for the Malaysian public sector supply chains to build capabilities and mitigate their vulnerabilities to handle disruptive events collectively. This calls for an integrated approach to the risk management process to effectively manage supply chain risks and disruptions.

Although it is impossible for the supply chain managers to eliminate all risks, the challenge now is how to make systems and supply chains sufficiently resilient to bounce back and thrive from catastrophes and disruptive events. As risks are increasingly shared across local, regional and national boundaries, building resilience to disruptive events requires key players not only to focus on their own interests, but also to take into consideration the interests of others. Thus, instead of taking a silo approach, all parts of the Malaysian public sector supply chain need to work together to build resilience to disruptive events and improve project performance, hence adopting an integrated approach.

This research therefore continues investigation of this area, by assessing the Malaysian construction supply chain's resilience capabilities and vulnerabilities in the above context. This will give project teams a better understanding of their supply chain disruptions and develop the actions required to utilise the supply chain's capabilities and mitigate their vulnerabilities, in the effort to improve public projects performance.

1.2 Research Problem

As discussed above, interconnected risks within the global economy have had catastrophic impacts on global supply chains (Kosansky and Taus, 2014; Wagner and Bode, 2006; Sheffi, 2005). In the United Kingdom, 80% of businesses disrupted by a major incident close within 18 months (Federation of Small Businesses, 2014). Large organisations in Europe, the Middle East and Africa also faced disruptions to their value chains which cost almost £450,000 per incident to recover, including costs associated with lost sales, lost customers, product recall and the work involved in having to rebuild the value chain (BDP International, 2013). These arguments show that survival and success in this uncertain environment demand that supply chains improve their risk management approach by incorporating resilience. This approach is hereby referred to in this study as the risk resilience approach. Risk resilience here means the ability to anticipate and adapt to change, absorb and recover from a broad range of risk events (including unexpected 'black swan' events), and to seize the opportunities hidden within those risk events (Kinman, 2012). The construction industry will also benefit from this as the industry's supply chains face constant disruptions in their day-to-day operations. The discussion below highlights the underlying research problem, by looking at the disruptions currently challenging construction supply chains from the global point of view, in developing countries, and specifically in the Malaysian construction context.

1.2.1 Supply chain disruptions in the global construction sector

Looking at the worldwide view of supply chain disruptions in the engineering and construction sector, the recent Business Continuity Institute (BCI) supply chain survey (2014) reported that adverse weather is the most common cause of disruption(71.4%), , followed by unplanned information technology outage (66.7%), data breach (33.3%), loss of talent or skills (33.3%), and transport network disruption (33.3%). The survey reported loss of productivity as the primary consequence of these supply chain disruptions, followed by increased cost of working and loss of revenue (Business Continuity Institute, 2014). The biggest concern in the findings is that although 84% of organisations reported supply chain incidents in 2014, with reported losses of more than €1million, almost three-quarters of them still have no full visibility of their supply chains. It was reported that the increased lack of top management commitment to supply chain resilience is one of the reasons why organisations are still vulnerable to supply chain disruptions.

Another recent survey on global construction supply chains conducted by StrategicRISK in 2014 found that almost two-thirds of construction sector risk managers viewed supply chain disruption as their number one concern; 71% of respondents believed that the overall level of supply chain risk in the construction industry would increase over the next 10 years (StrategicRISK, 2014). Supply chain, human capital, political instability and increased competition from rival businesses are other supply chain disruptions highlighted by these risk professionals. Understandably, managing project teams from different tiers of the construction supply chain is indeed challenging, especially with global disruptive events that cause large swings in capacities and resources in project delivery. This is evident from the global economic collapse of 2008, where the consequences were felt in the global construction sector, leaving half-built housing developments and empty building sites in countries such as Spain, Portugal and Ireland. The survey concluded that the construction industry has not yet adapted to the globalised nature of the modern commercial environment, making it challenging to keep up with modern supply chain complexities within the construction industry (StrategicRISK, 2014).

This shows that key players in the construction industry around the world are still vulnerable to supply chain disruptions. It is also worth noting that some of these disruptions may originate from the bottom tiers of the supply chain, which is often hard to foresee especially in a large supply chain. Hence, it is important for construction professionals to be aware of the disruptive events faced not only by their own organisation, but also by other supply chain members, in order to build the capability to respond efficiently to disruptive events. This will enable construction projects to progress effectively, reducing susceptibility to poor project performance.

1.2.2 Supply chain disruptions in developing countries

As in developed economies, various developing countries have also been affected badly by supply chain disruptions, with increasing reports on project performance deficiencies such as cost and time overruns, poor quality of work, technical defects, poor durability, and inadequate attention to safety, health and environmental issues (Ofori, 2012; Abdul-Rahman et al., 2007). Although the supply chain in developing countries shares many of the problems that arise in the developed countries, there are even greater adverse implications for poor performance of construction projects on long-term national socio-economic development (Ofori, 2012). Differences in economic development and the quality of infrastructure, such as road and rail networks, may also mean certain developing countries are more susceptible to certain disruptions than more mature, developed countries (Tukamuhabwa et al., 2015). For instance, acquiring the required resources, especially in rural areas, is more challenging as access might be more difficult than in developed countries.

The shortage of supply of the required professional skills is also prevalent in developing countries, as a result of lack of governance and training of the construction workforce. As a result, higher accident rates on site are frequently reported in developing countries (StrategicRISK Asia, 2014). It is indeed challenging to deal with a construction workforce that does not provide the extent or quality of service that firms in developed countries are used to (Ofori, 2012). This could be even more problematic in joint ventures that involve multinational organisations. Furthermore, developing countries are more vulnerable to particular supply chain threats such as political turmoil, including rebel activities and post-election violence, and to bribery, corruption and other unethical business practices (Transparency International, 2013). This goes to show that supply chains operating in the current dynamic environment in developing countries are exposed to formidable disruptions, some of which may not be an issue in developed nations, but could potentially have an adverse impact on the other nations if not handled appropriately. Indeed, emerging countries, especially in Asia, are currently building up their infrastructure to meet consumers' demand for a better standard of living. As construction is booming in Asia, so is the need to manage these related complexities of risk and supply chain disruption. It is therefore important for key players in developing countries to find a way to build resilience into their construction supply chains.

1.2.3 Supply chain disruptions in the Malaysian construction industry

Much like many efforts made by other developing countries, the Malaysian Government introduced its own transformation programmes under Vision 2020. One of the programmes was the Tenth Malaysia Plan which lasted from 2011 until 2015. Under this plan, an allocation of RM138 billion (€34.5 billion) was to be spent on physical development to be undertaken directly by the construction sector, including public sector projects. However, as discussed in Section 1.1, despite the ministries and Government departments' well meaning plans to meet this construction provision, the Malaysian National Audit Department (2014) identified several weaknesses and disruptions in terms of implementation which prevented the project objectives from being fully achieved, resulting in little impact of the projects on the targeted groups. The report consists of observations from the audit of 17 public projects of 14 Federal Agencies, managed by the Malaysian Public Works Department (PWD). The PWD is the umbrella organisation for public sector works and acts as a technical advisor to the Government on public projects governance (PWD, 2012). It is the main implementer of public projects and is responsible in managing public sector professionals across the various federal ministries and public states organisations in delivering public projects and maintaining the government's infrastructure assets.

Based on the report, the public sector organisations are still vulnerable in areas such as the management of their stakeholders and construction project teams, insufficient technical expertise, no coordination among parties involved in the supply chain, as well as several internal problems faced by contractors (National Audit Department, 2014). For instance, the construction of Paya Peda Dam in Terengganu faced significant delay due to the lack of expertise of the contractors hired to lead the construction of the dam. The contractors' lack of experience resulted in poor functionality of the dam's hydro mechanical gate system, causing an area of paddy fields to be flooded, so that the production of rice did not meet the stipulated demand in the district of Besut in 2014. This demonstrates the interdependent nature of the construction industry and other sectors, and how disruptions in the construction supply chain may have knock-on effects on other industries. Disruptions in public projects could also result in a considerable negative impact on the Government's revenue, performance and public reputation.

Other delays in local public projects caused by supply chain disruptions have also been highlighted in the past by researchers (Riazi et al., 2011; Joshi, 2009; Abdul-Rahman et al., 2006; Pratt, 2000). For instance, the Malaysia External Trade Development Corporation (MATRADE) project experienced nine years of delay and a 70% cost overrun due to disruptions arising from the first contractor abandoning the project and the appointment of another contractor (Riazi et al., 2011). Other projects include the Middle Ring Road 2 that underwent post-occupational ratification due to the appearance of cracks in 31 of its flyover piers, and the second Penang Bridge, which had recently been completed, that faced a delay of more than 12 months resulting from additional technical aspects that had not been considered in the early stages (Riazi et al., 2011). The inability to manage supply chain disruptions and inadequate execution of works have indeed affected the development of public projects in Malaysia, preventing the Government from receiving the best value for money on the expenditure incurred.

Furthermore, the current sudden plunge in global oil prices, tight fiscal budget measures, and the newly implemented federal 6% goods and services tax (GST) have also had a significant impact on local construction supply chains (Puspadevi, 2015). The downwards trend in global oil prices resulted in major uncertainties in the overall economic situation. Given the reduction in oil revenue, it is generally believed that the Government may postpone some major public projects (Malaysia Report, 2014). The implementation of GST in April 2015 also raised clients' concerns over the rise of construction costs, the compliance costs of operating supply chain concerns and the effect on competitiveness. This shows that the interdependent nature of the supply chain could also be triggered by the national economy. Considering the numerous large-scale projects underway, such as the Pan-Borneo Highway (RM27 billion) and the West Coast Expressway (RM5 billion) under the national plan, construction players need to build up their ability to adapt and thrive in the face of such challenges, to ensure the survival and growth of the Malaysian construction sector.

1.2.4 The need for a risk resilience approach

In this case, it can be seen that as the implementer of the public sector projects, the public organisations and their supply chain partners (referred to as the public sector supply chain from hereon) are to some degree still vulnerable to a diverse set of risks and disruptive events. This has resulted in the poor project performances highlighted by previous researchers and the Auditor's report. It is indeed not surprising that the Director General of the PWD described the industry as still living in the 1960's, with the management of disruption in public projects still poor (Zaini, 2000). The 'blame-game' culture is also often played out by key players in the supply chain when disruptions occur, even though in reality the construction processes are interrelated. In fact, supply chains should be able to deliver the maximum intended value of the project even if there are several disruptive events. As highlighted in the Malaysian public project cases outlined in Section 1.2.3, disruptions in public projects have become barriers to the public sector supply chain's achieving project objectives, resulting in poor project outcomes, and huge losses for the Government, contractors and suppliers. Disruptions in the construction supply chain are also sometimes beyond the direct control of project managers, and the fragmentation of the construction supply chain makes it even more challenging to build supply chain resilience in the construction industry.

With higher expectations from the public for the public sector professionals to deliver the intended large-scale projects, and with the rising challenges of the twenty-first century, it is time for the public organisations and their supply chain partners to move beyond the traditional risk management approach and change the way supply chain disruptions are managed. More flexible, resilient, and risk-resistant supply chains are needed to operate in this volatile construction environment in order to maintain growth in the Malaysian construction industry. Previous researchers such as Zaini (2000), Abdul-Rahman et al. (2005), Ibrahim et al. (2010) and Riazi et al. (2011) also believe that only with enhanced capabilities and capacity can the local industry withstand challenges in both good and bad times. There is therefore no doubt that there are possibilities for substantial improvements in the public sector supply chain operational strategies and competencies. This therefore calls for the need to build a risk resilience response framework to effectively manage supply chain disruptions in public projects and improve the supply chain's performance in delivering public projects.

1.3 Research Gap

The research into global supply chains indicates that interconnected risks are beyond a single organisation's control, and that key players worldwide are still vulnerable to supply chain disruptions (see Section 1.1). As there global supply chains are involved in construction (see Section 1.2.1), this area is important and vital for the performance of both developed and developing countries. Within the supply chain resilience literature, to date, researchers (Zsidisin and Wagner, 2010; Ponomarov, 2012; Pettit et al., 2013; Boone et al., 2013) have been focusing on the developed countries, particularly in the European Union and the USA. As discussed in Section 1.2.2, the economic differences that exist between developed and developing economies suggest that perceptions and responses to threats may differ between these contexts (Tukamuhabwa et al., 2015). The lack of good quality empirical work on supply chain resilience in developing countries represents a distinct knowledge gap that this study intends to address. Malaysia, a developing country, has very ambitious goals (as stated in section 1.2.3); however, disruptions faced by the supply chain involved in delivering public projects have prevented the Government from meeting its construction provisions. This scenario offers a major opportunity for the researcher to undertake the study within the Malaysian public sector context.

Looking at the existing literature, several views of resilience and disruption have evolved over time through multidisciplinary studies conducted by previous researchers (see Sections 2.3 and 2.4). However, to date, there have been few studies on resilience to disruptions in commercial supply chains. The wide-ranging consequences of disruption on the networked chains or supply chains within a commercial environment have not received adequate attention, either in theory or in practice. As pointed out in Section 1.1, supply chains dominate the construction industry and disruptions in this sector can cascade into other industries, sectors and regions. Resilience in the construction industry still remains under-researched.

Previous resilience studies are broad but limited in depth, most looking at various organisations across different industries (Pettit et al., 2013; Stephenson, 2010; McManus, 2008). More industry-specific research, such as in the context of the construction industry, is required to address this gap in the literature. It is also difficult to understand resilience by studying a single entity in the supply chain; it need to be examined across multiple related organisations in the network (Tukamuhabwa et al., 2015). Previous studies typically assessed resilience based on a single respondent from each firm, overlooking the effects of connectivity between organisations in the supply chain. The lack of empirical studies on the supply chain limits the current understanding of the interdependent risk of disruptions (discussed in Section 1.1) between organisations in the chain. As the resilience of a firm is determined by the resilience of its network (Sheffi and Rice, 2005; Wedawatta et al., 2010), and as the emerging risk of disruptions reaches the level of networks, this calls for studies beyond organisational boundaries to develop resilience characteristics within organisations and supply chains.

Furthermore, although many resilience strategies have been proposed by previous researchers, building resilience can mean different things in different supply chains. For instance, previous disaster management strategies that worked well in a specific location, time, or context have led to very poor performance in slightly different environments (such as the construction industry), as the disaster relief supply networks differ from commercial supply chains (Day, 2014). For example, Day (2014) argued that in natural disaster relief efforts, it is more important to ensure that sufficient resources such as food are procured and moved as rapidly as possible to places where they are needed, than to hold the traditionally efficient minimal stock levels. Large stocks must therefore be on hand in this case to be distributed as widely as possible following a disaster event. However, with commercial supply chains, holding large stocks or inventories may cause waste or erode profits, especially if firms over-invest in resources that are not necessary (Pettit et al., 2013). In this case, the commercial supply chains need to find a strategic balance between the resources required and the uncertainty in demand, and to ensure that the best quality of service or product can be provided even when disruptions occur. Hence there seems to be wide scope for study in this area, although several successful strategies already exist. Malaysian public sector construction can certainly adopt some of the good practices currently available. However, some of the unique interdependent impacts that affect supply chains in construction shape and determine the broader strategies of fostering resilience in this context. The existing resilience studies in Malaysia are also still limited to the field of individual psychology, assessing how individuals cope in changing environments (Buang, 2012; Madihie, 2009); and disaster management, assessing how organisations respond to extreme weather events (Roosli and O'Keefe, 2013; Billa et al, 2006). This general theoretical gap shows that there is still room for improvement in the resilience literature with regard to building supply chain resilience within the Malaysian construction industry.

A further specific gap was also identified from the literature. Researchers in the Malaysian construction industry (Goh and Abdul-Rahman, 2013; Siang and Ali, 2012) are still focusing on the risk management process at the pre-disruption stage, by analysing the probability and impact of the risk of 'potential disruption' in construction projects. Little work is presented on post-disruption activities in terms of the supply chain's response and recovery following an 'actual disruption' (see Section 2.3). Hence the supply chain's ability to learn from existing disruptions and utilise current capabilities to mitigate such problems have not received much attention in the literature, which this study intends to address. Furthermore, although the proactive strategies may be preferred in practice as they can be applied to prepare for a disruption rather than to respond to it, managers may be reluctant to implement such proactive strategies due to the financial implications of mitigating potential disruptive events which may not ultimately occur (Tukamuhabwa et al., 2015). More elaborate and comprehensive supply chain resilience strategies are needed to justify investment. Assessing the capability and vulnerability factors of the supply chain in dealing with disruptions as they materialise can help to determine their level of resilience, which in turn enables the researcher to develop specific resilience strategies to cater for different levels in which the supply chain is vulnerable.

This study therefore intends to address the identified gap in the knowledge by developing a resilience response framework to build up the resilience of the Malaysian public sector supply chain to disruptions. Understanding the level of resilience of the supply chain in responding to a wide array of unexpected events and disruptions will help the public sector supply chain to manage disruptions effectively in future projects, and thereby improve public projects performance. The aim and objectives of the research are presented in the following section.

1.4 Research Aim and Objectives

This research aims to develop a resilience response framework to improve the preparedness and build resilience of the supply chain against disruptions in the effort to improve the Malaysian public sector projects delivery. The following objectives are identified in order to achieve the research aim:

1. To examine the phases of supply chain disruptions faced by Malaysian public sector projects.

2. To examine the concept of resilience and its applicability in managing supply chain disruptions.
3. To analyse the emergent vulnerability and capability factors of the public sector supply chain in coping with supply chain disruptions.
4. To identify the causes and the cascading effects of supply chain disruptions to the Malaysian public sector project performance.
5. To establish and validate the resilience response framework to improve supply chain performance on meeting its resilience goals to mitigate against disruptive events in Malaysian public sector projects.

1.5 Research Contributions

Whilst past studies on managing risks in the construction industry have added value to the existing body of knowledge in improving performance, they rarely concentrate on the modern-day complexities related to supply chain risks and to risks which are interdependent across the construction supply chain. This study bridges this theoretical gap by assessing supply chain disruptions beyond organisational boundaries to develop resilience characteristics within organisations and their supply chain partners. Another theoretical contribution to knowledge is the assessment of supply chain resilience in the context of a developing country, Malaysia, where research in this area is not adequately available. Although poor project performance such as delays and cost overruns are common in Malaysia, there has been limited empirical investigation into developing resilience of the construction supply chain. This research therefore potentially bridges this gap by identifying the construction supply chain's vulnerability, which undermines their capability to recover and even thrive from disruptions, as shown in the case of the Paya Peda Dam (see Section 1.2.3). Furthermore, as the resilience assessment in this study is tailored particularly to the construction industry, this will help to expand the applicability of supply chain resilience assessment to a new context, adding valuable findings and significant new knowledge to the existing literature. Finally, the study has the potential to advance the overall state of knowledge in mitigating disruptive events affecting supply chains which are globally networked.

In terms of the study's practical contributions, this research will offer public organisations' managers relevant insights into their organisations' critical areas of vulnerability and their current resilience capabilities. The management will also be given significant information on the links between their vulnerabilities and capabilities, allowing them to utilise their capabilities to mitigate the critical vulnerabilities and prioritise their investments on areas that need further improvement. In addition, the public organisations will be able to gain a better understanding of the resilience capabilities and vulnerabilities of the contractors and consultants engaged in delivering public projects, which might not have been obvious to the managers before. Overall, it is believed that the output from this study will help to inform and guide the public organisations and their supply chain partners in building resilience to supply chain disruptions in public project delivery.

1.6 Structure of the Thesis

The thesis is structured into seven chapters as described below:

Chapter 1 provides the background of the research to introduce the research topic. It includes the problem statement, research gap, research aims and objectives, the study's contribution to knowledge and practice, and the outline of the thesis.

Chapter 2 discusses the current state of the Malaysian construction industry and introduces the industry's key players. This is followed by a thorough review of the literature of supply chain disruption, supply chain resilience, supply chain vulnerability and capability, and pathogenic influences. It also includes the development of the conceptual framework.

Chapter 3 describes in detail the research design and methodology. This includes the philosophical stance of the researcher that leads to the selection of a suitable research approach, strategy and techniques to fulfil the research aim and objectives. The reliability and validity of the adopted research techniques are also addressed. This is followed by a summary of the research process along with ethical considerations.

Chapter 4 presents the results of the questionnaire survey. The results are analysed using descriptive statistics and further inferential statistics to make comparisons between the vulnerabilities and capabilities of the groups of respondents.

Chapter 5 presents the analysis of the interviews with key players in the industry. It highlights the emergent critical pathogens identified from the interviews that make the public sector supply chain vulnerable to disruptions in public projects.

Chapter 6 discusses the key findings of the study by triangulating the results from the questionnaire survey in Chapter 4, with justification from the interview findings and pathogenic influences in Chapter 5. Critical links between the concepts and factors are also presented in developing the final resilience response framework. The final framework and its validation are then discussed at the end of the chapter.

Chapter 7 (Conclusion) provides a summary of the study by revisiting the research aim and objectives and presenting the key findings of the study. It underlines the theoretical and practical contributions, along with the limitations of the study and suggestions for future research areas. References and appendices are presented at the end of the thesis.

1.7 Summary

Chapter 1 presents the research area, the Malaysian construction industry's supply chain resilience to disruptions and the justification of the research context. The research problem areas and significant gap in knowledge were discussed, and the research aim and objectives identified to address these issues. The expected contribution of this study to knowledge and practice, and a brief description of the structure of the thesis, were presented. Overall, this chapter set the context of the research areas which will be discussed in detail in the following chapters. The next chapter is a review of the literature.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In fulfilling the research objectives, this chapter begins by providing the background of the Malaysian construction industry, with a critical discussion on the current state and the challenges faced by the supply chain in the local construction industry. The significant role of the Malaysian PWD in managing the public sector professionals and delivering public projects is first discussed. This is followed by a comprehensive literature review of the definition and various phases of disruptions, in order to develop a workable definition of supply chain disruptions in construction. The term resilience and its applicability in managing supply chain disruptions are defined, leading to the breaking down of the concept of supply chain resilience into two key elements: vulnerability and capability. Finally, the additional related concept of pathogens and its applicability to the resilience context is presented. These concepts collectively lead to the development of the conceptual framework for this study.

2.2 Background of the Malaysian Construction Industry

The Malaysian construction industry has played a significant role in the lifestyle of the local community, contributing to the economic development of the country ever since independence in 1957. The industry generally consists of two types of work: general construction work such as building and civil works, and special trades such as plumbing and electrical works (Ibrahim et al., 2010). These provide numerous jobs for foreign and local workers, with thousands of people working in the client organisations (including both public and private sector), contractors, surveying, engineering, architecture, management, and manufacturing. Indeed, besides generating wealth for the country's overall development, the construction industry has also contributed to the growth of other industries in the manufacturing, financial services and professional services sectors (CIDB, 2008). For instance, the construction of advanced buildings and infrastructure uses highly mechanised production techniques from both the manufacturing and professional services sectors, acquiring new technologies and expert advice in delivering such innovative projects.

Both the public and private sector play a significant role in the Malaysian construction industry. The former involves Government bodies such as the Ministry of Works, the Public Works Department (PWD), the Construction Industry Development Board (CIDB), the Contractor Service Centre (PKK), the Board of Engineers, the Board of Architects and the Board of Surveyors (Kamal and Flanagan, 2012). According to Ibrahim et al. (2010), the industry has been largely spurred on by Government spending to improve the nation's infrastructure. This includes expenditure for the delivery of public buildings and infrastructure projects such as Kuala Lumpur International Airport (KLIA), the Petronas Twin Towers and the administrative capital of Putrajaya. These public bodies therefore play a significant role in the overall growth and development of the Malaysian construction industry. Apart from the public bodies, larger contributions from the private sector could also be seen when the Ninth Malaysia Plan (9MP) (2006 to 2010) was introduced by the Government. Under this plan, construction organisations from the private sector were encouraged to become involved with the development of Government projects.

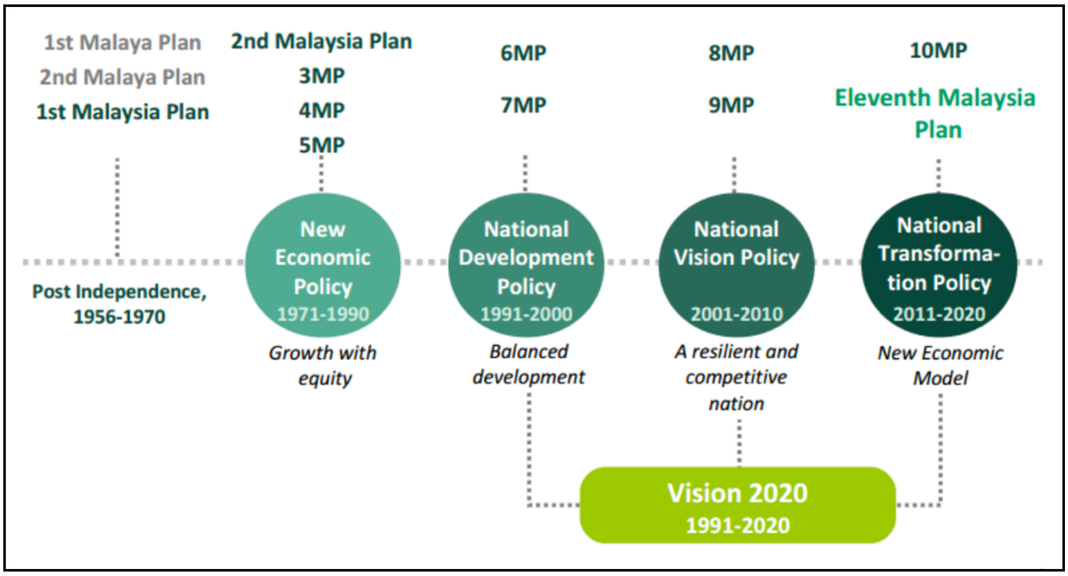

Figure 2.1: The series of Malaysian national plans
(Source: Economic Planning Unit, Prime Minister's Department, Malaysia)

Following the 9MP, the national plan to become a developed country by the year 2020 (through Vision 2020, in Figure 2.1) continued with the Tenth Malaysia Plan (10MP), 2011 to 2015. The 10MP basically charted the development of all the national economic sectors within the stipulated five years, including the budget allocated to fulfil both the Government Transformation Programme and the New Economic Model, as presented by the Economic Planning Unit (EPU) of the Prime Minister's Department and the Finance Ministry. A total of RM138 billion (€34.5 billion) was allocated to physical development in the construction sector, including the development of public projects (CIDB, 2008). The PWD played a significant role in this plan in becoming the Government's main technical advisor on all matters involving the public professionals and public projects delivery (e.g. technical auditor, building competencies, coordination of resources, policies), and is responsible for the construction and maintenance of the Government projects. The Malaysian Construction Industry Development Board (2008) also targeted a growth in the construction industry of 3.7% per annum over the five-year period.

Based on the Department of Statistics Malaysia (2014), the industry grew at a rate of 14.3% in the first half of 2014 with projects worth RM69 billion carried out until the third quarter of 2014. Overall, with the increased Government spending on public infrastructure, the construction industry output was expected to record a considerable annual growth rate of 11.48% from 2013 to 2017 (CIDB, 2012). In 2014, a total of RM46.5 billion was set aside for federal Government development expenditure, of which 2.4% was allocated to the housing sector, 19.6% to the infrastructure or transport sector, and 7.7% to public utilities (Department of Statistics Malaysia, 2014). The significant key economic indicators below signify the growth of the construction sector in the year 2014 (Department of Statistics Malaysia, 2014):

- A 6.2% economy growth rate during the first quarter of 2014,
- A 7.4% increase in domestic demand in the first quarter of 2014 led by the expansion in consumption and private investment,
- A public consumption growth rate of 11.2% in the first quarter of 2014.

Other factors include changes in the demographics of the country, with an annual population growth rate of about 2%; the migration of foreign workers and socio-economic growth also contributed to the expansion of the construction market (CIDB, 2012).

The Eleventh Malaysia Plan (11MP), from 2016 to 2020, was introduced as the closing chapter of the Vision 2020 plan (Figure 2.1). Although some of the objectives had been achieved in 10MP, the Government are still facing challenges in raising the nation's economy to be on a par with those of developed countries. 11MP therefore includes the aim of strengthening the infrastructure to support economic expansion, to re-engineer economic growth for greater prosperity (including transforming the construction industry), and transforming the public service to increase productivity. The growth of the construction industry particularly is evident under the 11MP, with a proposed contribution of RM327 billion or 5.5% to GDP by 2020 (EPU, 2015). This is due to the increasing demand for housing and continued investment in future large-scale projects such as new power plants, highways, urban transport systems, ports and airports (CIDB, 2015). Most importantly, the plan also highlights the need to transform public sector service delivery in order to be more cost effective and better equipped to meet the future demands and expectations of the nation. This includes improving service delivery with citizens at the centre, rationalising public sector institutions for greater productivity and performance, strengthening talent management for the public service of the future, enhancing project management for better and faster outcomes and capitalising on local authorities for quality services at the local level (EPU, 2015). This shows that considering the rapid development of the economy and the construction industry, there are still key areas in the public sector that need to be improved to efficiently deliver the key construction projects.

Overall, the 11MP identified key challenges faced during the implementation of 10MP, that are crucial to address. Understandbly, the challenges facing the Malaysian construction industry and the public sector are becoming increasingly complex due to global economic uncertainties, technological changes, and the rapidly rising expectations of citizens for the Government to deliver sophisticated infrastructure and services. Further challenges faced by the Malaysian construction industry are discussed in the following section.

2.2.1 Challenges in the Malaysian Construction Industry

According to Abdul-Rahim (2010), in 9MP (2006–2010), the public sector supply chain experienced poor project delivery despite various strategies and recovery measures taken to implement over 7,000 projects of this plan. Some of the projects were not completed within the stipulated time, even after introduction of 10MP. Abdul-Rahim (2010) pointed out the failures of the public projects with regard to issues pertaining to the traditional success factors of time, cost and quality, as follows:

- 80% of the public projects until 2009 could not be completed within the original contract period (Joshi, 2009).
- Changes in scope are common in public projects, resulting in cost overruns and delays.
- Poor quality has always been associated with public projects, despite various quality systems adopted during their implementation.

Some of the completed buildings were also reported to be non-functional due to inappropriate execution of works (Jaafar and King, 2011), suggesting that the problems may have derived from not only from the public organisations' internal capacities, but also their supply chain partners. These problems have together become a permanent issue for the Government in meeting the targets stipulated in the provisions. Furthermore, despite the progress of the infrastructure developments achieved in the 10MP, problems such as road congestion in urban areas, inadequate public transport, capacity constraints in ports, and bottlenecks in logistics are still prevalent in the Malaysian construction industry. The Government therefore calls for further improvements in the industry to improve overall productivity and performance of public sector services.

In addition, there is growing concern about the prevalent payment issues in the Malaysian construction industry, including non-payment, slow payment and under-payment which continue to rise (Judi and Abdul-Rashid, 2010). These payment issues have resulted in the construction organisations facing cash flow problems which make it difficult to complete the projects undertaken. They have also resulted in poor trust between the contracting parties and the project owners. Financial difficulties can also ultimately hamper productivity and the quality of the construction projects. Accidents on construction sites are another growing issue in the local construction industry. In 2007 3,395 accidents were reported, of which 2.8% and 0.3% resulted in death and permanent disabilities respectively in the construction industry (CIDB, 2008). These accidents caused the authorities to stop the work on site, causing significant delays in project delivery. Such accidents also tarnish the reputation and image of the construction industry.

As discussed in Section 1.2.3, the Malaysian construction industry is also facing significant external challenges such as global economic shocks and geopolitical risks. The severe fall in the prices of major export commodities, decline of the Ringgit Malaysia against major currencies, and the risk of economic slowdown of the national major trading partners are some of the key challenges highlighted in the 11MP (EPU, 2015). These have indeed affected the local supply chain, especially in terms of rises in the price of construction materials due to inflation and the depreciating currency. Considering the global economic uncertainties, inadequate fiscal measures by the Government are also recognised as a great challenge under the 11MP in ensuring the successful delivery of stipulated key infrastructure projects. These challenges can indeed siginificantly affect the Government's efforts to transform the nation's infrastructure and economy.

Overall, although both the public and private sectors of the construction industry face significant challenges in adapting to the challenges (Jaafar and Aziz, 2009), the public sector is governed by a strict set of rules and regulations, a burden with the additional responsibility of ensuring the public's money is spent properly and wisely. This is not surprising as the public organisations ultimately exist for the benefit of the citizens (Gould, 1997). In this case, the private sector has much more freedom when proceeding with a project (Gould, 1997) as it is not tied up to any specific Government rules, as long as the process undertaken is legal and ethical (CIDB, 2008). It is therefore important for the public sector to overcome these challenges to the industry, as any failures in its projects are highly visible to the public. This can result in the loss of trust of the public in Government bodies, which can subsequently damage the overall plans for national development.

2.2.2 The Role of the Malaysian Public Works Department (PWD)

As discussed in Section 1.2.3, PWD is the umbrella organisation for public sector works, formed in 1972 under the Malaysian Ministry of Works. The PWD's main role is as technical advisor to the Government, with responsibility for the implementation of public projects and the maintenance of the country's infrastructure assets (PWD, 2012). From a policy-maker's point of view, PWD is at the heart of policy making to improve the competencies of the public sector professionals across the federal ministries and public state organisations and mitigate disruptions that affect construction supply chains' performance. The aim of the department is to provide world-class services and become a centre of excellence for asset management, project management and engineering services in developing Malaysia's infrastructure through creative and innovative human resources and state-of-the-art technology.

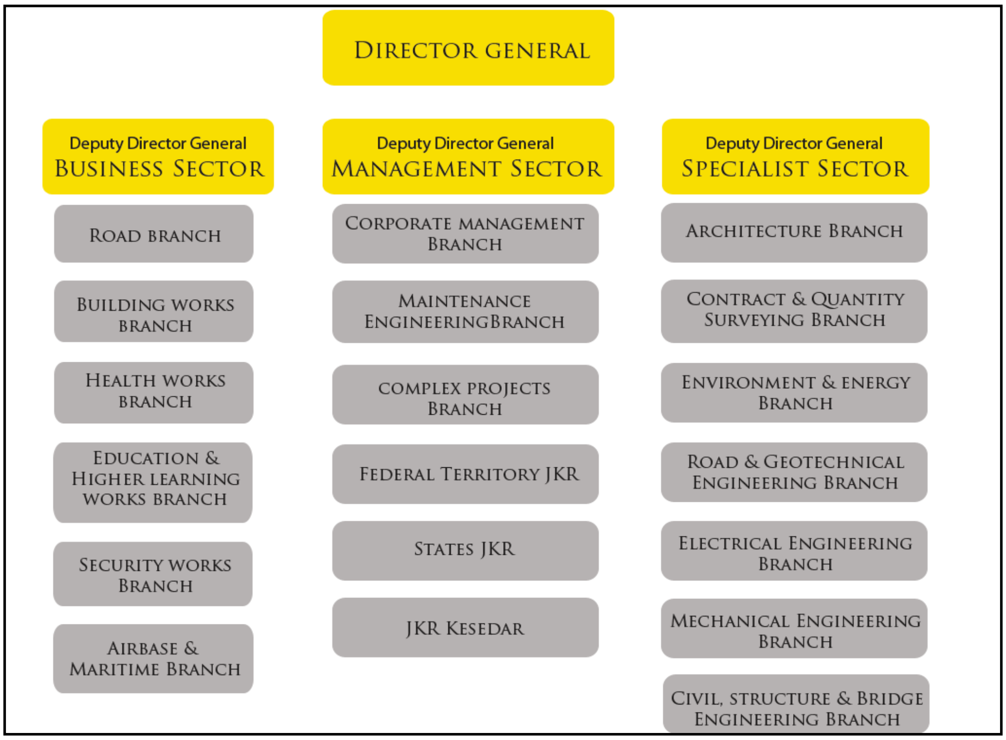

Figure 2.2: Organisational Structure of Malaysian Public Works Department (PWD, 2012)

The PWD is structured in three main sectors, business, specialist and management, as shown in Figure 2.2. According to Ngah (2011), there are still miscommunications among the branches and departments as every department is led by different project managers and functional managers. The unclear roles and responsibilities of departments in PWD also contribute to the delays and errors of public sector professionals across the states and federal organisations in delivering public projects. Under PWD, the public sector organisations serve numerous clients consisting of departments, authorities, and states, including the twenty-eight ministries. Consultants and contractors are engaged by the public organisations under the traditional, design and build and public private partnership procurement routes to deliver the public projects. Overall, the public organisations had over 1,900 projects worth RM25 billion allocated under 10MP (PWD, 2012). Considering the importance of the public organisations in delivering the projects for the development of the nation’s economy, and with the large number of parties involved in the public organisations’ supply chain, improved performance between the parties is significant in fulfilling the country’s construction provision. The public sector supply chain network is discussed further in the following section.

2.3 Supply Chain Disruptions

Supply chains in the face of disruption is a subject that has motivated the interest of numerous researchers and practitioners. Zsidisin et al. (2000) defined a disturbance as a consequential situation that significantly threatens the normal course of operations of the affected supply chain members. This scenario entails making decisions or taking actions in order to minimise such effects. Similarly, Svensson (2000), Hendricks et al. (2008) and Kleindorfer and Saad (2005) defined supply chain disruption as an unplanned and unanticipated event that disrupts the normal flow of goods and materials in a supply chain. Craighead et al. (2007) pointed out that the occurrence of such disturbances that negatively affect a supply chain is an unavoidable fact, and all supply chains are inevitably at risk.

Some authors refer to disturbances as ‘disruptions’ (Ponomarov and Holcomb, 2009), while others refer to them as ‘risk’ (Chopra and Sodhi, 2004; Goh et al., 2007), ‘errors’ (Love and Smith, 2016), ‘uncertainty’ (Mason-Jones and Towill, 1998) or even as ‘crisis’ (Loosemore, 2000). In the context of this research, the term used to refer to such disturbances is disruption, which is defined as a foreseeable or unforeseeable event which affects the usual operation and stability of an organisation or a supply chain (Barroso et al., 2008). It is an event that takes place at one point in the chain and can adversely affect the performance of one or more parties located elsewhere in the supply chain and the normal flow of goods and materials within a supply chain (Craighead et al., 2007). The supply chain risk, on the other hand, is the expected exposure of a supply chain to the potential impact of disruptions, usually characterised by the likelihood of a disruption and the impact of disruption if it occurs (Zsidisin et al., 2005).

In the context of the construction sector, a supply chain consists of upstream and downstream linkages. The upstream linkage in relation to the position of a main contractor consists of the activities and tasks leading to preparation of the production on site, involving construction clients and design team; downstream consists of activities and tasks in the delivery of construction products involving construction suppliers, sub-contractors and specialist contractors in relation to the main contractor (Akintoye et al, 2000). This fragmentation of the sequential design-construction process often results in construction organisations working in silos, reducing the organisations’ ability to detect any risk of disruption that may occur along the supply chain network. Figure 2.3 presents a basic example of the supply chain network in construction. The main contractors with a direct commercial relationship with the client and design team are considered as Tier 1. Tier 2 consists of sub-contractors and suppliers with a direct contract with the Tier 1 main contractor, and Tier 3 contains sub-contractors and suppliers working for the sub-contractors in Tier 2. Tier 3 sub-contractors may also employ suppliers and sub-contractors, hence, there could be up to four or five tiers of supply chain involved in delivering the project as it grows more complex. The source of disruption may be located inside or outside the chain and can occur in any node (i.e. a contractor or supplier) or link (i.e. the transportation of raw material between supplier and contractor) of the supply chain network.

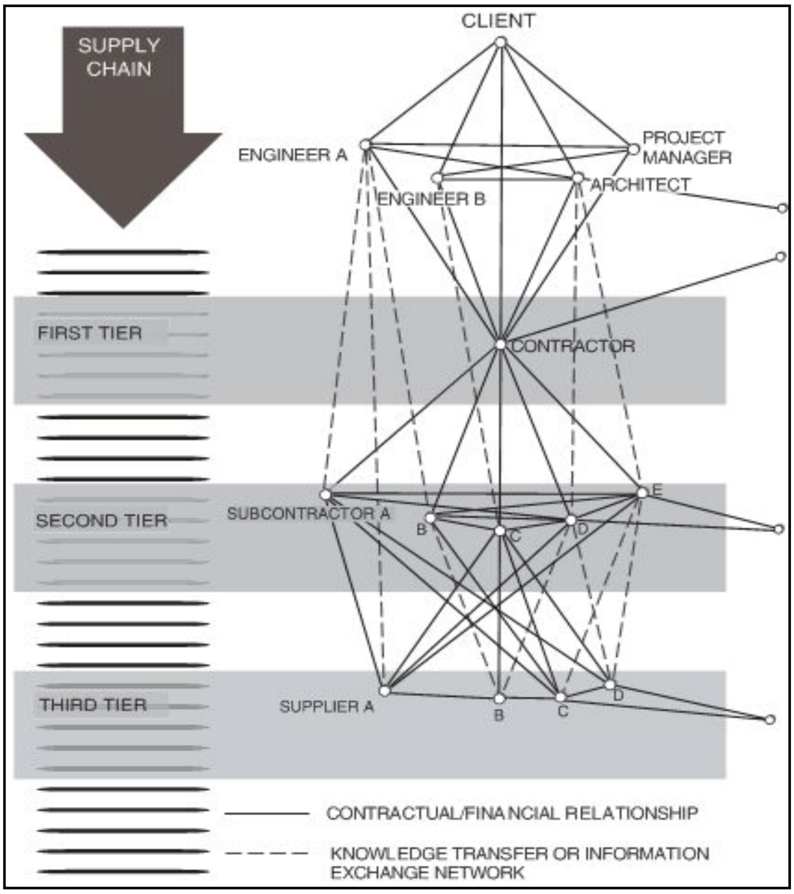

Figure 2.3: Construction supply chain network (Adapted from Hope, 2012)

From the point of view of this study, a typical supply chain network in the context of the Malaysian construction industry is represented in Figure 2.4.

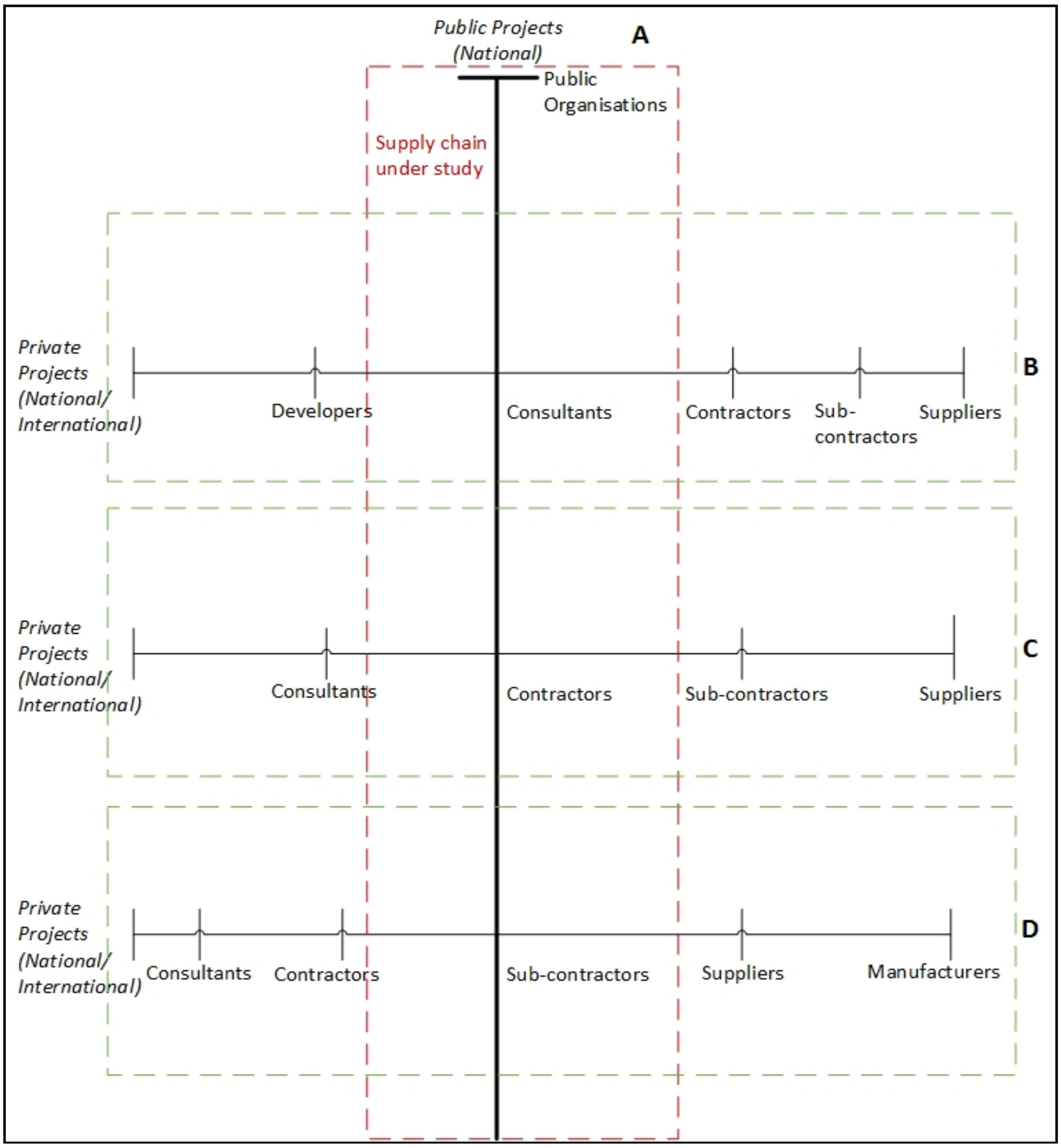

Figure 2.4: Superimposed public and private supply chains in the
Malaysian construction sector

The public sector, indicated as supply chain A in Figure 2.4, includes public organisations that act as the project owners on behalf of their clients (i.e. local ministries), and are in charge of implementing the public projects funded under the Government's stipulated provisions. A majority of the contractors and consultants working in the public projects are from the private sector. In addition to the public sector work these consultants and contractors also serve private clients within the private sector supply chain, depicted as B, C and D in Figure 2.4. Due to the growing complexity of the structure, this research considers the public sector initiated supply chain (supply chain A) as the main focus of this study. It can be observed here how managing the complex interdependencies both within and between these several supply chains is indeed challenging, as disruptions arising from any part of this chain will subsequently have a cascading impact on others, both locally and internationally. For instance, the failure of timely payment by the public organisations to the contractors in supply chain A will subsequently affect the contractors' cash flow and pre-planned programmes for other private sector projects involved in supply chain C. As the contractors are also working with other supply chains, the payment issues may subsequently lead to further impacts such as the contactors sacrificing time, cost and quality or, in the extreme case, the abandonment of projects in order to survive financially. In this case, practitioners often underestimate the interdependencies of this payment-related issue which may result in extreme consequences across the industry and the economy. As discussed in Section 2.2.1, delayed payment and non-payment in the Malaysian construction industry have often led to disputes and financial problems for industry players (Judi and Abdul-Rashid, 2010; Ameer-Ali, 2006), affecting the survival of the construction organisations in the entire delivery chain.

The interdependent nature of the supply chain has also resulted in the poor project delivery reported in the series of Malaysian Plans (2006–2015), that included non-functional buildings due to inadequate execution of the work (Jaafar and King, 2011). This reflects the complex nature of supply chain impacts. The negative effects of disruptions frequently cascade through the supply chain, due to dependencies (temporal, functional and relational) between supply chain entities (Svensson, 2000), as portrayed in Figure 2.4. Disruptions caused by clients are also common in public projects, where frequent changes in the scope of public sector projects result in cost overruns and delay (Abdul-Rahim, 2010). Certainly, the phenomenon such as the bullwhip effect shows that regardless of its magnitude, disruptions such as a small change in demand can spread and amplified from tier to tier in the supply chain (Lee et al., 1997; Taylor 2000), causing disruption to the operational flow of the entire supply chain. The discussion above shows that the fragmentation nature of the supply chain and the inability to manage the interdependencies of supply chain disruptions are recurrent issues for the Malaysian Government in meeting the 2020 targets. This is not surprising as the fragmentation of the construction industry have also been highlighted in the past Latham (1994) and Egan (1998) reports as one of the barriers to efficiency in supply chain performance. The reports show the relevance of adopting practices such as partnering and supply chain management in managing interdependent supply chain to overcome poor project performance (Latham ,1994; and Egan, 1998). Hence, in this case, due to the interdependent nature of the supply chain, the disruptions faced by both the public organisations and the respective supply chain partners (referred to as the private organisations from hereon) are considered in this study to obtain a more balanced perspective on the magnitude of the impact of disruptions in public sector projects.

2.3.1 Managing the Pre-, During and Post-Disruption Phases

In order to build the public sector supply chain's capability to withstand disruptive events, it is important to understand how to manage supply chain disruptions. Previous literature exists on managing supply chain disruptions from the manufacturing, retail (Xiao and Yang, 2008; Oke and Gopalakrishnan, 2009), automotive and oil and gas sectors (Behdani, 2013), but little attention has been paid to the disruptions faced by the supply chain in the construction industry, especially in the Malaysian context. By looking at disruptions as a process, the existing literature can be categorised into three main phases: the pre-disruption, during disruption and post-disruption phases, as tabulated in Table 2.1.

Despite the differences in terminology used in the framework presented by researchers from different disciplines (see the extended version of Table B1 in Appendix B), there is a level of agreement that the pre-disruption phase involves the proactive approach of identifying, assessing and mitigating the risk of disruption by assigning the necessary treatments to the risk identified. For instance, Billa et al. (2006) studied flood disaster management in Malaysia and described the activities at the pre-disruption phase to include the 'detection' of flood through the collection of meteorological data, flood 'forecasting' through the interpretation of the data collected, and the dissemination of 'warnings' to the public (see row 2 of Table 2.1). In the crisis management literature, Cockram and Van Den Heuvel (2012) believe that managers should have a wide range of proactive resilience activities in place at the pre-crisis phase to both prevent and mitigate the impact or duration if the crisis occurs. Sheffi and Rice (2005) agree with this and find that the effects of disruption can be minimised if a company can foresee and prepare for disruption before it occurs.

In the context of this study, this pre-disruption phase is equivalent to the risk management process before construction begins on site. This proactive approach to risk management is common in the Malaysian construction industry. However, despite this approach being widely practised in Malaysia, as the nature of the supply chain becomes more complex, it is difficult for the associated risks to be mitigated by individual participants in the chain. As the project progresses from one phase to another, its associated risk also shifts among the general contractors, sub-contractors, suppliers and other parties in the supply chain. Most research in the Malaysian construction industry (Goh and Abdul-Rahman, 2013; Siang and Ali, 2012) focuses on the risk management process in the pre-disruption phase, and there is a paucity of literature on the supply chain's response following 'actual disruptions' in construction. Hence, the supply chain's ability to learn from existing disruptions or utilise the supply chain's current capabilities to overcome such problems has received little attention.

During the disruption, an effective reactive response is important to reduce the spread of its impact. The response should include the implementation of the contingency plans set up during the pre-disruption phase. Berg et al. (2008) termed this 'reactive supply chain risk handling', which directly defines the success of the risk management process and includes the process of 'incident handling', 'accident handling' and 'execution of contingency plans' (see row 1 of Table 2.1). In other words, for this study, the effectiveness of the risk management programmes set by the construction organisations in the supply chain can be determined during this phase by assessing how well the incidents/accidents are handled (i.e. the time to react) or how well the developed contingency plans are followed during disruptions. However, Sheffi (2005) argues that in some cases, the pre-planned contingency measures might not be able to contain the disruptions, hence alternative responses outside the traditional work routines and standard operating procedures are usually required to prevent the spread of the disruption. This may be due to the large number of uncertainties and the difficulty in interpreting low-probability events beforehand during the decision-making process (Camerer and Kunreuther, 1989). It is therefore important for this study to consider the ability of the supply chain to react outside the traditional system responses to counter such disruptive events.

The post-disruption phase involves the recovery and learning process. It means dealing with the long-term effects or impacts of an event and how to return to 'business as usual' or the new 'normal', if major change has taken place (Cockram and Van Den Heuvel, 2012). The management should review the disruption management procedure, so that the company can take corrective actions (product design, process control, supplier audits, etc.) to prevent or reduce the likelihood of future disruptions (Pyke and Tang, 2010). The supply chain can then be re-designed to become more resilient in future (Blackhurst et al., 2005).

Table 2.1: Summary of disruption phases from previous literature (see extended version in Appendix B)

No.	Authors (Year)	Disruption Phases			Area of Study
		Pre-Disruption	During Disruption	Post Disruption	
1.	Berg et al (2008)	1. Proactive Risk Management - Identify, evaluate, manage and monitor risks	2. Reactive Risk Handling - Incident/accident handling - Execution of contingency plans	3. Results and Outcomes - Achievement of business objectives - Cost of risks	Assessing supply chain risk management programs
2.	Billa et al (2006)	1. Detection 2. Forecasting 3. Warning	4. Response	5. Reaction	Flood management planning
3.	Blackhurst et al (2005)		1. Disruption Discovery	2. Disruption Recovery 3. Supply Chain Redesign	Managing supply chain disruptions
4.	Cockram and Van Den Heuvel (2012)	1. Pre-crisis Preparation	2. Crisis Response	3. Post-crisis Recovery	Crisis management
5.	Pyke and Tang (2010)	1. Readiness	2. Responsiveness	3. Recovery	Mitigating product safety risks via 3Rs
6.	Sheffi and Rice (2005)	1. Preparation	2. Disruptive Event 3. First Response 4. Initial Impact 5. Time of Full Impact	6. Preparation for Recovery 7. Recovery 8. Long-term Impact	Supply chain view of the resilient enterprise

Looking at the literature in the context of the Malaysian construction industry, the researcher has found little work on post-disruption activities in the response of the supply chain to 'actual disruption'. Busby and Zhang (2008) suggested that risk analysis should not simply be a consensual analysis of threats and consequences; it should also involve inspecting how different actors respond to these threats, and how some of these responses are themselves threats in other actors' eyes. It is therefore important for this study to consider an integrated approach of both pre- and post-disruption stages and the proactive and reactive approach in an effort to improve project performance and build resilience within the Malaysian public sector supply chain.

An example of the integrated approach of handling disruptions can be seen in the 3R framework presented by Pyke and Tang (2010), which has three main stages: readiness, responsiveness and recovery (see row 5 of Table 2.1). The 3R framework was presented for a specific case of product safety risk (see Figure 2.5). Under this framework, it was suggested that the related company should prepare the necessary channels in case a recall becomes necessary or disruptions occur (readiness), create an action plan which allows a quick response to the problems at hand (responsiveness), and after a disruption, take steps to restore its supply chain back to normality (recovery). Although this framework presents the overall link between the pre-disruption, during disruption and post-disruption phases comprehensively in a closed loop, its drawback is that it is difficult to implement due to the lack of details of the sub-steps required to handle a disruptive event. The framework was also designed for a specific type of disruption, which is the risk of product safety. It is therefore important for this study to consider a wide range of supply chain disruptions in developing the resilience response framework for the public sector supply chain.

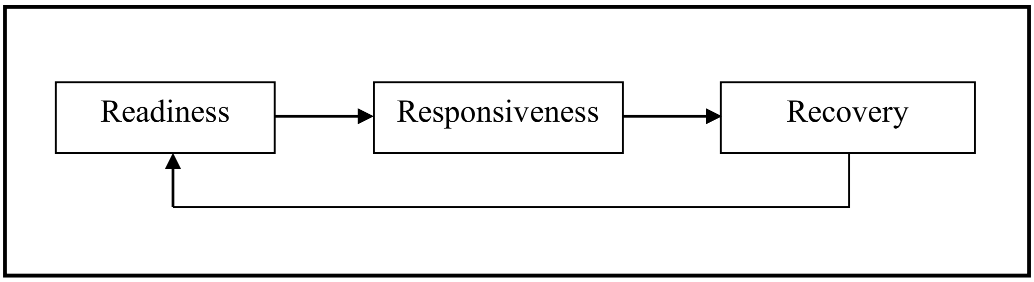

Figure 2.5: The 3R framework for mitigating a disruptive event (Pyke and Tang, 2010)

Another integrated approach to handling disruptions was presented by Sheffi and Rice (2005) through eight stages of disruption, as shown in Table 2.1 (see Appendix B for the full description of the disruption stages). Unlike Pyke and Tang (2010), these researchers considered the level of performance of an organisation or supply chain before, during and after disruption in a timeline graph showing the level of impact of the disruption on business performance (see Figure 2.6). They stressed that it is important for managers to consider the impact of disruption as it is not always immediate; it may take time for the abnormality to show its full effect on system performance. For example, if the client relationship or organisation's reputation is damaged, the impact of disruption can be long lasting and difficult to recover from.

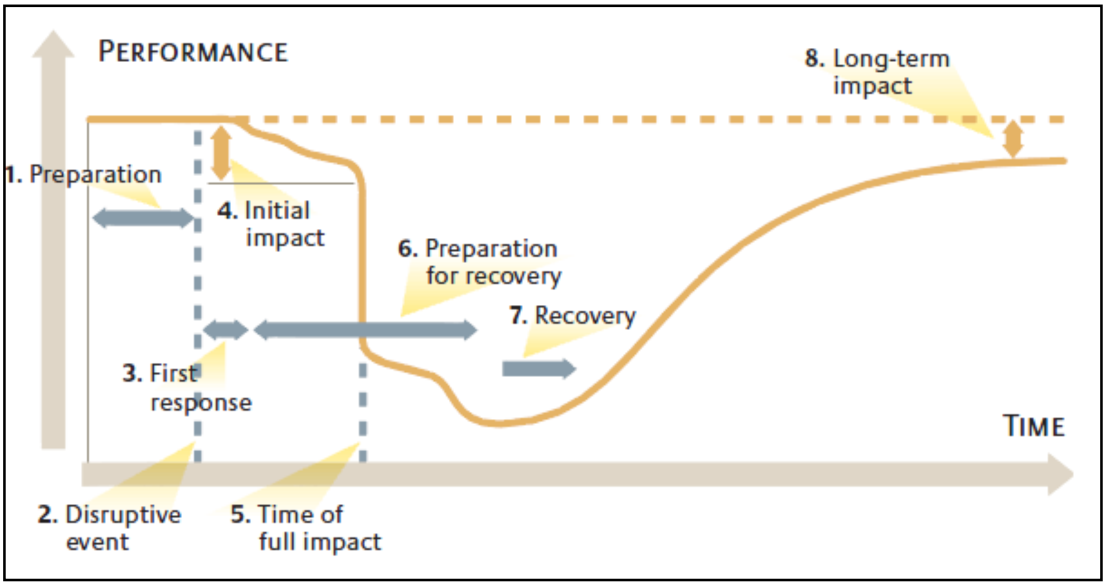

Figure 2.6: The eight stages of disruption (Sheffi and Rice, 2005)

However, although the framework in Figure 2.6 is useful in mapping the impact of disruption on performance, the drawback is that it does not provide details on how the organisation can improve their performance at the preparation, response and recovery stages. One of the ways to tackle this drawback is by listing the necessary capability factors needed to maintain the organisation's performance at different stages of disruption. Another drawback of the framework is that it does not indicate the factors that cause the organisation's performance to drop significantly during the initial or full impact stage. Although Sheffi and Rice (2005) pointed out the vulnerabilities of organisations (such as the loss of key suppliers, and quality problems) that cause poor performance, these vulnerabilities were listed in a separate framework in their study. Hence, one of the ways to improve the framework in Figure 2.6 is by incorporating the vulnerabilities in the main framework, so that supply chain managers can clearly see both the capabilities and vulnerabilities of the supply chain in resonding to disruptions. Along with the interdependent impacts of disruptions (discussed in Section 2.3), this research will also consider the emergent capability and vulnerability factors of the supply chain in developing the resilience response framework. These elements are reflected in Objectives 3 and 4 of this study (see Section 1.4).

A summary of the integrated disruption phases in this study is presented in Figure 2.7. The construction supply chain's response to disruptive events can be assessed against these disruption phases. The pre-disruption phase includes the proactive risk management plan, followed by its implementation during disruption. The degree of severity of a certain disruption depends on factors specific to the structure of the supply chain (density, complexity and criticality), and supply chain mitigation capabilities (readiness, responsiveness and recovery). The adoption of significant measures in managing supply chain disruptions will enable the supply chain to quickly return to its original state, or an even better state (Peck, 2005) in the post-disruption phase, and therefore demonstrate resilience.

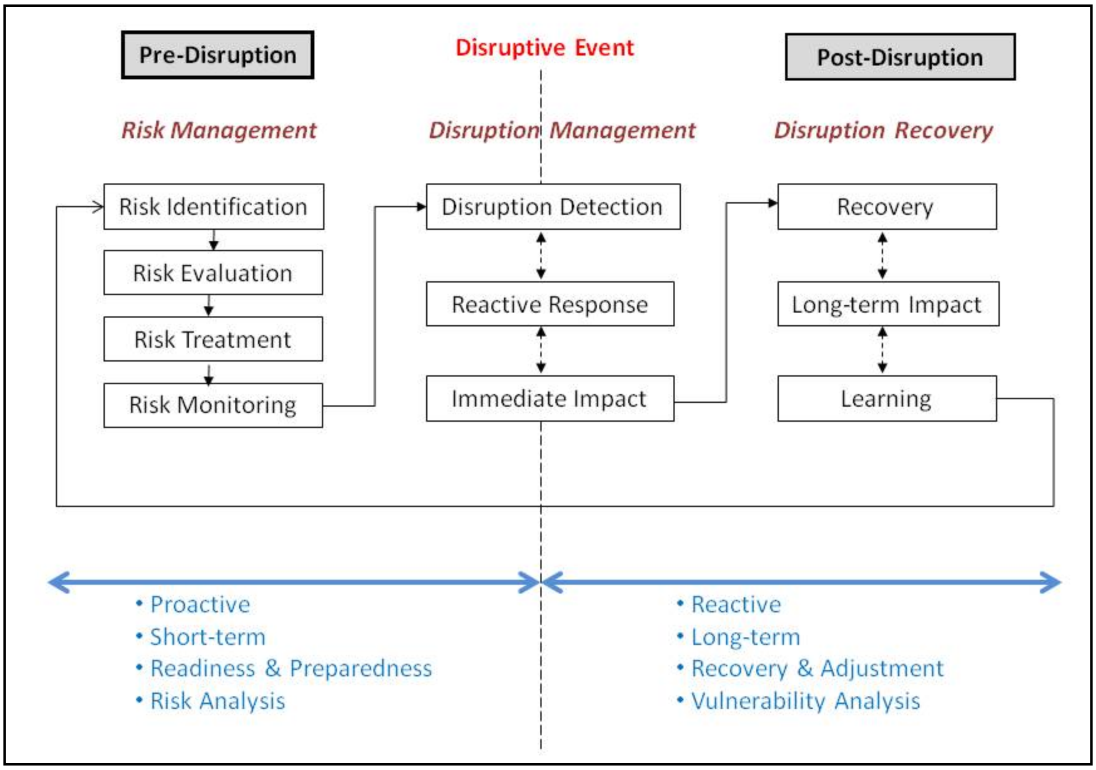

Figure 2.7: Summary of the disruption phases

Next, we look at the literature on the supply chain resilience in managing the supply chain disruptions.

2.4 Supply Chain Resilience

Resilience is a multidisciplinary concept, of considerable interest to various industries in different countries, with various backgrounds such as the social, ecological, computing and engineering sciences (Peck, 2005; Ponomarov and Hollcomb, 2009; Pettit et al., 2010; Limnios and Mazzarol, 2011). Limnios and Mazzarol (2011) highlighted two opposing concepts of resilience: either offence (adaptation) or defence (resistance) to internal or external disruption. A system or supply chain may be adaptive in reacting to disruption by changing its structure, processes and functions to increase its ability to survive. On the other hand, a supply chain may also be resilient in terms of its ability to resist such changes and absorb the shocks by maintaining its current structure and processes.

However, earlier research by Miller and Friesen (1980) pointed out that some organisations demonstrate a combination of both adaptive capacity and resistance to change. The researchers believed that organisations would neither be able to change their tactics and reaction to each slight change in their environment, nor remain static, as they have to evolve through time. Hence, even if an organisation or supply chain has a tendency to adapt its strategies to its changing environment, it is also equally important to reinforce or improve these strategies in order to persist in the long run. This shows how the current state and attributes of the organisation and its supply chain have a significant influence over thee strategic approach in responding to disruptive events.

In the supply chain context, Peck (2005) defines supply chain resilience by relating it to the ability to recover from or adjust easily to adversity or change (i.e. supply chain disruptions caused by disturbances). Fiksel (2006) proposes a similar definition, but considers that a resilient system will have the ability not only to “survive and adapt in face of turbulent change”, but to also “grow” or thrive in the face of disruption. Ponomarov and Hollcomb (2009) define resilience as the capability of the supply chain to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function. For the purpose of this research, supply chain resilience is defined as the supply chain’s ability to react to the negative effects caused by disruptions that occur at a given moment in order to maintain the supply chain’s objectives or recover to a better state (Barroso et al., 2008).

In order to deal with resilience it is important to identify the disruption areas, vulnerabilities, and how the disruptions can be mitigated through the development of capabilities. Indeed, Pettit et al. (2010) suggested that supply chain resilience can be assessed in terms of two dimensions: vulnerabilities and capabilities, which are explored in this study. They believe that empirical studies can provide management insight into linkages between each vulnerability and a set of successfully employed capabilities to combat that vulnerability. Hence, by reducing its vulnerabilities, the supply chain can increase its resilience to disruptive events (as per Figure 2.8). Most supply chain resilience literature (Pettit et al., 2013; McManus, 2008), however, seems to cover multi-sectoral issues and the coverage of construction per se is limited. A more industry-specific research, such as in the context of the construction industry in this study, is required to address this theoretical gap. The assessment of the capabilities and vulnerabilities could benefit this study considerably in determining the current level of resilience of the public organisations and their supply chain. This in turn, will help to highlight key areas that need to be improved in the effort to build resilience to disruptions in public projects. The following sections provide further discussion on the vulnerability and capability factors.

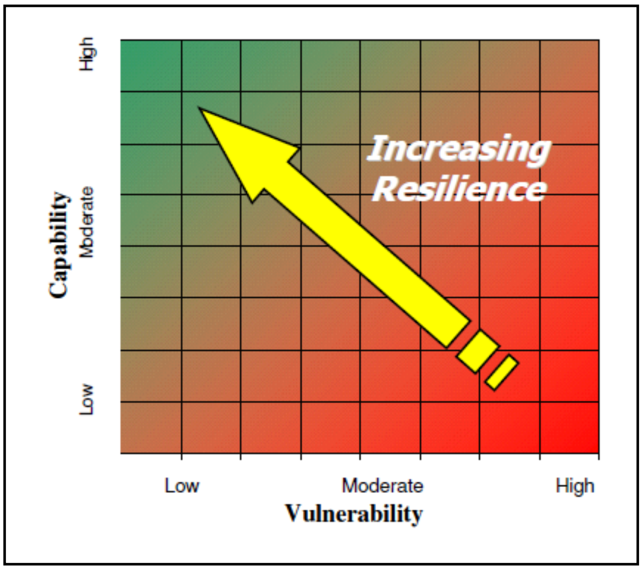

Figure 2.8: Measurement of resilience (Pettit et al, 2010)

2.5 Supply Chain Vulnerability

The term vulnerability has been used and defined by various researchers in the field of supply chain risk and resilience, although there is still no clear agreement in the literature as to what vulnerability is. Indeed, the term vulnerability is often confused with risk (Ezell, 2007). The main difference between them is that vulnerability highlights the notion of susceptibility to a disruption by defining the characteristics of the system or supply chain that will change the possibility for harm (Ezell, 2007; Brooks, 2003). On the other hand, risk focuses on the likelihood and severity of the consequences of disruption. This was highlighted inand Rausand's (1998) study, where they argue that unlike risk analysis, vulnerability analysis focuses on the whole disruption period including the actions to mitigate, restore and restart the activities after a disruption occurs, until a new stable situation is obtained.

While risk includes positive and negative impacts, vulnerability is seen as a combination of a disruption and the resulting negative consequences. Svensson (2000) defined vulnerability as the existence of random disruptions that lead to deviations in the supply chain of components and materials from normal, expected or planned activities, all of which have negative consequences for the manufacturer and its sub-contractors. Similarly, Christopher and Peck (2004) suggested that supply chain vulnerability can be defined as an exposure to serious disruptions, arising from risks within the supply chain as well as risks external to the supply chain. Juttner et al. (2002) defined vulnerability as "the propensity of risk sources and risk drivers to outweigh risk mitigating strategies, thus causing adverse supply chain consequences".

On the other hand, Wagner and Bode (2006) defined the concept of vulnerability in a supply chain context more precisely, stating that "supply chain vulnerability is a function of certain supply chain characteristics and that the loss a firm incurs is a result of its supply chain vulnerability to a given supply chain disruption". In their next work, Wagner and Bode (2009) further defined the concept of supply chain vulnerability as follows:

> While a supply chain disruption is the trigger that leads to the occurrence of risk, it is not the sole determinant of the final loss. It seems consequential that also the susceptibility of the supply chain to the harm of this situation is of significant relevance. This leads to the concept of supply chain vulnerability. The basic premise is that supply chain characteristics are antecedents of supply chain vulnerability and impact both the probability of occurrence as well as the severity of supply chain disruptions (p. 278).

For the purpose of this research, the latter definition is adopted. Supply chain vulnerability is defined as the "fundamental factors that make an enterprise susceptible to disruptions" (Pettit et al., 2010). According to Sheffi and Rice (2005), reducing these vulnerability factors means reducing the likelihood of a disruption and increasing resilience: the ability to recover from a disruption. If supply chain managers can alleviate these supply chain attributes, they can reduce vulnerability and the detrimental effects on the focal organisation and the supply chain as a whole.

Looking at the vulnerability drivers, Wagner and Neshat (2010) categorised them into three groups: supply side, demand side and supply chain structure vulnerabilities. Those on the demand side reside in the downstream supply chain operations. These include the customer (i.e. customer dependence, financial situation of the customer), the product and its characteristics (i.e. its complexity and lifecycle), the outbound supply chains (i.e. the physical distribution of products to the end customer), and the distribution and transportation operation required for serving the customer (Wagner and Neshat, 2010; Svensson, 2000). The demand side vulnerability drivers can also reside in the uncertainty surrounding the random demands of customers (Wagner and Neshat, 2010). In the case of the construction industry, constant changes in customer requirements during construction can cause significant time and cost overruns and reduce project performance.

Meanwhile, vulnerability drivers on the supply side reside in the supply base, the supplier portfolio or the supplier network (i.e. supplier-supplier relationships, supply base complexity, supply base structure). Wagner and Neshat (2010) pointed out that the characteristics of individual suppliers in an organisation's supplier portfolio also influence supply chain vulnerability. This includes financial instability of the suppliers and the consequences of supplier insolvency or bankruptcy. This is an important consideration in construction as poor financial performance or insolvency of contractors and suppliers can hamper the progress of the project, making the supply chain more vulnerable to any disruptive events that occur during project delivery. The last category, supply chain structure vulnerabilities, result to a large degree from the disintegration of supply chains and the globalisation of value-adding activities (Wagner and Neshat, 2010). When supply chains have to cover a larger number of international markets and regions of the world, the more susceptible are they to natural and man-made disasters. In fact, Zsidisin et al. (2005) argued that today's supply chains contain less slack, with lower inventories, fewer buffers and leaner logistics operations, making them more fragile and vulnerable to disruptions.

On the other hand, Pettit et al. (2010) consolidated 39 vulnerability factors into seven main categories: *turbulence* (i.e. natural disasters, fluctuations in prices, political disruptions) that are beyond the supply chain's control; *deliberate threats* such as theft and terrorism which are aimed at disrupting operations or causing human or financial harm; *external pressures* that create business constraints or barriers (i.e. competitive innovation, price pressures); *resource limits* which include supplier, production and distribution capacity; *sensitivity* which involves the importance of carefully controlled conditions for product and process integrity; *connectivity* which includes the degree of interdependence and reliance on outside entities; and *supplier or customer disruptions*. It can be seen here that there are overlapping vulnerability factors between Pettit et al. (2010) and Wagner and Neshat's (2010) work, despite the different category terminology used.

Meanwhile, Sheffi et al. (2010) and Blos et al. (2009) highlighted that vulnerability can be expressed in terms of financial vulnerability (i.e. fluctuations in prices, price pressures from competition), strategic vulnerability (i.e. extent of supply network, ineffective planning), hazard vulnerability such as natural disasters, and operations vulnerability (i.e. supplier disruptions, utilities availability). Chowdhury et al. (2012) adopted the same main factors: hazard, operational and financial vulnerabilities, and added another category: demand and supply vulnerabilities, which includes factors such as unpredictability of demand and customer disruptions. In determining the vulnerability parameters for this study, the vulnerability factors are grouped into four main categories as described below (McManus, 2008; Christopher and Peck, 2004; Einarsson and Rausand, 1998):

a) Organisation Vulnerability - Vulnerabilities arising from within the organisation that are under direct control of the organisation
b) Operational Vulnerability - Vulnerabilities arising from the supply chain network that the organisation has little or no control over
c) External Vulnerability - Frequent changes in external factors that are beyond the organisation and its supply chain's control
d) Financial Vulnerability - Negative financial impact caused by the market and economy that are beyond the organisation and its supply chain's control

These factors were incorporated in the survey described in Chapter 4 to determine the quadrant or area shown in Figure 2.9 in which the supply chain members are most vulnerable, in the attempt to build supply chain resilience. The vulnerability may derive from sub-factors within the organisation, external to the organisation but within the supply chain network, or from factors external to the supply chain network, as depicted in Figure 2.9**.** Taking into account the factors discussed above, a summary of the supply chain vulnerability factors is presented within the stated categories in Table 2.2 below.

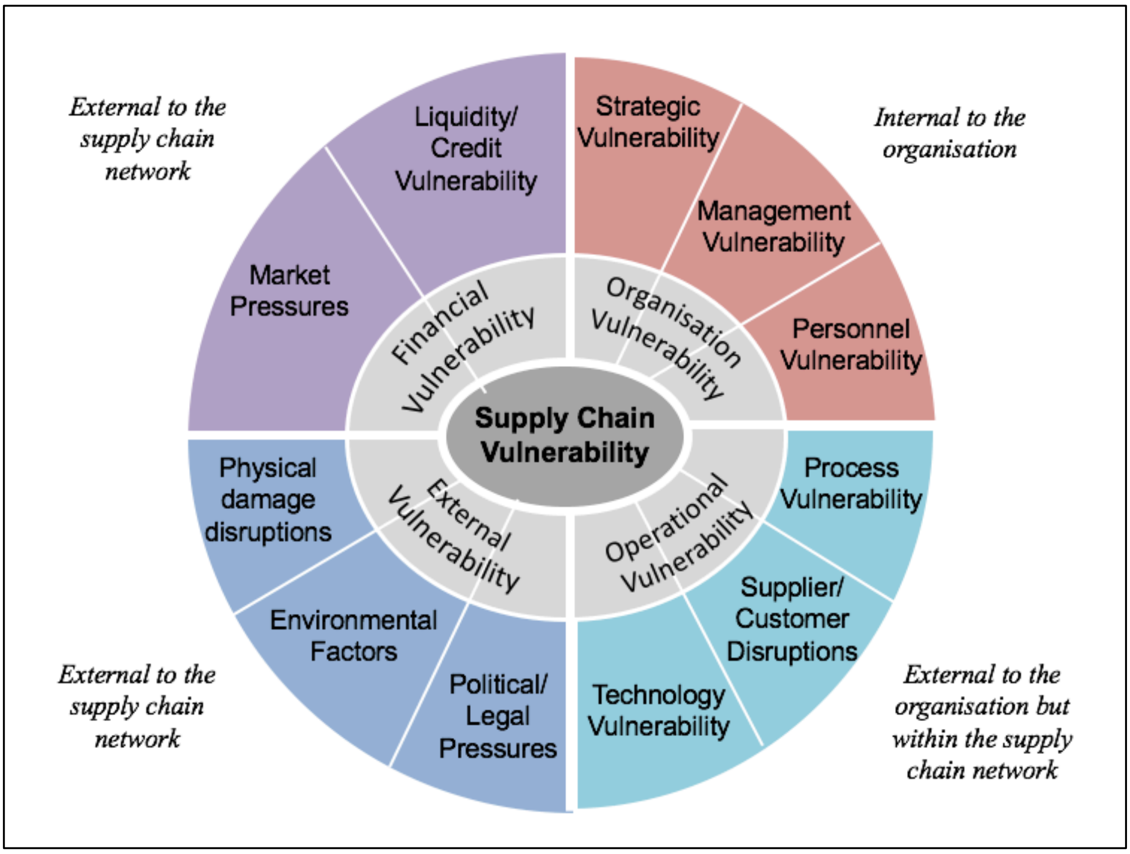

Figure 2.9: Supply chain vulnerability factors

Table 2.2: Summary of Supply Chain Vulnerability Factors

Vulnerability Category	Supply Chain Vulnerability Factors	Pettit & Fiksel (2010)	Sheffi (2005)	Blos et al (2009)	Chowdhury et al (2012)	Svensson (2000)	Peck (2005)	Blackhurst et al (2008)	Wagner & Neshat (2010)
Strategic Vulnerability	Scale/extent of supply network	X	X			X	X		X
	Degree of outsourcing	X		X	X		X		
	Reliance upon specialty sources	X				X			
	Unpredictability of demand	X	X		X	X	X	X	X
	Innovation (competition)	X	X	X	X		X		
	Supplier trust, loyalty, relations, reliability	X	X	X	X	X	X	X	X
	Customer disruptions	X	X	X	X				X
	Ineffective planning		X						
	Complexity	X					X		X
	Product purity		X						X
	Restricted materials		X						
	Fragility		X						
	Visibility of disruption to stakeholders	X							
	Concentration of capacity	X							X
	Inadequate management oversight		X						
	Technology decisions		X	X					
	Timing of business decisions		X						
	Budget overruns/Unplanned expenses		X						
Operational Vulnerability	Import/Export channels	X							
	Supplier capacity	X	X						X
	Production capacity	X			X			X	
	Distribution capacity	X			X				X
	Utilities availability	X	X	X	X				
	Human resources	X	X	X	X				
	Reliance upon information flow	X	X		X		X	X	
	Unforeseen technology failures	X	X	X	X				
	Labor disputes	X			X	X	X	X	
	Transportation disruption (During import and export as well as domestic routes)			X	X				X
	Reliability of equipment	X	X	X	X		X		

	Potential safety hazards	X	X						
	Shortage of skilled workers		X						
	Product quality problem (defection in design and production, damage, wrong component or material)			X	X			X	
	Raw material availability	X			X				
	Loss of key personnel		X	X					
	Loss of key supplier		X	X					X
External Vulnerability	Natural disasters	X			X	X	X	X	
	Exposure to political disruptions	X	X	X	X		X	X	
	Health pandemic/spread of disease	X	X		X				
	Piracy & theft	X		X	X		X	X	
	Terrorism & sabotage	X	X	X	X		X	X	
	Product liability	X	X						
	Accident in plant (fire, property damage, boiler explosion, operator accident)		X	X	X				
	Loss of key facility		X	X					
	Political/Regulatory changes	X	X	X			X		
	Social/cultural changes	X			X		X		
	Environmental changes	X			X				
	Public Reputation	X	X						
Financial Vulnerability	Fluctuations in prices	X	X	X	X			X	
	Price pressures (competition)	X	X						

Although the supply chain vulnerability factors in Table 2.2 above are classified into 11 categories, it is worth noting that certain factors may overlap and have very close links. These sub-factors are further discussed below.

2.5.1 Organisation Vulnerability

In this study, 'strategic vulnerability' refers to the inadequate business decisions undertaken by an organisation on its products or services, that may put the organisation at significant risk of failure to achieve its business objectives when disruptions occur. They include decisions to outsource operations to different suppliers, reliance upon specialty sources, operating in a geographically concentrated area, and a high degree of complexity of the products themselves (Pettit et al., 2010). Pettit et al. (2010) also discussed how the degree of interdependence and reliance on outside entities can make an organisation vulnerable to disruptions. When connectivity extends beyond suppliers and customers, as organisations move toward more outsourcing, these additional layers of management contribute to increased interdependencies (Pettit et al., 2010). Even though outsourcing can be effective in reducing costs or obtaining specialised resources (e.g. special information technology services), it also brings about significant risks that can make the organisation more vulnerable to disruptions.

On the other hand, 'management vulnerability' refers to the management level of the organisation in executing the business decisions. Vulnerability can arise from inadequate management oversight to control or supervise supply chain members, late information and decision making, budget overruns due to poor planning, poor information flow, and poor control of deficiencies in the operations that can be highly visible to the organisation's stakeholders. Lastly, 'personnel vulnerability' relates to the staff within the organisation. Factors such as the shortage of skilled workers, labour disputes, hazardous working conditions, and the loss of key personnel during operations can influence the vulnerability of an organisation or supply chain (Einarsson and Rausand, 1998).

2.5.2 Operational Vulnerability

The vulnerability factors within the supply chain network can be categorised in three groups: process vulnerability, supplier or customer disruptions and technology vulnerability. Process vulnerability refers to vulnerability arising from any link of the supply-production-distribution chain (see Figure 2.10), as described below:

- The inbound or supply side of the chain relates to the creation, delivery and availability of supplies when and where needed (i.e. the availability of restricted materials, utilities or raw materials).
- The processes or production part including all the activities and manufacturing steps performed to produce the completed project (i.e. production capacity, reliability of material or equipment used).
- The outbound or distribution side of the chain including all the distribution processes and transportation operations required for serving the customer. The quality of service or product provided is also considered here.

According to Sheffi and Rice (2005), in any organisation's supply chain, disruptions can occur at any section of the chain as material and information flows from supplier through a production or conversion process to the distribution channels. In construction, during the conversion process, materials are combined with labour, information, technology and capital to produce the completed project (Benton and McHenry, 2010). There is a high level of interdependence between the supply-production-distribution chain in delivering construction projects which can create vulnerability in the supply chain. Project quality, budgets and completion times can easily be affected if disruptions occur. Therefore, it is important to manage vulnerability within this chain to mitigate disruptive events in construction projects.

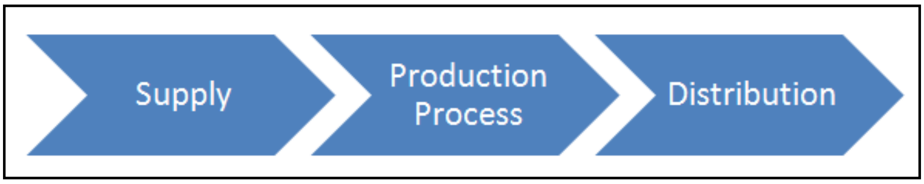

Figure 2.10: Supply chain elements (adapted from Sheffi and Rice, 2005)

Meanwhile, the 'supplier or customer disruptions' relate to the susceptibility of suppliers and customers to disruptions (Pettit et al., 2010), which can affect an organisation's ability to produce their products or services, especially in an interdependent environment such as the construction industry. Supplier disruptions could arise from an infinite list of possibilities, such as supplier equipment failure, supplier's poor capacity in dealing with unplanned changes in demand and insolvency (Svensson, 2000). This is an important consideration in construction as incompetent contractors and suppliers can hamper the progress of the project, making the supply chain more vulnerable to any disruptive events that may occur during project delivery. Customer disruptions are equally important, often resulting from unexpected changes in customer demands. In this case, the organisation must be prepared with flexible options to mitigate short-term disruptions and adapt as necessary if long-term impacts are expected (Pettit et al., 2010). Lastly, ‘technology disruptions’ include the vulnerability of the supply chain to technology changes in the industry and unexpected technology failures faced by the supply chain during operation.

2.5.3 External Vulnerability

According to Pettit et al. (2010), external pressures are influences, not specifically targeting the organisation, that create business constraints or barriers. They include ‘political or legal pressures’ such as changes in Government regulations that may enforce limitations or add expenses to operations. Other vulnerabilies under this category include ‘environmental factors’, such as natural disasters and health pandemics, and ‘physical damage disruptions’ involving accident or deliberate threats such as piracy and theft aimed at disrupting operations or causing human or financial harm (Pettit et al., 2010).

2.5.4 Financial Vulnerability

‘Market pressures’ in this category involve fluctuation in material prices that may rise above acceptable levels and make it impossible to continue cost-effective production (Einarsson and Rausand, 1998). A system may also be vulnerable to price pressures from competitors offering similar products or services at a lower price, resulting in the loss of business opportunity. Lastly, ‘liquidity or credit vulnerability’ involves issues relating to money and management of monetary assets that might be affected by changes in financial and economic policies (Pathirage et al, 2012).

The following section discusses the supply chain capabilities that could help mitigate the vulnerabilities.

2.6 Supply Chain Capability

Supply chains need to be capable of resilience against disruptions (Christopher and Peck 2004). Indeed, resilience is the capacity of a supply chain to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function (Ponomarov and Hollcomb, 2009).

According to Pettit et al. (2010), capabilities are attributes that enable an enterprise to anticipate and mitigate disruptions. They can prevent an actual disruption (i.e. security measures deterring a terrorist attack), mitigate the effects of a disruption (i.e. stock piles of emergency supplies) or enable adaptation following a disruption (i.e. development of new products or services, or entering a new market). Through the proposed Supply Chain Resilience Assessment and Management (SCRAM) tool, Pettit et al. (2010) investigated 14 main capability factors: flexibility in sourcing, flexibility in order fulfilment, capacity, efficiency, adaptability, visibility, anticipation, recovery, dispersion, collaboration, market position, organisation, security and financial strength.

On the other hand, Christopher and Peck (2004), researchers from the Cranfield Centre for Logistics and Supply Chain Management, developed an initial framework for a resilient supply chain. They suggested four key principles in building supply chain resilience: i) resilience can be built into a system in advance of a disruption (i.e. re-engineering), ii) a high level of collaboration is required to identify and manage risks, iii) agility is essential to react quickly to unforeseen events, and iv) the culture of risk management is a necessity (Christopher and Peck, 2004). The secondary capability factors mentioned in their research are supply chain agility, availability, efficiency, flexibility, redundancy, velocity and visibility. Similar to the Cranfield studies, researchers at the Massachusetts Institute of Technology analysed many case studies of supply chain disruptions with a focus on identifying vulnerability characteristics and management responses: flexibility (i.e. interchangeability, flexibility of supply, postponement for flexibility), redundancy (i.e. inventory for redundancy, redundant capacity, redundant IT systems), customer relation management, security and collaboration (Sheffi, 2005).

The discussion above shows a number of common capability factors that existing researchers agree on. Flexibility is one of the most important. In construction, flexibility in a project is the capability to adjust the project to the prospective consequences of uncertain circumstances within the context of the project (Husby et al., 1999 as cited in Olsson, 2006). In other words, flexibility is the possibility of construction and technical changes with minimum cost and disruption. Pettit et al. (2010) highlighted two main flexibility factors: flexibility in sourcing and flexibility in order fulfilment. This can be assessed by looking at the supply chain members' ability to quickly change inputs or the mode of receiving inputs from the supply side, and their ability to quickly change outputs or the mode of receiving outputs at the demand side. Flexibility can be improved by utilising materials or inputs that can be incorporated in multiple finished products. In construction, this could be the utilisation of standardised components that can be used in many components of the building design during construction. This would reduce the cost of inventory and the risk of an individual stock out. The use of alternative suppliers is also important in the event of a single or multiple-supplier disruption.

Olsson (2006) pointed out that flexibility in products could also be related to the degree of modularity in projects. Modularity refers to the possibility of dividing the project into more or less independent sub-units. According to Miller and Lessard (2000), modularity can enable projects to cope with uncertainty because individual components do not have a critical role. Major ‘one-piece’ projects such as bridges and tunnels have a low level of modularity, based on the ‘we do not build half a bridge’ approach. On the other hand, for flexibility in the demand side, the ability of a supply chain to quickly increase the capacity of storage and distribution services to meet surge demand without carrying large amounts of excess capacity is extremely profitable when facing unpredictable demand (Pettit, 2008). Alternate distribution channels are also important when a supply chain faces transport disruptions or if an entire network is disrupted.

Another key capability factor is the system’s efficiency (see Tables 5.4 and 5.5). Efficiency is linked to the immediate outcome of a project. It is a question of doing things right and producing project outputs in terms of the agreed scope, quality, cost and time (Olsson, 2006). As stated by Pettit (2008), the capability to produce outputs with minimum resource requirements is important to improve efficiency. The goal is to reduce all cost drivers while still meeting customer demands. Waste elimination is one of the ways to improve system efficiency. This concept is the core of the lean philosophy derived from the Toyota Production System. The wastes here are the unnecessary output through overproduction, excessive rework and high inventory stock of materials. By controlling these wastes, a project can be completed on time and within cost with fewer disruptions. The resources used in construction, including labour, plant and materials, can similarly determine the supply chain’s level of efficiency. Consistently producing the most from labour and equipment will reduce overall costs for a given amount of output. Bottlenecks in the process need to be reduced, as they are the key cause of the loss of efficiency in construction, hampering the progress of the production process.

Other main capability factors (such as adaptability, capacity and visibility) identified by previous researchers are also considered for assessment in this study. However, it is worth noting here that despite the importance of these capabilities, past researchers (Wedawatta and Ingirige, 2016; Juttner and Maklan, 2011) argued that improving resilience against one threat might increase vulnerability to another. For instance, improving collaboration among supply chain partners may cause additional threats due to sharing sensitive information (Jüttner and Maklan, 2011). On the other hand, increasing flexibility through sub-contracting may increase the susceptibility of the construction supply chain to severe weather conditions in different geographic regions (Wedawatta and Ingirige, 2016). Hence, the fact that the resilience strategies are interrelated suggests that it is important to understand the trade-offs between appropriate capabilities to mitigate particular critical areas of vulnerability. The effects of an organisation's vulnerabilities and capabilities on another organisation's resilience to disruption in a supply chain are, however, under-researched and tend to have been overlooked by previous researchers (Pettit et al., 2013; Zsidisin and Wagner, 2010; McManus, 2008). It is therefore important for this study to consider the dynamics of the effects between the public organisations and their supply chain partners' vulnerabilities and capabilities to mitigate disruptive events collectively in public projects.

Overall, the main categories of capability factors from Pettit et al.'s (2010) work are adapted in this study, as the researcher has found that it provides a comprehensive list of capabilities that are applicable and useful to guide the assessment of the supply chain in this study. The definitions of the capability factors are summarised in Table 2.3 and the related sub-factors are listed in Table 2.4.

Table 2.3: Definition of the main capability factors that enable resilience
(Adapted from Pettit et al., 2010)

Main Capability Factors	Definition
Flexibility	Ability to quickly change inputs/outputs or the mode of receiving inputs/delivering outputs
Capacity	Availability of resources to enable sustained production levels
Efficiency	Capability to produce outputs with minimum resource requirements
Visibility	Knowledge of the status of operating resources and the environment
Adaptability	Ability to modify operations in response to challenges or opportunities
Anticipation	Ability to detect potential future events or situations
Recovery	Ability to return to normal operational state rapidly
Dispersion	Broad distribution or decentralization of resources
Collaboration	Ability to work effectively with other entities for mutual benefit
Market Position	Status of a company or its products in specific markets
Security	Defense against deliberate intrusion or attack
Financial Strength	Capacity to absorb fluctuations in cash flow

Table 2.4: Summary of Supply Chain Capability Factors

Capability Category	Supply Chain Capability Factors	Chowdhury et al (2012)	Pettit et al (2010)	Sheffi (2005)	Peck (2005)	Blackhurst et al (2008)	Christopher & Peck (2004)	Cranfield (2002)	Ponomarov & Holcomb (2009)
Flexibility	Commonality (facilities, processes)		X	X					X
	Product commonality (modularity, interchangeability)	X	X	X					X
	Multiple uses for supplies	X	X	X					
	Supplier contract flexibility	X	X	X	X			X	
	Multiple sources		X	X	X			X	X
	Alternate distribution channels	X	X		X	X			
	Risk pooling/sharing		X	X					X
	Multi-sourcing		X						
	Delayed commitment, Production postponement	X	X	X					X
	Inventory management		X						
	Fast re-routing of requirements	X	X						
Capacity	Reserve capacity (materials, assets, labor, inventory)	X	X	X	X		X	X	
	Redundancy (assets, labor)	X	X	X	X		X	X	X
	Backup energy sources/communications	X	X	X					X
Efficiency	Waste elimination	X	X	X				X	
	Labor productivity	X	X						X
	Asset utilization		X						
	Product variability reduction	X	X						
	Failure prevention		X						
Visibility	Business intelligence gathering	X	X	X		X		X	X
	Information technology		X		X			X	X
	Products, Assets, People visibility	X	X		X			X	
	Collaborative information exchange		X						X
Adaptability	Fast re-routing of requirements		X	X					
	Process Improvement, Lead time reduction	X	X	X	X			X	X
	Strategic gaming & simulation		X	X	X				

	Strategic gaming & simulation		X	X	X				
	Seizing advantage from disruptions		X	X					
	Alternative technology development		X		X				X
	Learning from experience, Reengineering	X	X	X	X				
Anticipation	Monitoring early warning signals	X	X	X	X				
	Forecasting	X	X	X	X	X		X	
	Deviation, Near-miss analysis		X	X	X				
	Contingency planning, Preparedness (Training/Drill/Exercise plans)		X	X					X
	Risk management, Business continuity planning		X	X			X	X	X
	Recognition of opportunities		X	X					
Recovery	Crisis management		X	X				X	
	Resource mobilization		X						
	Communications strategy		X						
	Consequence mitigation	X	X						
Dispersion	Distributed decision-making		X	X					
	Distributed capacity & assets		X	X				X	
	Decentralization of key resources (including data)		X	X					
	Location-specific empowerment		X						
	Geographic dispersion of markets		X						
Collaboration	Collaborative forecasting, Customer relationship management		X	X	X			X	X
	Communications - internal, external	X	X	X	X	X		X	X
	Postponement of orders		X						
	Product life cycle management		X						
	Risk sharing with partners	X	X						X

Market position	Product differentiation	X	X						
	Customer loyalty/retention	X	X						
	Market share	X	X						
	Brand equity		X						
	Customer relationships		X						X
	Customer communications		X						X
Security	Layered defenses		X	X	X			X	
	Access restriction		X	X				X	
	Employee involvement in security		X	X					
	Collaboration with governments		X	X	X			X	
	Cyber-security	X	X	X					
	Personnel security		X						
Financial strength	Insurance		X						
	Portfolio diversification		X						
	Financial reserves & liquidity		X						
	Price margin		X						

The 12 main capability factors and sub-factors listed in Table 2.4 above will be assessed in the survey in this study, along with the 11 main vulnerability factors previously identified in Figure 2.9. The following section describes the pathogenic influences that affect the supply chain resilience.

2.7 Pathogenic Influences

In addition to the supply chain vulnerability factors discussed in Section 2.5, it is important to consider the underlying reasons as to why a supply chain member might be more vulnerable in certain areas than others. Previous studies on supply chain resilience tend to look at vulnerability as a static condition without considering the latent conditions, thus missing some of the key driving forces that influence the dynamics of supply chain vulnerability. These latent conditions have been referred to as 'pathogens' in previous studies (Busby and Hughes, 2004; Busby and Zhang, 2008; Love et al., 2008) and identified as the key factors that set the conditions for disruptions such as errors, failure and disputes to occur in construction projects. The characteristics of pathogens in construction and their applicability to this study are further discussed in the following sections.

2.7.1 Pathogens in Construction Projects

In studying the latent conditions in projects, Busby and Hughes (2004) found that earlier studies on error, accidents and failure in projects have traditionally concentrated on individuals' errors rather than considering team errors (Reason, 1990). Furthermore, most studies assessed the relationship between the general qualities of the project organisation and its success or failure overall (Munns and Bjeirmi, 1996), without considering the mechanisms that produce such specific errors and failures in the first place (Busby and Hughes, 2004). Busby and Hughes (2004) attempted to address this issue by taking into account Reason's (1990) and Turner's (1978) work, which they provided a distinctly systemic way of thinking about error and failure; they introduced the term 'pathogens', whose greatest conceptual value is that they remain dormant in the system until an actual failure occurs. This term originated in the field of biology as an analogy for the development of disease in natural organisms. Pathogens were defined by Busby and Hughes (2004, p. 428) by the following qualities:

- They are relatively stable phenomena that have been in existence for a substantial time before the problem occurs.

- Before the problem occurs, they would not have been seen as obvious stages in an identifiable sequence failure.
- They are strongly connected to the problem, and are identifiable as principal causes of the problem once it occurs.

Subsequently, through interviews conducted with 22 staff in a UK engineering firm, they identified eight main categories of pathogen that had caused significant problems in large-scale engineering projects, as listed in Table 2.5. They include pathogens arising from an organisation's or individual's 'practice', such as reusing existing design solutions without considering the distinct nature of the project, causing substantial rework; and pathogens arising from 'convention' where standard routines have been used in projects, overlooking the fact that the standard task is inappropriate until disruptions occur.

Table 2.5: The main categories of pathogen (Busby and Hughes, 2004)

Category	Description
Practice	Pathogens arising from people's deliberate practices
Task	Pathogens arising from the nature of the task being performed
Circumstance	Pathogens arising from the situation or environment the project was operating in
Convention	Pathogens arising from conventions, standards, routines and codes of practice
Organisation	Pathogens arising from organisational structure or operation
System	Pathogens arising from an organisational system
Industry	Pathogens arising from the structural property of the industry
Tool	Pathogens arising from the technical characteristic of the tool

It can be seen that many of the pathogens involve practices or strategic decisions that have been deliberately adopted as a way of dealing with disruptions, and that until the practices or decisions are shown to be faulty, they remain a fundamental part of the organisation's day-to-day practice (Busby and Hughes, 2004; Love et al., 2008). This ultimately results in the increasing probability of a problem occurring over time in subsequent projects. It is therefore important to identify and mitigate these pathogens before a disruptive event occurs, to ensure projects are not repeatedly exposed to the same risk.

The same pathogen metaphor was used in a subsequent study by Busby and Zhang (2008) to emphasise the causes of organisational breakdown that are built into projects at their inception. The study found that project participants sometimes have different interpretations of what actions or decisions are pathogenic and what decisions are taken as adaptive or protective measures. For instance, a person's protective measure to adhere to standard procedures to limit risk might be seen as a pathogen by another person for the inflexibility and limited possible lines of action it imposes in tackling problems during project delivery. Busby and Zhang (2008) believe that this kind of discrepancy could become problematic during project delivery. Despite identifying the pathogens and their effect on project performance, neither study addressed the managerial actions that should be taken to mitigate such pathogens in projects.

In a different context, Love et al. (2008) adopted the pathogen metaphor to address the underlying conditions that contribute to project disputes. Although they did not sub-categorise the pathogens like Busby and Hughes (2004) did, they made an attempt to find the interrelated connections between these pathogens as they discovered that the combination of a number of pathogens could lead to disruptive events, such as disputes in construction projects. Ultimately, Love et al. (2011) supported the view of Busby and Hughes (2004) that, essentially, before the problem becomes apparent, project participants often remain unaware of the impact upon project performance that particular decisions, practices or procedures can have. Furthermore, similar to Reason's (2000) point of view, Love et al. (2011) believe that these pathogens, once combined with active failures (inappropriate acts by people who are in direct contact with the system) could cause significant problems and have an adverse impact on project performance. While their study was able to provide some useful links between the pathogens, the researchers did not look into other parties in the supply chain; only the client and contracting groups were assessed. A more comprehensive study would look into other members of the supply chain, such as consultants and sub-contractors, to obtain a more balanced perspective of the pathogenic influences. Nor were the inherent vulnerability and capability factors of the organisation and supply chain considered in any of the studies reviewed, which this study aims to assess.

2.7.2 Integration of Pathogens in Resilience Studies

Thus, past studies have adopted the concept of pathogens in various contexts: Reason (1990) addressed them in relation to human errors in the medical sector, Busby and Hughes (2004) in relation to error in construction projects and Busby and Zhang (2008) in organisational breakdown, while Love et al. (2008) conducted a series of studies evaluating the pathogens of project disputes. Although no studies relating to pathogens in supply chain resilience exist, their use by previous researchers suggests that the concept can be adopted in other areas of research, especially research relating to failure. In this study, failure generally means failure to achieve project objectives due to a foreseeable or unforeseeable disruptive event that affects the usual operation and stability of an organisation or supply chain (Barroso et al., 2008).

Identifying the pathogens in the resilience context will also help address the research gap in previous resilience studies, which tended to overlook the latent conditions that made an organisation vulnerable to disruptive events in the first place. Researchers have focused on the performance and capability of organisations to survive, adapt and grow in the face of disruptions (Pettit et al, 2013; McManus et al, 2007; Sheffi, 2005), without addressing the root cause or inherent pathogens that reside in the system. However, implementing resilience strategies without considering pathogens means that organisations will make the same mistakes repeatedly, making them more vulnerable to disruptive events. Considering the increasing complexity of construction projects and the uncertain environment, there is need for a clear understanding of the pathogens listed in Table 2.5 that influence the vulnerability of the supply chain. While disruptions in construction projects are often difficult to foresee and to eliminate entirely, pathogens can be identified and mitigated before a disruptive event occurs. This further supports the possibility of adopting pathogens in this supply chain resilience context.

Overall, the identification of the pathogens in this study will help the researcher systematically to assess how vulnerable the public sector supply chain members are to making significant errors, thus providing the foundation to build appropriate strategies for their prevention. Indeed, it is difficult for public organisations to see the whole of their supply chain operations, given the large scale of public projects (Section 2.2) and the extent of their supply chain network (Figure 2.4). This makes it harder for the public organisations to detect any hidden pathogens that lie within their supply chain network, and they tend to be overlooked in current risk management practice. Although the pathogens are hidden and may not be causing any problem at the moment, they might be triggered later and manifest themselves in catastrophic disruptions (Busby and Hughes, 2004) if they are not identified and mitigated much earlier in the project. The pathogens can also undermine the supply chain's capabilities, as discussed in Section 2.6, making further analysis important. In short, by tackling these pathogens or root causes, the supply chain vulnerabilities can be reduced and the risk of disruptions avoided in the first place. This also allows the researcher to obtain a holistic view in assessing and building resilience in the construction supply chain.

2.8 Development of the Conceptual Framework

The discussion on the background of the Malaysian construction industry in Section 2.2 shows that, despite the Government's plan for developing the nation's economy, the public sector supply chain still faces challenges in fulfilling the Government's provisions in the delivery of large scale infrastructure projects through the series of national plans. This in turn, affects their public reputation and their overall performance in delivering public projects, with calls for improvements in the competencies of the public organisations and their supply chain to mitigate the challenges discussed in Section 2.2.1. Sections 2.3 and 2.4 deal with Objectives 1 and 2 of this study (Section 1.4) in examining the phases of supply chain disruptions and understanding the concept of resilience. The discussion shows that there is a link between the disruption management and resilience literature in terms of how building resilience can help supply chains to adapt, survive and grow in the face of disruptions. It is also evident from the literature that in order to develop resilience, a supply chain needs certain capabilities to respond to the vulnerabilities and uncertainties it is facing. Vulnerability (Section 2.5) and capability (Section 2.6) factors were gathered from the literature to be used in the survey later in this study to assess the current level of resilience of the Malaysian public sector supply chain. This is an important step in fulfilling Objective 3.

Section 2.7 discussed the pathogenic influences that must be considered in identifying the root cause of supply chain disruptions (to fulfil Objective 4). Existing researchers (such as Busby and Hughes, 2004; Busby and Zhang, 2008) did not assess pathogens in relation to the supply chain's resilience capabilities and vulnerabilities, only looking at the pathogenic effects on projects. By bringing the pathogens into a different domain and combining the pathogenic influences with the supply chain's vulnerability and capability factors, the researcher will be able to assess supply chain resilience in a different approach, hence providing significant new knowledge to the existing construction and resilience literature. Once the first four objectives have been achieved, the resilience response framework proposed in Objective 5 can be developed.

The factors discussed above are conceptualised in Figure 2.11. The conceptual framework shows the overall links between the key issues discussed in the literature review. The top section of the diagram represents the phases identified in the disruption management literature, and the bottom section the factors identified from the supply chain resilience literature. The interactions between these two parts are represented explicitly in the conceptual framework.

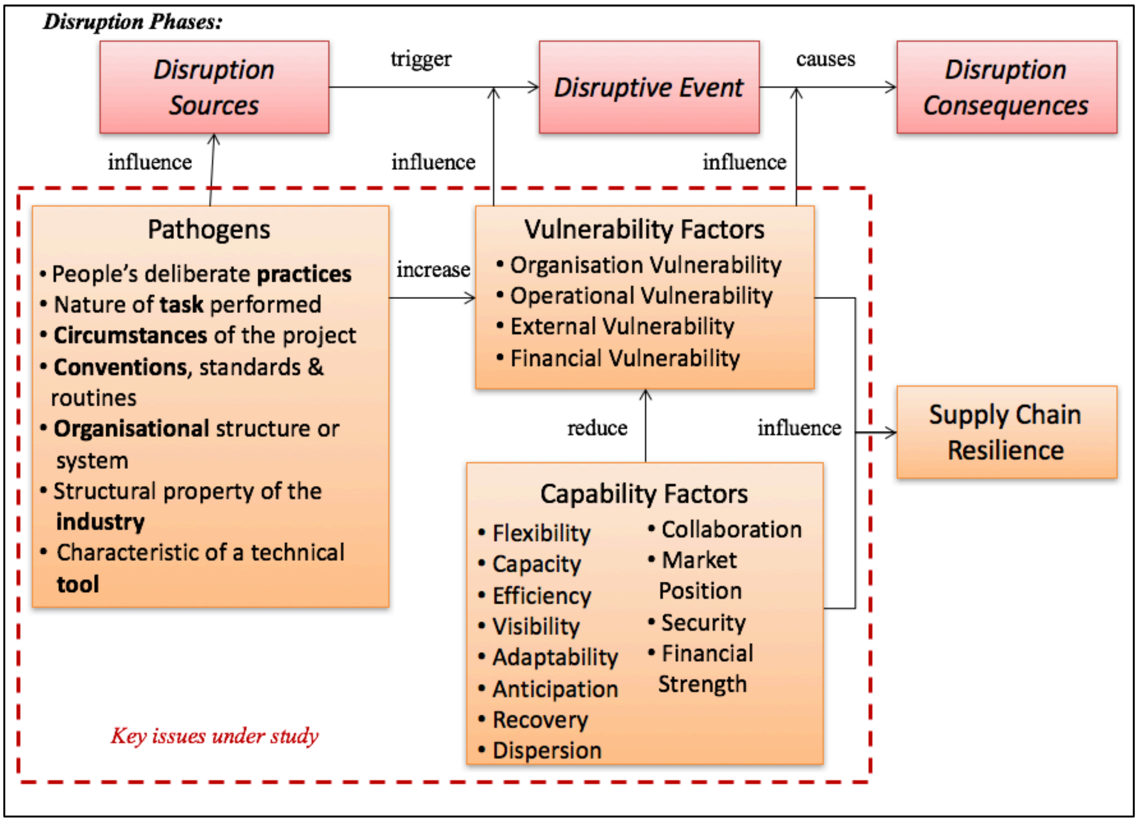

Figure 2.11: Conceptual framework of the study

Revisiting the research problem presented in Section 1.2.3, it is evident that supply chain disruptions are a constant problem in public sector projects. The literature showed that it is important to mitigate these disruptions, as their impacts are not always immediate and could have long-term effects on the public sector supply chain's operations. Understandably, considering that the public organisations deal with a large supply chain network and serves 28 ministries as clients, this makes it harder to detect any disruptions arising from the supply chain's operations. However, the conceptual framework presented in Figure 2.11 shows that supply chain disruptions can be managed by developing a specific set of capability factors that can reduce key areas of vulnerability. For example, referring to Figure 2.11, increasing 'flexibility in production' (capability) can reduce the supply chain's vulnerability to 'unplanned changes in demand' (vulnerability). Pathogenic influences are also included in the framework, to understand why the supply chain members are more vulnerable in certain areas than others. For instance, the individual's 'practice' of reusing existing design solutions without considering the distinct nature of the project (pathogen) can increase the organisation's vulnerability to 'unpredictability of design changes by client' (vulnerability), in turn delaying project delivery (disruption consequence). By tackling these pathogens, the supply chain vulnerabilities can be reduced and the risk of disruptions reduced in the first place.

Emerging questions also arise from the conceptual framework in terms of the dynamics of these vulnerabilities and capabilities: to what extent can a supply chain member's vulnerability or capability impact another party's level of resilience to disruptions? Furthermore, one could also question what is considered as pathogenic to the supply chain members, and whether the identified pathogens might be perceived as a capability or resilience measure by other parties in the supply chain? These emerging questions will therefore be considered and investigated empirically in this study. Overall, this framework is a useful guide for the researcher to fulfil the study's aim of building the public sector supply chain resilience to disruptions in public projects.

2.9 Summary

This chapter set the research context, the Malaysian construction industry, reviewing the background, national policies, key players and challenges. The literature confirm that the Malaysian construction industry plays a significant role in the economic growth of the country, particularly through the development of large-scale infrastructure projects. However, despite the industry's rapid growth, the public organisations are still facing constant challenges in dealing with their supply chain members and disruptive events in construction projects. These challenges are reflected in the series of national plans, showing that there are still key areas in the Government and public projects that need to be improved.

The chapter highlighted one of the ways to mitigate supply chain disruptions, by developing the public sector supply chain members' resilience to such disruptive events. The chapter reviewed and synthesised the literature on supply chain disruptions and resilience, followed by a compilation of a classified list of vulnerability and capability factors to be assessed in this study. The concept of pathogens in construction projects and the integration of pathogens in resilience studies were also critically discussed to fill the gap identified in the literature. Lastly, the conceptual framework was introduced, integrating the three major knowledge domains: supply chain disruptions, supply chain resilience, and pathogens. The research methodology is discussed in the next chapter of this thesis.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

The research methodology encompasses the rationale and the philosophical assumptions that underlie a particular study (Dainty, 2008). In fulfilling the aim and objectives of the study, the researcher has to decide upon the appropriate research methodology and formulate the adopted research strategy, while at the same time, ensuring an original contribution to an existing body of knowledge (Grix, 2001). Thus, in order to address the research problem highlighted in Chapter 1, the underpinning methodology adopted for this study is presented and discussed in this chapter.

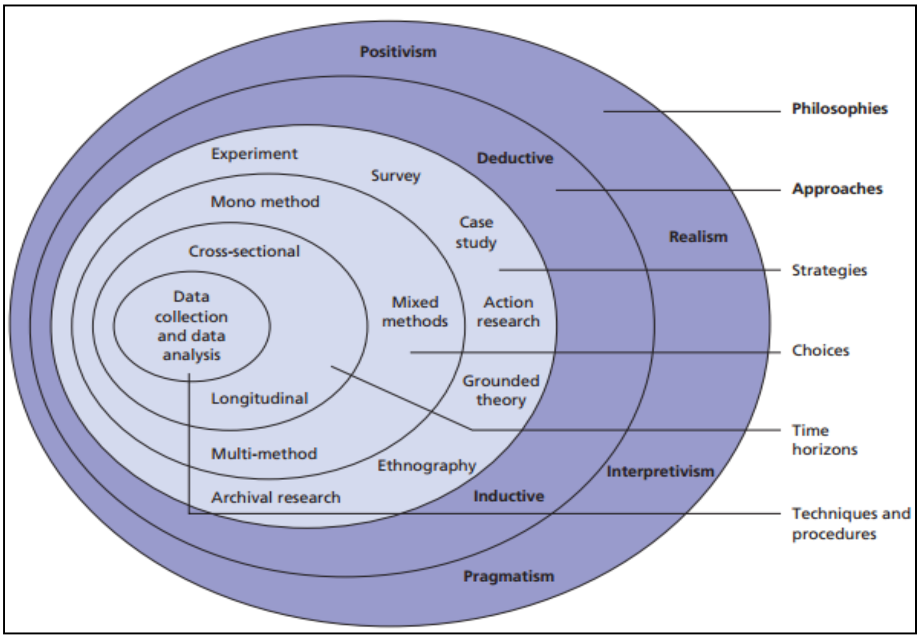

Figure 3.1: The Research Onion (Saunders et al, 2007)

For the purpose of this study, Saunders et al.’s (2007) research model, also known as the ‘research onion’, is adapted as a guideline to discuss the researcher’s selected methodology. The research onion, as shown in Figure 3.1, is a metaphor used to demonstrate the layers of key elements in developing an appropriate and effective research design. The following sections will discuss and justify the methodology adopted for this research by going through the main layers of this onion: the research philosophy, approach, strategy and techniques selected to address the research aim and objectives.

3.2 Research Philosophy

The research philosophy contains important assumptions about the way in which a particular researcher views the world, and these assumptions will underpin the research strategy and the methods chosen as part of the strategy (Saunders et al., 2007). Here, the main influence of the research philosophy is the researcher's personal view of what constitutes acceptable knowledge and the process by which this is developed. The researcher's philosophical stance may be specified by its ontological and epistemological tenets.

Ontology looks at the researcher's view on the nature of reality (Blaikie, 2000), subjectively or objectively. It has to be identified here whether the study is objective and external to the researcher, or socially constructed (subjective) and only understood by examining the perceptions of the human actors (Collis and Hussey, 2003). Epistemology refers to the "claim about what exists, what it looks like, what units make it up and how these units interact with each other" (Blaikie, 2000). The epistemological assumption is concerned with drawing the relationship between the researcher and his/her research. It is characterised either by a positivist or interpretivist perspective. The positivist view assumes that the the social world exists externally and that its properties should be measured through objectively instead of subjectively (Saunders et al, 2007). The epistemological assumption of the positivist paradigm is that the researcher is independent from what is being researched (Creswell, 2003) and thus the research is conducted in a value-free way. On the other hand, the interpretivist view sees reality as subjective and multiple as seen by participants in a study (Creswell, 2003). The epistemological assumption behind the interpretivist paradigm is that the researcher interacts with what is being researched, and thus are more concerned with the understanding of the research problem that is unique to the context instead of generalisability (Maxwell, 2006). The merits of these two paradigms, positivism and interpretivism, are widely debated in social science, resulting in the emergence of a new paradigm, pragmatism, which utilises a mixed method research inquiry (Johnson et al., 2007). Johnson and Onwuegbuzie (2004) stressed that it is a practical and outcome-oriented method of inquiry that is based on action, and leads, iteratively, to further action and the elimination of doubt. Pragmatism accepts, philosophically, that there are singular and multiple realities that are open to empirical inquiry and orients itself toward solving practical problems in the real world (Creswell and Plano Clark, 2007).

Ontologically this study favours a pragmatic view that combines objectivism and subjectivism. This pragmatic view allows the researcher to choose the methods (or combination of methods) that work best for answering the objectives of this study (Johnson and Onwuegbuzie, 2004). In developing the resilience response framework for this study, the researcher needs to firstly identify the critical vulnerability factors that currently challenge the public sector supply chain operations and assess the main capability factors that they currently employ in handling disruptions during project delivery. This can be achieved through the use of a questionnaire (see Section 3.3) that will allow the respondents to rate the extent of their agreement or disagreement with the statements listed under the vulnerability and capability factors previously compiled by the researcher from the literature review (see factors listed in Tables 2.2 and 2.4). It is worth noting that at this phase, the researcher does not attempt to predict the significant factors affecting the subject under study; instead, the statistical analysis will drive the result of the respondents' current level of resilience. The researcher will therefore maintain an objective stance and positivist view at this stage, not influencing the respondents, and the results are value free.

However, the researcher acknowledges that the quantitative data from the questionnaire alone does not capture and describe the complex interactions of the operation environment, organisational issues and societal culture (Kiessling and Harvey, 2005). In assessing the public sector supply chain, these factors are important as they could be pathogens (see Section 2.7) that influence the level of vulnerability assessed in the questionnaire. The subjectivist ontology approach and interpretivist view benefit this part of the study as they allow the researcher and respondents to justify the questionnaire results through argument in detail by relating the results to reality, enabling the researcher to obtain rich and complex data in terms of tacit knowledge, perception and human experience which could not be measured in the quantitative approach. This subsequently results in an in-depth study of the root cause of the respondents vulnerability to disruptions. The cascading effects of disruptions to the supply chain and project performance can also be assessed in this manner. This fulfils the fourth research objective, stated in Section 1.4.

In addition to the ontological and epistemological view, it is important to determine the position of the researcher's values in his/her research. This is also known as axiology, a branch of philosophy that studies the judgements of values (Saunders et al., 2009). Axiologically, this research favours a value bias or value-laden research approach as, ultimately, the researcher's values affect how the results of the study are interpreted. Although this research adopts a mixed method approach, which combines both quantitative and qualitative data, epistemologically it inclines more towards interpretivism, which acknowledges the difference between the objects of natural science and people within the phenomenon under study through the respondents' validation of the questionnaire results. Figure 3.2 shows the overall philosophical stance of this research.

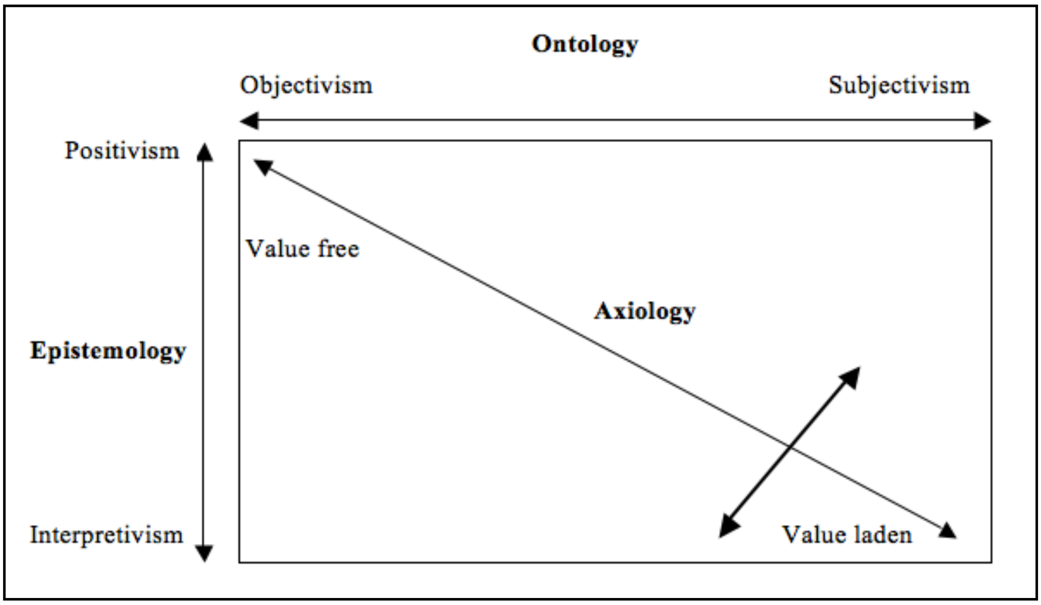

Figure 3.2: Philosophical stance of the research (Adapted from Sexton, 2007)

Based on this discussion, the researcher agrees with Tashakkori and Teddlie (1998) that, in practice, at one point one may more easily stand apart from what one is studying and takes the objectivist stance (in assessing the questionnaire), while at another point, the knower and the known must be interactive (through the respondents' validation of the questionnaire results). Hence, as a pragmatist, the researcher's goal is to search for useful points of connection between the objectivist and subjectivist stances. This approach also allows the researcher to fulfil the research objectives that cover both exploratory (what) and explanatory (why) questions.

3.3 Research Approach

In choosing the appropriate research approach, Saunders et al. (2007) suggested that the researcher should consider whether the study is guided by the generation of theory, also known as the inductive approach, or the testing of a theory through the deductive approach. The difference between the two approaches is that the inductive approach involves gathering empirical data to develop a theory in a situation where there are few or no theoretical preconceptions; in the deductive approach, the researcher typically develops hypotheses from existing theories, which are then tested against the data collected (Young, 2007). Although these two approaches differ considerably, Wallace (1971) argued that the logics of induction and deduction should be combined in an ongoing cycle to provide an explicit link between theory and research, as depicted in Figure 3.3. Saunders et al. (2007) also suggested that it is possible to combine these two approaches in a study through the utilisation of mixed methods.

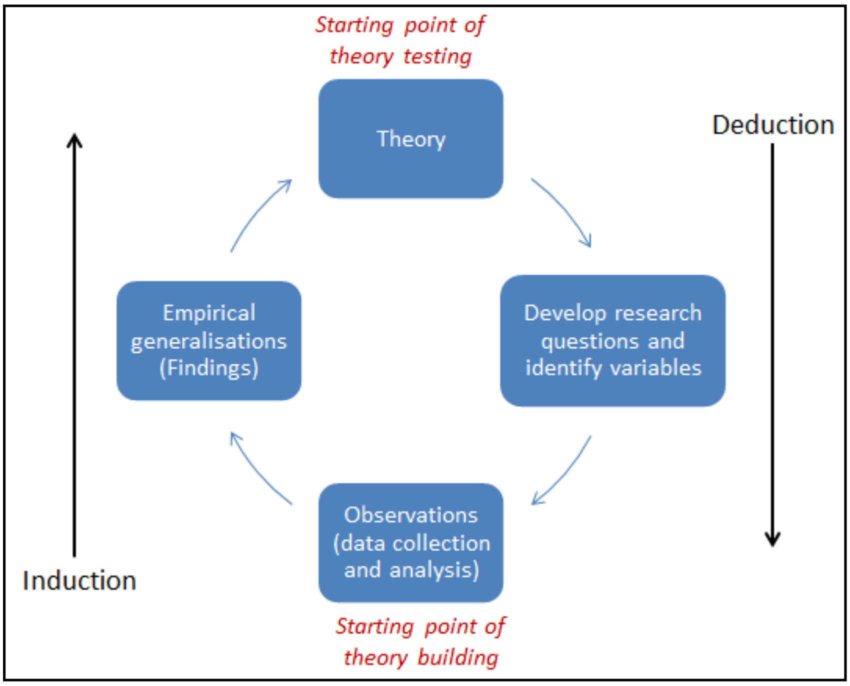

Figure 3.3: The research approach adopted in this study
(Adapted from Wallace, 1971 and De Vaus, 2001)

This researcher agrees with Wallace (1971), that research typically involves the ongoing cycle of theory building and theory testing, as depicted in Figure 3.3. In the case of this study, a deductive approach to first gather related theories on the topic of interest is necessary, especially at the beginning of the research phase, as pure induction with no initial theory may result in the researcher not obtaining any benefit from valuable existing theory. In this case, the topic of interest is supply chain resilience. The information collected from the literature review is adopted by the researcher as variables in the questionnaire survey, to analyse the emergent vulnerability and capability factors of the public organisations and their supply chain, as shown in Figure 3.3. According to Trochim (2005), this deductive reasoning is indeed most commonly associated with quantitative research whereby questionnaires, surveys and experiments are typically used to gather data that is revised and assessed in numbers through statistical analysis. Furthermore, at this point, although the deductive approach is less in-depth than the inductive approach, the deductive approach provides more breadth of information across a large number of cases (Young, 2007) and is therefore more generalisable than the inductive approach.

However, in order to fulfil the fourth objective of the study (Section 1.4), interviews would be best suited to gather underlying meaning of the results from the questionnaire. The interviews allow the researcher to discover issues or effects which may not have been obvious at the earlier stage of the investigation. This means that, although different respondents may discuss different capability and vulnerability factors in the questionnaire based on their particular situation, the interviews allow the opportunity to gather new constructs which are relevant in developing the resilience response framework. The pathogens identified through the interviews can also provide a comprehensive discussion to justify the questionnaire results. Collecting data through this interview process involves part of the inductive approach in developing new knowledge or theory for study, as shown in Figure 3.3. Subsequently, the outcome of this study will either adapt the existing theory or present an alternative theoretical framework in fulfilling the research aim.

Overall, the main difference between the quantitative and qualitative method adopted above is that the quantitative method is more structured, with the theory preceding observation, whereas the qualitative research is open and interactive and observation generally precedes the theory (Corbetta, 2003). Creswell (2003) suggested that it is possible to combine these methods to better understand the research problems, especially when the researcher's knowledge is based on pragmatic grounds, as in this study. Sale et al. (2002) claimed that the combination of these two methods is possible when both approaches share the same goal of understanding of reality and share the same tenets on the theory as well as the inquiry process.

According to Abowitz and Toole (2010), this mixed methods approach is particularly relevant for research in the construction industry, where social and natural science methods are frequently intertwined. Multiple approaches are also required in order to develop a holistic understanding of operations and supply chain management phenomena (Boyer and Swink, 2008). Newman et al. (2003) added that the complex nature of the research questions often necessitates the use of mixed methods. Hence, by using quantitative methods and qualitative interpretation of the empirical data in this study, the researcher will be able to triangulate the results and improve confidence in the resilience response framework.

As discussed in the research approach above, the researcher will use the quantitative and qualitative method sequentially (QUAN > QUAL). Creswell and Clark (2007) contend that this two-phase sequential approach makes it easier to implement the study as it allows a straightforward way to describe and report the data. This is also known as the explanatory sequential design, whereby the researcher starts with the quantitative data collection and analysis in Phase 1, followed by qualitative data collection and analysis in Phase 2, which builds on Phase 1 (Creswell and Clark, 2007), as depicted in Figure 3.4. This approach is useful for researchers who want to explore a phenomenon and expand on the quantitative findings. The research process will be further discussed in detail in Section 3.6.

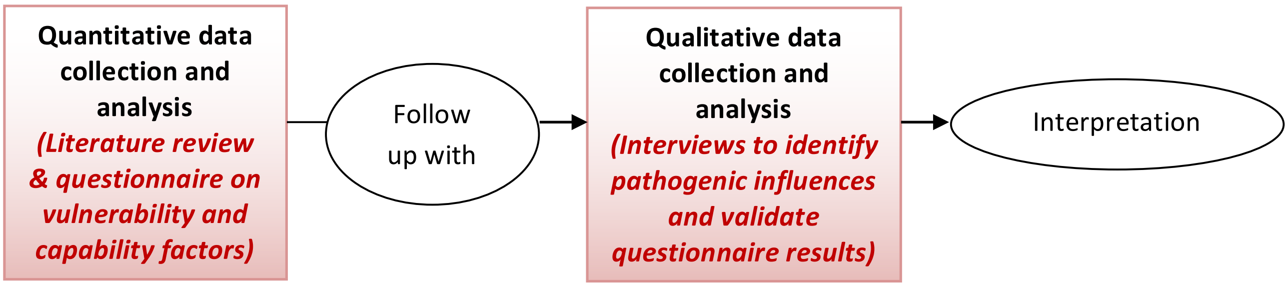

Figure 3.4: The explanatory mixed method sequential design
(Adapted from Creswell and Clark, 2007)

3.4 Research Strategy

The purposes of this research are to analyse the emergent vulnerability and capability factors of the public sector supply chain, and identify the causes and cascade effects of the disruptions on project performance. In achieving these objectives, various research strategies have been considered by the researcher, as deliberated below:

i. ***Case Study:*** The case study method involves the investigation of a contemporary phenomenon within the context of the real world through an empirical inquiry, and is usually applied when there is no clear evidence of the boundaries between the phenomenon and context (Yin, 2003). This method is usually adopted to address 'how' and 'why' research questions whereby multiple sources of evidence are used through an in-depth study of the relevant cases. Case studies are also generally used for exploratory, descriptive and explanatory purposes in research (Yin, 2003).

However, one of the drawbacks of the case study method is that the findings are only applicable to similar projects or cases, making generalisation of the findings to other types of project difficult. Furthermore, research bias may occur when adopting this method, due to the substantial reliance on self-interpretation of the cases in guiding the findings and recommendations. This researcher believes that it is important to obtain the project participants' views on the capability and vulnerability factors to guide the findings.

ii. ***Action Research:*** This method allows the researcher to actively participate in the process under study to identify and evaluate problems and potential solutions (Fellows and Liu, 2008). One of the benefits of conducting action research is that the researcher would be able to gather findings that have strong practical implications, gaining a deeper level of access to relevant information by working closely and building trust with the subject matter or organisational representatives.

    However, it will be difficult to gain full access to the Government body for privacy reasons and geographical distance, Malaysia. This method is also time consuming as the researcher would have to be employed by the organisation in order to carry out the study.

iii. ***Survey:*** Surveys are usually applied for theory testing, in which the researcher develops a conceptual framework through existing theories, designs an instrument to measure relevant constructs and collects relevant data to test the conceptual framework. Kraemer (1991) suggested that a survey is generally used to quantitatively describe specific aspects or variables of a given population and examine the relationships among them. Surveys are also particularly useful when the researcher intends to generalise the findings to the population under study.

    However, there are a number of issues that the researcher needs to consider in a survey to ensure that the findings are reliable and valid, such as the population and its accessibility, the appropriate size of the sample for the study, and how to efficiently administer the survey (Trochim, 2005). Bell (1996) pointed out that the reliability of the survey data also depends on the respondents' knowledge of the subject matter, the type of questions used, and the different interpretation of respondents of the questions or options of answers.

In fulfilling the aim and objectives of this study, the researcher finds that the survey method would be the best research strategy to be adopted in this study. Although the reliability of surveys greatly depends on the selected sample of respondents and how the respondents interpret the questions, by designing the survey appropriately with careful consideration in selecting the sample and relevant questions, the survey can be really useful in answering the 'who, what, where, how' form of questions addressed in the research objectives. The survey is also a cost-effective method of gathering data from a range of project participants, including those who may not like to be identified in the report. The survey can also be developed and assessed within the time frame available for this study.

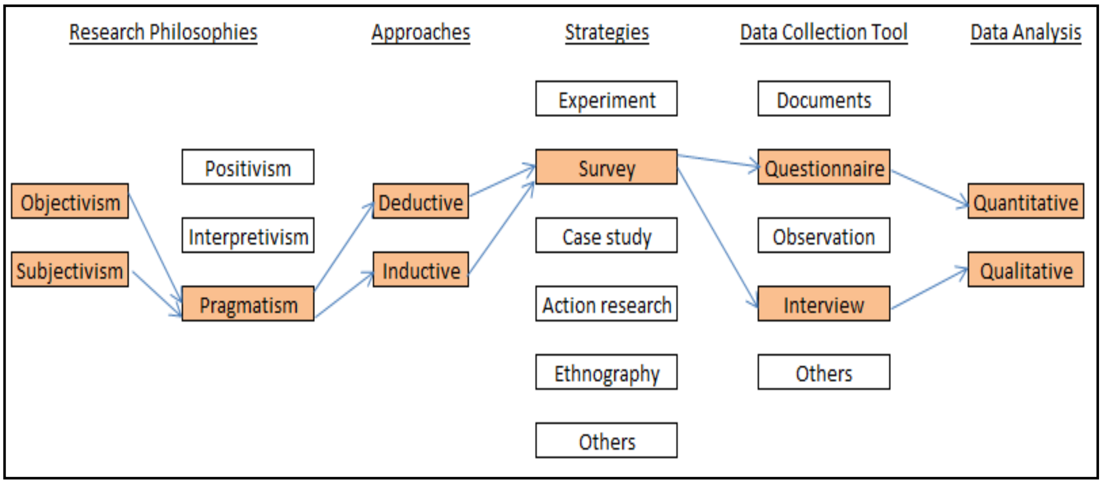

Figure 3.5: Research design of this study

Figure 3.5 summarises the overall research design adopted. It provides a holistic map, highlighting the researcher's philosophical stance, the appropriate selection of the research approaches, strategies for fieldwork, and the selected data collection and analysis techniques, identified from the available alternatives through a set of essential stages. It is important to show the sequence of stages of the research and to demonstrate the logical practical empirical plan (Yin, 2003). The data collection and analysis techniques are further discussed in the following section.

3.5 Research Techniques

There is a range of possible approaches to collecting data under the selected survey method, including questionnaires and interviews.

3.5.1 Questionnaire

A questionnaire survey is used to determine the emergent vulnerability and capability factors of the public sector supply chain. According to Fellows and Liu (2008), the questionnaire is a useful tool in collecting data scientifically from a large number of people in a short period of time. The researcher also believes that by using a questionnaire, a high validity of results can be obtained by gathering data from a range of relevant construction professionals working in the field. Self-administered questionnaires are used in this study, enabling the respondents to complete the questionnaire in their own convenient time, through the medium they prefer, either on paper or electronically. The same sets of questions are distributed to all respondents, making it easier for the researcher to analyse and arrange the data later in the study. A translated version of the questionnaire in the Malay language is also used where necessary.

However, in using the questionnaire tool, the researcher must take into account the risk of receiving a low response rate. To overcome this problem, a larger sample size is considered initially. There is also a risk of lack of control over how the respondents might interpret the questions, so to avoid misinterpretation the researcher decided to conduct a pre-test with experts in the field, to gain necessary feedback and insights on the content of the questionnaire. This also allows the researcher to ensure the validity and clarity of the questionnaire.

3.5.1.1 Data Sample for Questionnaire

The target population for the questionnaire distribution is all the professionals involved in Malaysian public sector projects. The probability sampling used in this study is stratified random sampling, whereby the target population is first separated into mutually exclusive, homogeneous groups, and then a simple random sample is selected from each stratum or group (Trochim, 2005). In order to reflect a balanced and unbiased point of view and ensure the validity of the research, two principal groups were targeted:

i) Public sector professionals working under the Malaysian public organisations engaged in delivering public projects.
ii) External private professionals from the private organisations engaged by the public organisations to undertake public projects: consultants (architects, quantity surveyors, engineers) and contractors.

Unlike simple random sampling, stratified random sampling is the best way to obtain the views of a representative sample from each stratum. It also allows the researcher to make inferences from within the strata or groups and comparisons across the groups (Trochim, 2005).

In recruiting these participants, the list of consultants was retrieved and selected randomly from the database of PWD contacts and from the respective professional bodies, such as the

Malaysian Institute of Architects (PAM), the Malaysian Institute of Engineers, and the Malaysian Institution of Surveyors. For the contractors, the data was collected from the Construction Industry Development Board (CIDB). Letters of invitation to participate in the study were sent out along with the participant information sheet (see Appendix C) before the survey was conducted.

According to the PWD, the estimated number of construction professionals from the public organisations working in public projects in 2014 was 3,800. The total number of contractors in Malaysia registered with CIDB at the end of September 2014 was 66,953, (see the first row of the second column in Table 3.1). However, due to the large numbers, the researcher decided to reduce the sample group by targeting contractors registered under Class G7 (projects greater than RM10 million) from the state of Selangor and the Federal Territory of Kuala Lumpur (also known as Wilayah Persekutuan), (see Total G7 column of Table 3.1). These states were chosen as they are the centre areas of cultural, economic and administrative development in Malaysia and it is assumed that such characteristics qualify the sample to represent the Malaysian construction industry as a whole. The population size of these targeted contractors was thereby reduced to 2,754 (total of class G7 contractors in Selangor and Wilayah Persekutuan). However, 12% of these contractors are inactive, resulting in the final total population of 2,424 active contractors, as highlighted in the 'active' column in Table 3.1. The total number of registered consultants (architects, quantity surveyors, engineers) is listed in Table 3.2 below.

Table 3.1: Total Registered Class G7 Contractors by State (CIDB, 2014)

CIDB MALAYSIA *Total Contractors Registered by State of Registered, Contractor Registration Grade and Contractors Classification*

End of Period	Total Contractors Registered	Contractors Registered by Contractor Registration Grade and Contractors Classification				
		G7				
		Total G7	Active	Semi Active	New	Dormant
September 2014	**66,953**	**5,418**	**4,683**	**82**	**280**	**373**
Johor	6,383	377	335	1	19	22
Kedah	3,560	200	159	11	8	22
Kelantan	3,265	130	90	6	1	33
Melaka	2,182	126	106	2	7	11
Negeri Sembilan	3,271	91	81	1	3	6
Pahang	3,867	137	125	1	5	6
Perak	4,465	147	128	2	10	7
Perlis	1,165	28	18	6	-	4
Pulau Pinang	3,358	346	295	7	17	27
Sabah	9,970	464	388	6	17	53
Sarawak	3,681	434	385	5	24	20
Selangor	10,844	1,270	1,132	4	74	60
Terengganu	3,780	184	149	20	4	11
Wilayah Persekutuan	7,162	1,484	1,292	10	91	91

Note : Active : Local contractors who have projects during the period their registration is in force. These contractors have experience and are serious about the construction.
Semi Active : Contractors who were not awarded any project during the durarion of their registration but ewre active in bidding for tender.
Dormant : Contractors who were not awarded any project during the period of their registration and did not bid for any tender.
New : Newly registered contractors.

Table 3.2: Local Professional Consultants Registered by Type (CIDB, 2014)

Type of Professional Consultants	2011	2012	2013
Architect[1]	1,782	1,844	1,858
Quantity Surveyor[2]	888	930	975
Engineer[3]	6,841	N.A	N.A

Source : [1] Board of Architects Malaysia
[2] Board of Quantity Surveyors Malaysia
[3] Board of Engineers Malaysia
Note : N.A – Not Available

Overall, a summary of the total estimated population size for this study is tabulated in Table 3.3 below. In order to determine the appropriate sample size (n) from the total population (N), the researcher adopted the formula given by Yamane (1967) whereby, for a 95% confidence level and the desired precision level of 10% (e), the optimum sample size for this study is 99 people. The calculation is shown below:

$$n = \frac{N}{1 + N(e)^2} = \frac{15{,}898}{1 + 15{,}898(.10)^2} = \mathbf{99}$$

The total population (N) is based on Table 3.3. The level of precision (e), sometimes referred to as sampling error, is the range in which the true value of the population is estimated to be. This range is often expressed in percentage points (e.g., ±10%). This means that in this case, if 60% of professionals in the sample ranked strongly agree on the statement of supply chain flexibility with a precision rate of ±10%, then the researcher can conclude that 50% to 70% of the professionals in the population agree with the statement. The precision rate in previous studies normally ranges from 4% to 10% at the 95% confidence level, depending on the maximum sampling error that the researcher is willing to accept and the specific objectives or analysis used. Roscoe (1975) used 10% as a rule of thumb of acceptable precision level, whereas Israel (1992) suggested that for a population of 15,000, a sample of 99 should suffice for a 10% precision level, a confidence level of 95% and p=.5. Previous researchers in the Malaysian construction industry (Abdul-Karim, 2013; Al-Tmeemy et al., 2012) also used the same 10% precision rate, which they found acceptable in obtaining the required sample of construction professionals in Malaysia. Therefore, in line with the calculation above, it was established that an overall target of a minimum valid 99 respondents was acceptable for the analysis in this study.

Table 3.3: Summary of Total Estimated Population Size of Respondents

Targeted Respondents	Number	Source (Year)
Professionals in public organisations	3,800	Public Works Department (2014)
Registered Contractors (Class G7)	2,424	Construction Industry Development Board (2014)
Registered Architects	1,858	Board of Architects Malaysia (2013)
Registered Quantity Surveyors	975	Board of Quantity Surveyors Malaysia (2013)
Registered Professional Engineers	6,841	Board of Engineers Malaysia (2011)
Total	**15,898**	

According to Fellows and Liu (2008), the normal expected useable response rate for research in the construction field ranges from 25% to 35%. Hence, in order to obtain more than 35%

response rate, the researcher distributed 220 questionnaires: 100 sets to the public organisations, 60 to contractors, and 60 to consultants. Overall, of the 220 questionnaires distributed covering the targeted population, 105 responses were received (response rate 48%), as listed in Table 3.4. The response rates from all respondents are within the acceptable range, as suggested by Fellows and Liu (2008). In line with the analysis of this study, research samples larger than 30 respondents can also ensure the benefits of central limit theorem (see for example, Roscoe, 1975, p.163; or Abranovic, 1997, p. 307-308). Fraenkel and Wallen (2007) also contended that for correlation studies, such as in the case of this study, a sample of at least 50 was deemed sufficient to establish the existence of a relationship.

Table 3.4: Questionnaire data collected

Respondents	Targeted Sample Size	Questionnaire sent	Questionnaire received	Response rate
Public Organisations	50	100	54	54%
Contractors	25	60	25	42%
Consultants	25	60	26	43%
Total :	100	220	105	48%

Overall, the sample size is acceptable within the context of the Malaysian construction industry, based on previous studies conducted by Sambasivan and Soon (2007), Alzan et al. (2011) and Abdul-Aziz and Ali (2004). Their sample sizes ranged between 50 and 150 respondents: Sambasivan and Soon (2007) studied the causes and effects of delays in the Malaysian construction industry with 150 respondents consisting of clients, consultants and contractors; Alzan et al. (2011) surveyed 100 contractors registered with CIDB Grade 7 to gather their perceptions on factors contributing to project delay; and Abdul-Aziz and Ali (2004) questioned 47 quantity surveyors from the public organisations to assess the quality performance of outsourced quantity surveying services. Hence, it was established that an overall sample of 105 respondents is sufficient for the analysis of this study.

3.5.1.2 Questionnaire Design

The questionnaire design was developed based on existing literature of similar studies (Pettit et al., 2010; Stephenson, 2010; Zhao et al., 2001). An example of the questionnaire is presented in Appendix C. The questionnaire is divided into five sections:

- Section 1 involves closed questions on the respondents' general profile;

- Section 2 involves closed questions on the respondents' past experience of disruptive events in public projects;
- Section 3 involves the use of a 5-point Likert scale (1-strongly disagree, 2-disagree, 3-neither agree nor disagree, 4-agree, 5-strongly agree) to determine the degree of agreement or disagreement of the respondents on statements relating to the supply chain vulnerability factors;
- Section 4 involves the use of the same 5-point Likert scale to determine the degree of agreement or disagreement of the respondents on statements relating to the supply chain capability factors;
- Section 5 involves a 5-point Likert scale on the relative level of importance (range from not very important, moderately important, to critical) of the main vulnerability and capability factors.

3.5.1.3 Method of Analysis for Questionnaire

The Statistical Package for the Social Science (SPSS Version 24) software was used to compute the data collected, conduct rigorous statistical data analysis and compare and analyse the relationships between the variables in the study. The results are presented using visual tools such as diagrams, frequency tables, bar charts and scatterplots computed by SPSS. The internal consistency and reliability of the survey measures were tested during the initial pilot study using Cronbach's Alpha Coefficient. According to Cavan et al. (2001), well-developed scales will have a Cronbach's Alpha value of 0.70 or greater; above this value indicates a good correlation between the item and the true scores (Churchill, 1979).

For the overall questionnaire results, the analysis was divided into five main sections corresponding to the sections in the questionnaire. Data from Sections 1 and 2 was subjected to descriptive statistics. According to Trochim (2005), the simplest distribution involves the list of every value of a variable and the number or percentage of the persons who selected each value. In this case, the respondents' background (Section 1) is presented as frequency and percentage in a table, and past experience of disruptive events (Section 2) as percentages through visual tools such as bar graphs and pie charts.

The composite scores for the Likert scales in Sections 3 to 5 were analysed on the interval measurement scale. The descriptive statistics used for the interval scale items include the measurement of mean for central tendency and standard deviations for variability, computed through SPSS. The use of mode was also taken into consideration in assessing the likert scale of the vulnerability and capability factors. An example of analysis of the mean and mode of the main vulnerability factors of the public organisations are presented in Table 3.5 below to compare the results between the two analysis. Table 3.5 shows that both analysis of the mean and mode yield quite similar results. However, in this case, as the composite scores of the sub-factors are considered in ranking the main vulnerability and capability factors, the mean score were ultimately used in the final analysis (see analysis in Section 4.4).

Table 3.5: Example of the results of mean and mode of the public organisations' vulnerability factors

Rank	Main Vulnerability Factors	Factor Label	Mean	Mode
1	Political/Legal Pressures	V6	3.66	4.00
2	Management Vulnerability	V2	3.58	4.00
3	Liquidity/Credit Vulnerability	V10	3.40	4.00
4	Strategic Vulnerability	V1	3.36	3.25
5	Market Pressures	V9	3.24	3.25
6	Process Vulnerability	V4	2.98	3.00
7	Environmental Factors	V7	2.96	3.00
8	Supplier/Customer Disruptions	V5	2.87	3.00
9	Personnel Vulnerability	V3	2.81	3.00
10	Physical Damage Disruptions	V8	2.62	2.40

Overall, the mean allows the researcher to compute the average score of the vulnerability and capability factors of the respondents. The computed standard deviation establishes the dispersion of the results through the assessment of the common trends running through the responses. Factors with a highly dispersed distribution of data will obtain a higher standard deviation than those with low distribution. This measurement of central tendency was used by previous researchers, such as Pettit (2008) and Stephenson (2010), in assessing the vulnerability and capability factors of respondents. Furthermore, scatterplots were used to assess the critical vulnerability and capability of the respondents by comparing their current vulnerability and capability scores (from Sections 3 and 4 of the questionnaire respectively) against the rated importance of the variables in Section 5 of the questionnaire. The scatterplots (see Section 4.5) present a two-dimensional coordinate graph, showing the relationship between the two abovementioned quantitative variables, with each observation in a data set plotted as a point in the graph (Lewis-Beck et al., 2003).

Additional non-parametric data analysis such as the Mann-Whitney U and Kruskal-Wallis tests were conducted to make judgments of the probability of observed difference between two or more groups of respondents being dependable or having happened by chance (Field, 2009). The Mann-Whitney U test is suitable here instead of the t-test, due to the expected skewed distribution in the data obtained from the Likert-scales construct measuring vulnerability and capability. For instance, when the majority of respondents select the positive anchor of 'agree' or 'strongly agree' in the construct, the distribution is expected to be negatively skewed; conversely, when the majority select the negative anchor of 'disagree' or 'strongly disagree', the distribution is expected to be positively skewed. Pallant (2013) agreed that many scales and measures used in the social sciences are not normally distributed and have scores that are skewed, either positively or negatively. It is worth noting here, however, that this does not necessarily indicate a problem with the scale, but rather reflects the underlying nature of the construct being measured. In this case, instead of violating the assumption of a normally distributed data in a parametric analysis, the used of non-parametric analysis, such as the Mann-Whitney U test, is preferred (Field, 2009; Pallant, 2013).

Correlational analysis using Spearman rho was also conducted to identify significant relationships among the vulnerability and capability factors. Correlation is a relationship measure among different factors or parties indicating the level of strength and direction of the relationship (Assaf and Al-Hejji, 2006). The Spearman rho correlation was also used to test the level of agreement or disagreement among the different groups of respondents (public organisations, consultants and contractors) on these factors. Spearman's correlation results range between the value of 1 and −1, whereby values closer to 1 indicate a perfect positive relationship (or high degree of agreement) and -1 implies a perfect negative relationship (or disagreement) (Assaf and Al-Hejji, 2006).

3.5.2 Semi-structured Interviews

While questionnaires can provide evidence of patterns amongst large populations, qualitative interview data often produces more in-depth insights into participants' attitudes, thoughts and actions (Kendall, 2008). Semi-structured interviews are conducted after the questionnaire results have been analysed. Naoum (2007) pointed out that some of the limitations of the questionnaire can be overcome by supplementing it with personal interviews. Conducting interviews with respondents also enables the researcher to obtain additional input that might not be available through the questionnaire findings. The researcher also aimed to gather the pathogenic influences (discussed in Section 2.7.1) through the interviews. Subsequently, the pathogens identified through the analysis of the interview data are compared against the pathogens laid out in Table 2.5. Semi-structured interviews were chosen to provide flexibility for the researcher to build arguments and gather as much as possible of the information required in addressing the specific issues. This also allows the researcher to meet the objective of identifying the causes and cascading effects of disruptions on public project performance.

The drawback of this approach, however, is that it might be difficult to make comparisons between the results as only a small number of interviews can take place, given time constraints. Nevertheless, this will not be an issue here, as the interview is treated as a complementary method to fill potential gaps in the questionnaire, as previously discussed. The interviews were conducted either by phone, video conference or face-to-face through the appointments agreed between the researcher and the participants. To give participants sufficient time to think about the subject matter, the interview questions (see Appendix D) were sent to them in advance.

In analysing the qualitative data, the computer software package NVivo (version 11) was used to identify relationships between existing themes and emergent new themes. These emergent themes from the interviews are useful in developing the final resilience response framework. As in previous studies (Love et al., 2010, 2011), content analysis and cognitive mapping were used to analyse and present the qualitative data. Content analysis is a technique in which the researcher interrogates data for constructs and ideas that have been decided in advance (Easterby-Smith et al., 2008). This technique is useful for the researcher to analyse key issues identified from the previous questionnaire findings. Furthermore, as different respondents may discuss different pathogenic influences based on their own situation, emergent pathogenic themes relevant to the study are also considered. Interviews were recorded and transcribed in Malay, and relevant parts were translated into English before the analysis.

Cognitive mapping was used to present the relationships between different issues gathered from the interviews. Cognitive mapping is a method of spatially presenting the data to identify patterns that will allow the researcher to understand the relationships between the data and its significance (Easterby-Smith et al., 2008). In this study, the transcribed interviews were imported in the NVivo software. Predetermined pathogenic themes from the literature (see Section 2.7.1) were used to construct the nodes in the software. These nodes are used to represent the concept, code or themes of the data (Easterby-Smith et al., 2008). It also allows the researcher to break the pathogenic themes into sub-themes during the analysis of the interview data. Emergent pathogenic themes from the interview were also identified to reflect the respondents' perceptions on the pathogenic influences that may not be within the predetermined pathogenic themes in the literature. The cognitive maps are then developed based on these nodes, and presented in the data analysis in Chapter 5 of the thesis.

3.5.2.1 Data Sample for Interviews

For the interviews, the non-probability method of purposive sampling was adopted, using the expert sampling approach to include particular professionals from both the public organisations and their supply chain (i.e. private organisations). These categories of professionals may have a unique, different or important perspective on the phenomenon in question, hence their presence in the sample should be ensured (Mason, 2002). The interview sample involved the participants that had responded to the earlier questionnaire. In the participant consent form distributed earlier with the questionnaire (see Appendix C), participants were given the option of whether they would be interested to take part in the subsequent interviews. This option helped the researcher to contact and assemble the relevant experts or professionals with experience working in public projects.

In terms of sample size for the interview, previous researchers (Pettit et al., 2013) conducted 10 to 40 interviews within a firm for their study on supply chain resilience. For this study, considering that the interview is supplementary to the questionnaire and is treated as qualitative data to fill any gaps in the questionnaire, 12 professionals were considered sufficient to be assessed. The interview sample comprised five professionals representing the public organisations, three engineering consultants representing the external private organisations working with public projects, and four contractors engaged by the public organisations, sufficient to represent the different groups of respondents. All respondents had over 20 years of experience working in public projects, hence were able to provide a meaningful perspective on their experience in dealing with disruptions in public projects. The respondents were also mainly involved in the large-scale engineering projects (roadworks, bridges, dams) in which the public sector supply chain is widely involved in. The 12 respondents were sufficient to provide an overview of the current real-world scenario of public sector projects, in identifying critical pathogenic influences.

An invitation letter, participant information sheet and a consent form for signature were given to the respondents before the interview was conducted. The interviewees were given the option to withdraw from the study at any point. Names and personal information remained anonymous throughout the data collection and analysis.

3.5.3 Validity

Validity is defined as the extent to which an instrument measures what it purports to measure (Kimberlin and Winterstein, 2008). Validity and reliability estimates, as Messick (1994) suggests, "should be uniformly addressed for all assessments because they are not just measurement principles, they are social values that have meaning and force outside of measurement wherever evaluative judgments and decisions are made" (p. 13). Using mixed methods research, a panel of experts could provide the data that would allow the quantification of the consensus of those social values that are key to the audience at hand (Newman et al., 2013). Hence, in order to attain validity for this study, a panel of experts was used to pre-test the survey instrument. The validition process is iterative as the experts provide feedback, the literature is reviewed, and consensus is sought (Cronbach, 1970, 1971; Haynes et al., 1995; Newman et al., 2003). Strategies to address issues: face, content, construct, internal and external validity, are discussed below.

Face Validity

Face validity involves the evaluation of an instrument's appearance by a group of experts to determine the extent to which the contents have actually been translated into meaningful constructs (Trochim, 2005). It is useful in establishing an instrument's ease of use, clarity and readability (Burton and Mazerolle, 2011). Lawshe (1975) suggested a minimum of four experts for pre-test to ensure validity. In this study, five experts (three professionals from the public organisations and two researchers) were invited to participate to provide recommendations to improve the instrument. These panelists from the construction industry were deemed to be experts for the purposes of this study as each practitioner has more than 10 years of experience in the field, and both researchers possess a PhD degree. Their initial comments on the conceptual framework are discussed Section 3.6.1 and their feedback on the survey instrument Section 3.6.2 (Table 3.6).

Content Validity

Content validity essentially addresses how representative instrument items represent the content or subject matter that the instrument seeks to measure (Newman et al., 2013). It can be estimated either qualitatively, through oral indication by a panel of experts who judge the appearance, relevance and representativeness of the survey's elements (Netemeyer et al., 2003); quantitatively, by quantifying the degree of consensus about the survey instrument among the experts (Newman et al., 2013); or by using a combination of both methods. For this study, content validity was established using both methods in two stages. The first stage, qualitative, was the intensive review of the literature; the second stage quantified the validity of a scale, requiring the panel of experts to rate the relevance of each item.

Widely used methods to quantify content validity for multi-item scales, as in this study, are by computing Lawshe's (1975) content validity ratio (CVR) and Waltz and Bausell's (1983) item-level content validity index (I-CVI). The former involves requesting the panel of experts to rate items according to the degree of relevance of the items in assessing the construct that they are assigned to. A 3-point rating scale was used; 1=Irrelevant, 2=Important, but not essential, and 3=Essential. For each item, a CVR was computed, the proportion of experts that considered the items to be important or essential. The formula to calculate the ratio (Lawshe, 1975) is:

Equation 1: $$\mathbf{CVR} = \frac{n_e - N/2}{N/2}$$

Where n_e is the number of experts who considered the item to be Essential or Important, but not essential and N is the total number of experts. The CVR values range from -1 to +1. The formula gives a negative result when less than 50% of the experts rate the item as essential or important, a null result when 50% rate it as irrelevant, and a positive result when more than half rate it as essential or important. Hence, the more experts perceiving one item as being important or essential, the more confident the researcher can be in considering that item as part of the construct. Lawshe (1975) suggested that the minimum acceptable value of CVI is 0.99 for five experts at 5% level of significance. The researcher can also compute the content validity index (CVI) of the scale by computing the mean of the CVR values of the retained items. The overall content validity will be higher if the value of the CVI is closer to 0.99 and vice versa (Lawshe, 1975).

Another way to measure the item's content validity is by computing the item-level content validity index (I-CVI) proposed by Waltz and Bausell (1983). The difference between this measure and Lawshe's index is that experts rate the items on a 4-point rating scale with slightly different anchors: 1=not relevant, 2=somewhat relevant, 3=quite relevant, and 4=very relevant (Davis, 1992). This index also gives the percentage of experts that rate quite relevant or very relevant of an item. However, a different formula is used by Waltz and Bausell (1983) to calculate this, hence the researcher decided to compute both indexes to ensure the content validity of the construct. The formula is represented as:

Equation 2: $$\textbf{I-CVI} = \frac{\textit{No. of judges rated 3 or 4}}{\textit{Total no. of judges}}$$

The scale-level content validity index (S-CVI) can also be computed by averaging the I-CVI of all items in the construct. For a scale to be judged as having excellent content validity, it would be composed of items that had I-CVIs of .78 or higher (Polit et al., 2007) and a minimum S-CVI of .80 (Davis, 1992).

Both the former content validity ratio (CVR) and the latter item-level content validity index (I-CVI) have widely been used in social and health sciences researches to test the content validity of questionnaire instruments involving likert-scale items that measures the characteristics or properties of an individual or a system (Sangoseni et al, 2013; Khazaee-Pool et al., 2016), such as in the case of this study. The questionnaire instrument in this study involves the assessment of the likert-scale items against the vulnerability and capability factors of the respondents' organisation. The content validity of the instrument is achieved by a rational analysis of the instrument by raters or experts on the research subject that are familiar with the construct of interest (Bolarinwa, 2015). However, it is worth noting here that the risk of using the index of CVR and I-CVI is that they might not adjust for chance agreement (Wynd et al., 2003). Nevertheless, Bolarinwa (2015) argued that researchers could combine more than one form of validity to increase the validity strength of the questionnaire. In this study, the content validity is combined with the following construct validity to strengthen the validity of the questionnaire.

Overall, to select items in the final draft of the questionnaire in this study, the following criteria were applied:

- Accept unconditionally if CVR is equal to or larger than 0.99 (Lawshe, 1975).
- If CVR is lower than 0.99, the researcher considered the item's I-CVI value, and accepted it if I-CVI is 0.78 or higher (Polit et al., 2007) and S-CVI is 0.80 or higher (Davis, 1992).
- Items that do not meet the above criteria were considered as having low content validity and discarded.

The results from this quantitative content validation are tabulated in Table 3.7 in Section 3.6.2.

Construct Validity

Construct validity refers to the degree to which inferences can legitimately be made from the operationalisations in the study to the theoretical constructs on which those operationalisations were based (Trochim, 2005). It raises the basic question of whether the measures chosen by the researcher "fit" together in such a way as to capture the essence of the construct (Straub et al., 2004). There are two types of construct validity: convergent and discriminant. Convergent validity is the degree to which measures of constructs that should be related theoretically are observed to be interrelated in reality, and discriminant validity is the degree to which measures of constructs that should not be related theoretically are, in fact, not interrelated in reality (Trochim, 2005). Construct validity can be tested using multitrait-multimethod analysis (MTMM), factor analysis and Q-sorting.

MTMM is a matrix or table of correlations that measure each of several constructs by each of several methods (i.e. a paper-and-pencil test, a direct observation, a performance measure) (Campbell and Fiske, 1959). However, MTMM has received little use since its introduction in 1959 (Trochim, 2005) as its rules of thumb are ambiguous (Alwin, 1973) and it is labour-intensive, requiring the use of two or more different methods in gathering all data (Straub et al., 2004). As this study only uses one method (survey instrument) in measuring the vulnerability and capability factors, it would not be reasonable to apply the MTMM method. An alternative method to test construct validity is factor analysis. Factor analysis involves the use of a mathematical tool in a complex and multi-step process to validate a scale or index by demonstrating that its constituent items load on the same factor; proposed scale items which cross-load on more than one factor are dropped. Factor analytic studies, however, require a large sample size of at least 300 to 500 respondents (Tabachnick and Fidell, 2007; Comrey and Lee, 1992). If the sample size is inadequate, factor analysis may not be appropriate as researchers will not be able to interpret the results of the factor solution (Burton and Mazerolle, 2011). Since this study does not meet the required sample size (n=105) for factor analysis, an alternative method to establish construct validity is used, as discussed below.

Another variant of factor analysis is the use of Q-sorting (Moore and Benbasat, 1991; Segars and Grover, 1998; Storey et al., 2000). Q-sorting combines validation of content and construct through experts who group items according to their similarity. This process also eliminates (discriminates among) items that do not match posited constructs (Straub et al., 2004). There are two ways in which this can be done (Storey, et al., 2000):

- Exploratory, when respondents are given the items and asked to group and identify category labels for each group.
- Confirmatory, when the categories are already labelled and respondents are asked to classify each item in one of the categories.

The latter procedure was adopted in this study, whereby categories or constructs and their definition were developed from the literature and presented in a short Q-sort instrument with a separate sheet of random listing of items or factors. The Q-sorting was conducted with a different panel of experts from the ones used in the previous face and content validity pre-test. In this case, three researchers from Malaysia and three key industry players with more than 10 years of experience in the field were involved. They were asked to indicate which construct was most closely associated with each scale item.

Analysis for this confirmatory procedure was made by calculating the percentage of respondents that have correctly classified an item (Straub et al., 2004). When this percentage is low, there are items that do not discriminate well in relation to other items in a different construct (Zait and Bertea, 2013). Hinkin (1998) suggested that a minimum correct item classification of 75% is sufficient in providing evidence of construct validity. However, as only a small number of expert judges (n=6) assessed the pre-test, the decision was made to measure what half of the experts perceived as the appropriate construct. Hence, the researcher considered items with a good level of construct validity to be those that were correctly classified at a rate of 50% and above. The results of this Q-Sorting can be seen in Table 3.8 in Section 3.6.2.

Internal and External Validity

Internal validity is related to the extent to which conclusions can be drawn about the causal effects of one variable on another. Relationships are more likely to be causal in research that has high internal validity; with low internal validity, causality cannot be inferred as confidently (Judd et al., 1991). For this study, the following methods recommended by Merriam (1998) were adopted to maximise internal validity:

- *Triangulation.* In order to strengthen the validity of the findings in this study, data were collected from several sources: theoretical concepts in the literature, questionnaires and semi-structured interviews. This allows the researcher to explain the relationships and causal effects between the constructs, hence ensuring validity of the findings.
- *Member checks.* The survey results and interpretations of this study are presented to the respondents after analysis for validation. For instance, the interview transcripts are sent back to the interviewees to ensure that the content and conversation were accurately captured in the transcript. This ensured credibility and truthfulness in the data collected.
- *Peer examination.* Research data and findings were reviewed and commented on by several non-participants in the field who are familiar with the subject. This was done through the University's Interim Assessment and Internal Evaluation process, whereby two to three experts review and provide comments on the survey data and findings.
- *Participatory or collaborative modes of research*. Respondents are involved in both the questionnaire and interview phases of the study. This enables the researcher to arrive at significant conclusions as a result of consensus among respondents from different perspectives, which can significantly strengthen the research findings and interpretations.
- *Researcher's bias.* To reduce researcher's bias, data are collected, analysed and interpreted as impartially as possible. This includes conforming to ethical rules and principles, performing the evaluation as accurately as possible and reporting the findings reliably.

Meanwhile, external validity is the extent to which one can generalise the results of the research to the populations and settings of interest (Judd et al., 1991). External validity was designed into the study through the use of a random sample that includes both ends of the supply chain: both public organisations and external private organisations who are representatives of the target population. The generalisability of the assessment tool was also further improved by basing it on a broad set of extant literature, followed by a pre-test by a panel of eleven experts. This ensures that the questions reflect how the target population talks and thinks about the issue under study.

3.5.4 Reliability of Survey Instrument

The term reliability has several synonyms including consistency, repeatability, reproducibility, precision, dependability and stability (Sharma and Petosa, 2012). Reliability estimates are useful in assessing the degree of consistency with which it measures the attribute it is supposed to be measuring (Polit and Hungler, 1999), assessing how reproducible the survey instrument's data are (Litwin, 1995), and the extent to which the instrument is free from random error (Hoyle et al., 2002), so that interpretations based on current and future use of the instrument can be made with confidence. The common methods observed in the literature to assess reliability are test-retest reliability and internal consistency reliability.

Test-retest reliability evaluates reliability across time, and is measured by having the same set of respondents complete a survey at two different points in time to see how stable the responses are (Litwin, 1995). The correlation or strength of association of the two sets of scores is then calculated (Kimberlin and Winterstein, 2008). However, the problem with test-retest reliability is that if the time between tests is too short, respondents may remember how they answered on the first occasion and might simply provide the same response during the retest, resulting in an overestimate of the test's reliability. Alternatively, if the duration is too long, learning or a change in health status could alter the way respondents perform in the second test (Kimberlin and Winterstein, 2008), causing significant bias to the reliability results. The test-retest method is also time-consuming and there is no information about its reliability until the results of the second test are collected.

Another statistical technique to test reliability is the measurement of internal consistency. The most widely used method for estimating internal consistency reliability is Cronbach's alpha, whereby the internal consistency of a group of items is measured to test how well the different items measure the same issue (Litwin, 1995). Cronbach's alpha is based on the average inter-item correlation among the items on a scale. The assumption here is that items measuring the same construct should be correlated; significant correlations indicate reliability of the construct being measured. The value of Cronbach's alpha ranges from zero to one, with values closer to one indicating higher internal consistency. An acceptable level is generally considered to be equal or over 0.70 (Carmines and Zeller, 1979; Nunnally and Bernstein, 1994). However, in developing newer scales, other researchers considered lower values such as 0.50 and 0.60 to be acceptable (Hair et al., 1998; Loehlin, 1998; Min and Mentzer, 2004; Sharma and Petosa, 2012; Pettit et al., 2013). The item-total correlations can also be examined along with Cronbach's alpha to ensure that the measurement scale is uni-dimensional; that is, it measures only one concept, rather than a mixture of different concepts. The corrected item-total correlations are the correlations between scores on each item and the total scale score (Field, 2009). These correlations should be reasonably strong if the scale is internally consistent. An item-total correlation higher than 0.30 (Kline, 1993; De Vaus, 2001) suggests that each item has a good correlation with the domain.

In this study, reliability was controlled through the pre-test and pilot study of the survey instrument. The initial pre-test with five experts and the subsequent Q-sorting with six experts were designed to rectify interpretation issues in relation to the format and content of the instrument. Following initial improvements, 20 targeted respondents (10 professionals from the public organisations, and 10 professionals from the private organisations engaged to deliver public projects) completed the entire resilience assessment along with additional open-ended questions in a feedback sheet, providing their views on the format, readability and arrangement of the instrument. Verbal feedback was also captured by the researcher. By clearly defining terms and removing ambiguous items , the reliability of the instrument was improved. Furthermore, as the questionnaire involves a group of items in a construct, Cronbach's alpha and item-total correlations were examined to establish the reliability and uni-dimensionality of the scale. Previous researchers such as Pettit et al. (2013) have also used Cronbach's alpha to assess the reliability of their survey, in which the minimum acceptable value of alpha was set at 0.50. For this study, a higher alpha value limit of 0.60 (Hair et al., 2010) is used to demonstrate reliability (see results in Table 3.9 of Section 3.6.2).

3.6 Research Process

The research process highlights the step–by-step action-wise sequence of activities from the very early stage of the research through the data analysis and presentation of findings (Oates, 2005). Figure 3.6 summarises the overall research process including the research methods and outcomes of the study. The research is divided into three phases:

- Phase I – Development of Conceptual Framework
- Phase II – Development of Survey Instrument
- Phase III – Development of Resilience Response Framework

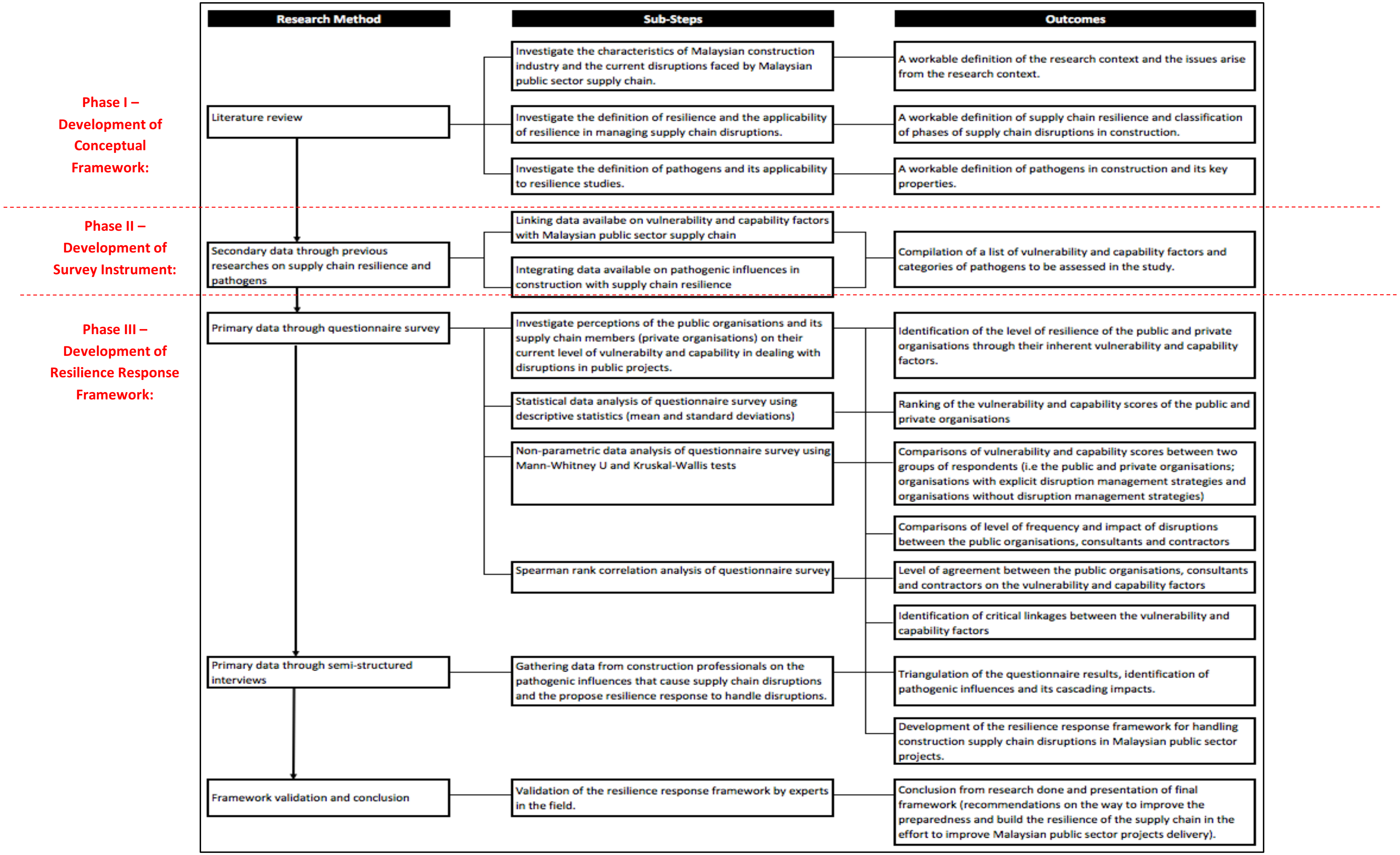

Figure 3.6: Research methods and expected outcomes

The phases depicted in Figure 3.6 are further discussed in the following sections.

3.6.1 Phase I - Development of Conceptual Framework

Phase I is the development of the conceptual framework, whereby the first step taken (see Figure 3.7) is to define the research parameters and specify the research needs so that the themes or constructs could be generated to match the research aim and objectives. In this case, the researcher specified the need to develop a risk resilience approach to effectively manage supply chain disruptions in Malaysian public projects, as discussed throughout Chapters 1 and 2.

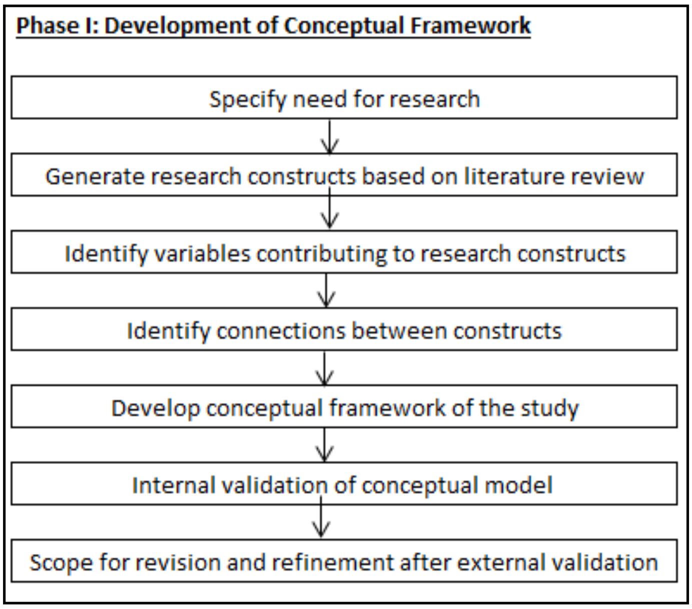

Figure 3.7: Research process Phase I – Development of Conceptual Framework

In sourcing the literature, the university library's Summon search engine and Google Scholar were used in accessing a range of electronic databases (i.e. Science Direct, Emerald, Elsevier, and EBSCOhost), including a range of books and working papers. The key strategy in reviewing the literature includes assessing the research topic area at the general level (i.e. worldwide and other industries), before reviewing the literature specifically in the context of the construction industry, followed by the Malaysian construction industry. The researcher began with using keywords such as 'supply chain disruptions', 'supply chain risk', and 'construction risk' to understand the research phenomena and establish a workable definition of the terms. In this case, further research on the causes of supply chain risks had resulted in the identification of a new keyword; 'pathogens'. The pathogenic influences were then reviewed in greater detail to understand the theories behind it and how it is applicable to the research under study. The researcher also reviewed the literature on ‘resilience’, ‘supply chain resilience’, ‘supply chain capability’, and ‘supply chain vulnerability’ to identify how resilience could improve the supply chain’s ability to respond and recover from supply chain disruptions. This allows the researcher to review contrasting theories or procedures and determine the current level of knowledge surrounding the research area in establishing the scope of the study.

Overall, the literature review resulted in the generation of three main research constructs: supply chain vulnerability (Section 2.5), supply chain capability (Section 2.6) and pathogenic influences (Section 2.7). This stage was crucial for the recognition of gaps in the literature and in establishing the scope and boundaries of the research. Key factors or variables contributing to the main constructs and their sub-constructs were then gathered through an extensive review of the literature, and the connections between these main constructs were illustrated in the conceptual framework presented in Section 2.8. The first five steps in Phase I were discussed in Chapters 1 and 2. The last two steps, on internal and external validation of the conceptual framework, are further discussed below.

Following the development of the conceptual framework, internal validation was conducted to check both the integrity and logic of the framework by revisiting the research needs (Macmillan et al., 2001) and by gaining expert feedback. Revisiting the research aim, to build resilience to disruptions of the Malaysian public sector construction supply chain, the purpose of the conceptual framework is to show the link between key issues discussed in the literature review and how the interactions between the main research constructs (vulnerability, capability and pathogens) can assess supply chain resilience. In order to ensure the internal validity of the conceptual framework, the researcher adopted the factors that were collected from previous literature to be further assessed in this study.

The researcher then obtained initial feedback on the conceptual framework from five experts: three professionals from the public organisations and two researchers. This was useful in ensuring the clarity of the content of the framework. Following the feedback, wordings and terms for factors used in the framework were amended and the links between constructs were made explicit by using words such as influence, trigger, causes and reduce. The professionals from the public organisations found these words useful in making the framework self-explanatory, and the simple terms used made it easier for managers to understand the focus of the study. Therefore, it can be established that the framework theoretically succeeded in presenting its purpose.

However, due to the conceptual nature of the framework, further external verification from the real world was needed to ensure its validity. This is the final step of Phase I, in preparation for the questionnaire and interviews to collect data from professionals in the field. Overall, the outcome of Phase I is a conceptual framework that is subject to subsequent revision or expansion following data collection and analysis.

3.6.2 Phase II – Development of Survey Instrument

Phase II, illustrated in Figure 3.8, begins with the experts' pre-test of the initial draft of the survey instrument, inorder to gather initial feedback on the list of vulnerability and capability factors identified in Phase I, and to identify areas in the survey that need further development or refinement. It is also important to pre-test the survey to ensure that researchers and respondents interpret the survey in the same way and that it will function as a valid and reliable assessment tool (Converse and Presser, 1986).

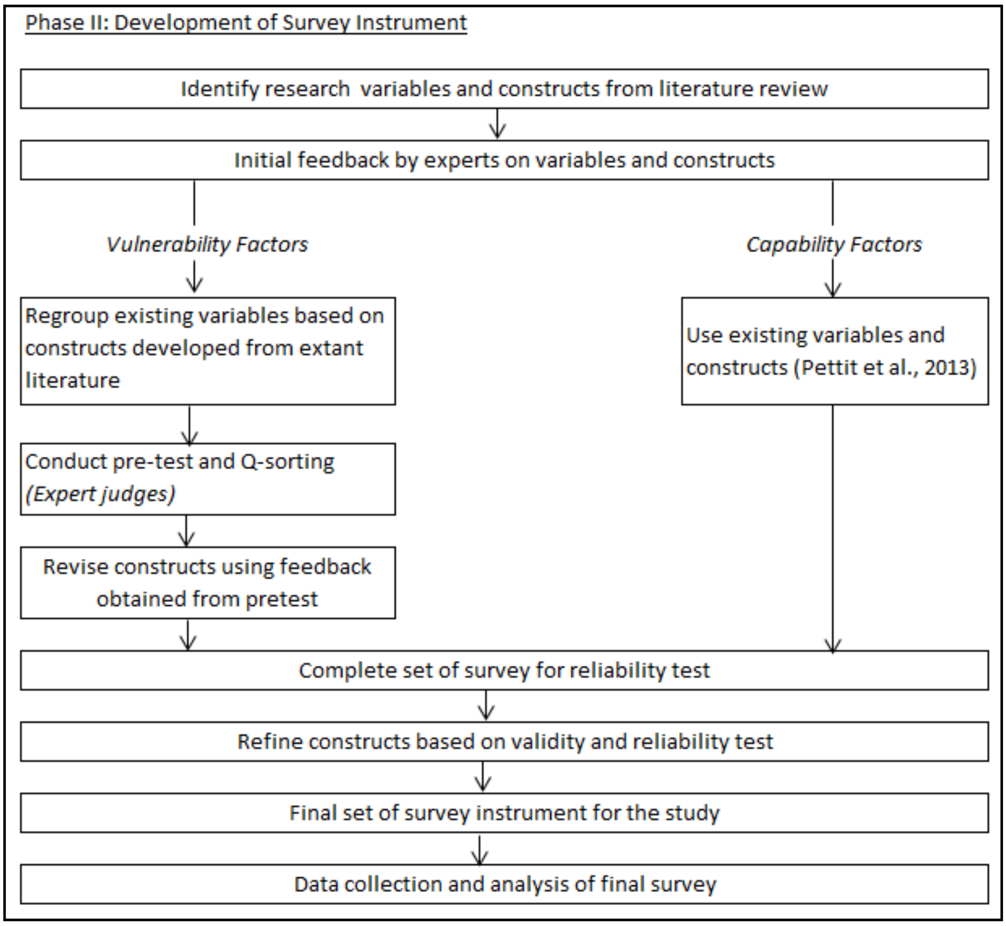

Figure 3.8: Research process Phase II – Development of Survey Instrument

The results from the pre-test of the survey instrument and the pilot study to assess reliability as shown in Figure 3.8 are further discussed below.

Pre-test Data Analysis

The following three steps were undertaken during the pre-test:

First, the initial questionnaire draft, which includes the identified variables and research constructs from the literature review, were presented to the same five experts as in Phase I; they were requested to make initial recommendations on the layout of the questionnaire, clarity of the contents and instructions (presented as the second step in Figure 3.8). This procedure allows the researcher to test the face validity and content validity of the questionnaire (as discussed in Section 3.5.3). The necessary changes were made following the experts' feedback, as indicated in Table 3.6 below. Some irrelevant factors were deleted, and statements reworded to improve clarity.

Table 3.6: Feedback on questions and changes addressed through the pre-test

Focus	Description	Feedback and recommended changes
Content	Is the content of the questions appropriate to the research? Are the questions relevant?	• All experts agreed that the content of the questions were appropriate and relevant for the research area.
Instructions and cover page	Are the instructions of the questionnaire clear?	• The cover page which includes the research problem and the research aim and objectives was helpful and easy to understand. • A suggestion was made to highlight the purpose of the questionnaire in the cover page as well. • Some of the words in the instructions of the sections need to be underlined and bold to attract respondents' attention. • Instructions in Section 5 were not self-explanatory and need to be further clarified by the researcher. The instructions were therefore reworded accordingly to avoid confusion.

Questions	Are all the wordings used in the questions and vulnerability and capability statements clear or ambiguous?	• Generally, all the wordings in the questions are clear. Some experts suggested using simple terms that all managers and operatives can understand. Some terms were therefore reworded accordingly. • It was suggested to allow the respondents to tick more than one option for question number 4 in Section 1 as they might be involved in more than one project phase in construction. • The term suppliers in questions in Sections 3 and 4 needs to be defined as 'a separate firm that provides either products or services to the respondent's firm'. A footnote was therefore added to define what suppliers meant in this context. • To include both products/services in the vulnerability and capability statements as some respondents might be offering services instead of products in the supply chain.
Layout	How appropriate is the layout or order of the questionnaire?	• All experts agreed that the layout and order of the sections are very good and easy to read.
Length	How acceptable is the length of the survey to the respondents?	• Once duplicated questions are deleted, and factors are refined to shorten the questionnaire, the experts find that the duration of approximately 20 to 30 minutes was viewed as a reasonable length to complete the questionnaire.

Another key recommendation was on the classification of the vulnerability factors. Although the experts found that the pre-established scales and constructs of the capability factors in Pettit et al.'s (2013) study are useful and can be directly adopted in the survey to assess the resilience of the public sector supply chain, for the vulnerability factors, the experts argued that it would be valuable to the public sector supply chain to assess the vulnerability based on where the vulnerability arises (i.e. from within the organisation, from the supply chain, or from external factors beyond the control of the firm and its supply chain). Hence, in line with the theoretical concept and the experts' feedback, the vulnerability factors were regrouped and classified as discussed below.

Secondly, as it was suggested that the vulnerability factors be regrouped; the content validity of the vulnerability factors was assessed by the five experts to ensure the definition of the vulnerability constructs was clear. To calculate the content validity ratio (CVR) discussed in Section 3.5.3, through a short questionnaire, each industry expert was asked to rate if the vulnerability factors measured by the construct were either essential, useful but not essential or irrelevant in assessing the public sector supply chain resilience. This help the researcher to further refine the vulnerability factors based in their importance.The experts were also asked to rate on a four-point Likert scale (1=not relevant, 2=somewhat relevant, 3=quite relevant and 4=very relevant) each item based on its relevance and clarity in measuring the construct it was supposed to measure, for the purpose of computing the item-content validity index (I-CVI). Using Equations 1 and 2 (Section 3.5.3), the CVR and I-CVI for the vulnerability factors were calculated accordingly, as shown in Table 3.7.

Looking at the CVR values in Table 3.7, 11 out of the 41 items fell below the 0.99 threshold, as highlighted in red. This includes items such as V3.3-operating in extreme or hazardous conditions, V3.4-loss of key personnel, V4.1-large number of members in supply chain, V4.7-limited distribution capacity, and V5.2-suppliers have limited capacity in dealing with demand changes. Despite obtaining a CVR value of 0.60, it is worth noting here that four out of the five experts selected these items as essential or important, but not essential, as seen through the breakdown of the results in Table E1 of Appendix E. Although there is 80% agreement on the essentiality of these items, Lawshe's (1975) formula and stringent minimum CVR value of 0.99 for a small number of experts seems to require all experts to agree that those items are essential or important, but not essential be retained in the study. Hence, in this case, the researcher took into account the I-CVI value to determine whether to retain or discard the items with a CVR value of 0.60. It can be seen from Table 3.7 that these items obtained a high I-CVI value of 0.80, which is above the minimum of 0.78. Thus it was decided that these items be retained in the study.

The lowest CVR value of 0.20 was identified in items under the technology disruptions and environmental factors constructs, whereby two of the five experts perceived these items (V6.2-unforeseen technology failures and V8.2-health pandemic/spread of disease affecting employees) to be irrelevant to the study. The I-CVI values of both of these items were also below the 0.78 threshold. However, looking at the total average of the scale content validity index (S-CVI), the environmental factors construct is still within the acceptable S-CVI value of 0.80; thus the researcher decided to retain the item in the construct for further analysis. However, the technology disruptions construct fell below the S-CVI's 0.80 threshold, with the S-CVI value of 0.70. This construct was therefore considered to have low content validity and was eliminated. Overall, considering that more than 70% of the 41 items obtained a CVR and I-CVI value of 1.00, it can be considered that the rest of the constructs have a good level of content validity.

Table 3.7: Results of the items' content validity ratio (CVR), item content validity index (I-CVI) and scale content validity index (S-CVI)

Vulnerability Factors	CVR $\frac{ne - N/2}{N/2}$	I-CVI $\frac{N_{3 \text{ or } 4}}{N}$
Strategic Vulnerability		
V1.1 Degree of outsourcing to different suppliers	1.00	1.00
V1.2 Reliance upon specialty sources in delivering products/services	1.00	1.00
V1.3 Threat by competitive innovations	1.00	1.00
V1.4 Concentration of suppliers/operation facilities at the same area	1.00	1.00
V1.5 Complexity of services/production operations	1.00	1.00
CVI / S-CVI (Average value of items):	1.00	1.00
Management Vulnerability		
V2.1 Inadequate management oversight	1.00	1.00
V2.2 Late information and decision making	1.00	1.00
V2.3 Visibility of errors or deficiencies to stakeholders	1.00	1.00
V2.4 Reliance upon information flow in operations	1.00	1.00
V2.5 Budget overruns/Unplanned expenses	1.00	1.00
CVI / S-CVI (Average value of items):	1.00	1.00
Personnel Vulnerability		
V3.1 Shortage of skilled workers	1.00	1.00
V3.2 Labor disputes or strikes	1.00	1.00
V3.3 Operating in extreme or hazardous conditions	0.60	0.80
V3.4 Loss of key personnel	0.60	0.80
CVI / S-CVI (Average value of items):	0.80	0.90
Process Vulnerability		
V4.1 Large number of members in supply chain	0.60	0.80
V4.2 Unpredictability of demand by client	1.00	1.00
V4.3 Scarce or limited raw material availability	1.00	1.00
V4.4 Poor availability of utilities (electrical power, water, sewer) for production	1.00	1.00
V4.5 The use of failure-prone equipment/product	1.00	1.00
V4.6 Limited production capacity	1.00	1.00
V4.7 Limited distribution capacity	0.60	0.80
V4.8 Product quality problem	1.00	1.00
V4.9 Transportation disruption during operation	1.00	1.00
CVI / S-CVI (Average value of items):	0.91	0.96

Vulnerability Factors	CVR $\frac{ne - N/2}{N/2}$	I-CVI $\frac{N_{3 \text{ or } 4}}{N}$
Supplier or Customer Disruptions		
V5.1 Suppliers face frequent disruptions	1.00	1.00
V5.2 Suppliers have limited capacity in dealing with demand changes	0.60	0.80
V5.3 Loss of key supplier	0.60	0.80
V5.4 Customer face frequent disruptions	1.00	1.00
CVI / S-CVI (Average value of items):	0.80	0.90
Technology Disruptions		
V6.1 Technology changes in the industry	0.60	0.80
V6.2 Unforeseen technology failures	0.20	0.60
CVI / S-CVI (Average value of items):	0.40	0.70
Political or Legal Pressures		
V7.1 Exposure to political disruptions	0.60	0.80
V7.2 Political/Regulatory changes affecting operation	1.00	1.00
CVI / S-CVI (Average value of items):	0.80	0.90
Environmental Factors		
V8.1 Exposure to natural disasters	1.00	1.00
V8.2 Health pandemic/spread of disease affecting employees	0.20	0.60
V8.3 Pressure from public opinion/reputation	1.00	1.00
CVI / S-CVI (Average value of items):	0.73	0.87
Physical Damage Disruptions		
V9.1 Products regularly stolen or vandalised	1.00	1.00
V9.2 Accidents during operation (i.e. fire, workers accident)	1.00	1.00
V9.3 Terrorism & sabotage	0.60	0.80
CVI / S-CVI (Average value of items):	0.87	0.93
Market Pressures		
V10.1 Fluctuations in prices	1.00	1.00
V10.2 Price pressures from competition	1.00	1.00
CVI / S-CVI (Average value of items):	1.00	1.00
Liquidity or Credit Vulnerability		
V11.1 Finance policies & procedures affecting management of money & assets	1.00	1.00
V11.2 Lack of financial resources	1.00	1.00
CVI / S-CVI (Average value of items):	1.00	1.00

* Where ne = number of experts selected "essential" or "important, but not essential", N = total number of experts,
* $N_{3 \text{ or } 4}$ = number of experts rated "3=quite relevant" and "4=very relevant

Thirdly, Q-sorting was conducted with three researchers from Malaysia and three key industry players to ensure that the relevant vulnerability factors fall in the right constructs (as discussed in Section 3.5.3). The correct classification percentage was calculated by identifying the frequency of experts that selected the correct construct for each item. Based on the computed Q-sorting results in Table 3.8, seven items obtained 100% correct classification (value shown as 1.00 in the table), six items were correctly classified at a rate of 83%, 14 items received a correct classification rate of 67%, and 11 items were correctly classified by half (50%) of the respondents. The high percentage of correct classification shows that these 38 items exhibit consistent meaning across the panel of experts, thus confirming their adequacy in capturing the pre-specified vulnerability constructs.

Table 3.8: Results of Q-sorting analysis

Vulnerability Factors		Percent
Strategic Vulnerability		
V1.1	Degree of outsourcing to different suppliers	0.67
V1.2	Reliance upon specialty sources in delivering products/services	0.50
V1.3	Threat by competitive innovations	0.50
V1.4	Concentration of suppliers/operation facilities at the same area	0.67
V1.5	Complexity of services/production operations	0.50
Management Vulnerability		
V2.1	Inadequate management oversight	1.00
V2.2	Late information and decision making	1.00
V2.3	Visibility of errors or deficiencies to stakeholders	0.33
V2.4	Reliance upon information flow in operations	0.50
V2.5	Budget overruns/Unplanned expenses	0.67
Personnel Vulnerability		
V3.1	Shortage of skilled workers	0.67
V3.2	Labor disputes or strikes	0.67
V3.3	Operating in extreme or hazardous conditions	0.17
V3.4	Loss of key personnel	0.67
Process Vulnerability		
V4.1	Large number of members in supply chain	0.33
V4.2	Unpredictability of demand by client	0.67
V4.3	Scarce or limited raw material availability	0.50
V4.4	Poor availability of utilities (electrical power, water, sewer) for production	0.50
V4.5	The use of failure-prone equipment/product	0.67
V4.6	Limited production capacity	0.83
V4.7	Limited distribution capacity	0.67
V4.8	Product quality problem	0.67
V4.9	Transportation disruption during operation	0.67

Supplier or Customer Disruptions		
V5.1	Suppliers face frequent disruptions	0.83
V5.2	Suppliers have limited capacity in dealing with demand changes	0.67
V5.3	Loss of key supplier	0.67
V5.4	Customer face frequent disruptions	0.83
Technology Disruptions		
V6.1	Technology changes in the industry	1.00
V6.2	Unforeseen technology failures	1.00
Political or Legal Pressures		
V7.1	Exposure to political disruptions	0.83
V7.2	Political/Regulatory changes affecting operation	0.83
Environmental Factors		
V8.1	Exposure to natural disasters	1.00
V8.2	Health pandemic/spread of disease affecting employees	0.50
V8.3	Pressure from public opinion/reputation	0.50
Physical Damage Disruptions		
V9.1	Products regularly stolen or vandalised	0.50
V9.2	Accidents during operation (i.e. fire, workers accident)	0.50
V9.3	Terrorism & sabotage	0.50
Market Pressures		
V10.1	Fluctuations in prices	1.00
V10.2	Price pressures from competition	1.00
Liquidity or Credit Vulnerability		
V11.1	Finance policies & procedures affecting management of money & assets	0.67
V11.2	Lack of financial resources	0.83

However, three items in Table 3.8 (highlighted in red) obtained below the previously selected minimum 50% correct classification rate: V2.3-visibility of errors or deficiencies to stakeholders and V4.1-large number of members in supply chain, for which only two out of the six experts (0.33 percent) classified the items to the pre-specified construct; for V3.3-operating in extreme or hazardous conditions only one expert classified it correctly (0.17 percent). It is worth noting here that these items had higher percentage values, but for a construct other than the one posited by the researcher. Hence, the decision was made to reclassify them according to the construct proposed by the majority of experts: visibility of errors or deficiencies to stakeholders was a strategic vulnerability rather than a management vulnerability; large number of members in supply chain was considered as supplier or customer disruptions instead of process vulnerability; and operating in extreme or hazardous conditions was perceived to be more suitable under the environmental factors construct that are beyond the supply chain's control, instead of personnel vulnerability. These amendments were therefore made accordingly before the pilot study of the completed survey draft was conducted.

Pilot Study to Assess Internal Consistency of Survey Instrument

After the pre-testing, the survey was ready for the reliability test, as depicted in Figure 3.8. The pilot study was conducted with 20 respondents (10 respondents from the public organisations and 10 respondents from the private organisations representing the public organisations' supply chain members). This is a useful process to test the survey from a methodological standpoint, allowing the researcher to assess the validity and reliability of the survey instrument and to predict any difficulties that may arise during the data analysis of the complete sample (N=105), which might otherwise have gone unnoticed (Litwin, 1995).

Cronbach's alpha and corrected item-total correlations were computed in SPSS, based on the data collected (N=20) to test the internal consistency and uni-dimensionality of the vulnerability (V1 to V11) and capability (C1 to C12) constructs. Table 3.9 presents the number of items and the Cronbach's alpha value for each construct. The table highlights three of the 23 constructs that fell below the Cronbach's alpha limit of 0.60 for the pilot study. The construct V6-technology disruptions obtained the lowest alpha value of 0.333. The validity of this construct was also an issue based on the low S-CVI value computed previously (Table 3.7). Plus, the item-total correlation of the items in the construct was also below the 0.30 threshold, with a value of 0.20 (see Table F1 in Appendix F). The poor correlation between these items suggests that the items are too heterogeneous to form a construct and are therefore not reliable to measure the construct technology disruptions. The researcher therefore decided to remove this construct in the main study, to ensure that the survey instrument remain valid and reliable.

The construct V9-physical damage disruptions also fell slightly below the 0.60 threshold, with an alpha value of 0.586. The item-total correlation of the items in the construct, however, was encouraging, ranging from 0.32 to 0.51 (Table F1 in Appendix F). This indicates that each item has a good correlation with the domain. The low alpha value of this construct might therefore be due to the low number of questions in the construct or the small number of respondents assessed in the pilot study. Hence it was decided that the construct remain in the study for further analysis as it could possibly bring significant managerial insights to the study.

Table 3.9: Internal reliability of vulnerability and capability factors

Vulnerability Factors	V1	V2	V3	V4	V5	V6
Number of Items	6	4	3	8	5	2
Cronbach's Alpha (Pilot Sample N=20)	0.723	0.615	0.814	0.916	0.852	0.333
Cronbach's Alpha (Main Sample N=105)	0.520[a]	0.649	0.586[a]	0.872	0.819	0.734
Vulnerability Factors	**V7**	**V8**	**V9**	**V10**	**V11**	
Number of Items	2	4	3	2	2	
Cronbach's Alpha (Pilot Sample N=20)	0.695	0.842	0.586	0.750	0.726	
Cronbach's Alpha (Main Sample N=105)	0.683	0.645	0.785	0.737	0.699	
Capability Factors	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
Number of Items	5	3	4	3	4	5
Cronbach's Alpha (Pilot Sample N=20)	0.929	0.537	0.917	0.788	0.796	0.840
Cronbach's Alpha (Main Sample N=105)	0.829	0.715	0.882	0.816	0.825	0.829
Capability Factors	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**
Number of Items	3	4	3	4	3	3
Cronbach's Alpha (Pilot Sample N=20)	0.884	0.735	0.793	0.839	0.737	0.824
Cronbach's Alpha (Main Sample N=105)	0.861	0.747	0.633	0.770	0.777	0.804

[a] The mean inter-item correlation for V1 is 0.2 and V3 is 0.3 indicating that each item has good correlation with the domain (Briggs and Cheek, 1986)

Another factor that remains below the 0.60 threshold is the capability factor, C2-capacity, with an alpha value of 0.537. This construct was also an issue in Pettit's (2013) study, whereby a lower Cronbach's alpha value of 0.515 was obtained for the same construct. However, despite the lack of uni-dimensionality, Pettit (2008) had argued that the classification maintains a logical structure that allows for the computation of an overall capacity capability score. He believes that the construct represents multiple independent measures of capacity at the production locations, including internal assets such as inventory, equipment, labour,and utilities (Pettit, 2008). Furthermore, it can be observed through Table F2 in Appendix F that the construct's low Cronbach's alpha is due to the poor item-total correlation of the sub-factor, reserve capacity (materials, assets, labour, inventory). This item may not correlate well with the other two items in the construct because reserve capacity might not be perceived as a significant capability, as it can be cost-prohibitive to some respondents to store additional capacity. Hence it was suggested by Pettit (2008) to further explore this factor in detail in the subsequent phase of the study to obtain a comprehensive result. The construct therefore remains in this study for further analysis. Overall, the remaining factors' reliability estimates ranged from 0.615 to 0.929, proving that the survey instrument was reliable and consistent for the total sample (N=105).

3.6.3 Phase III – Development of Resilience Response Framework

Once the validity and reliability of the survey instrument have been determined, data analysis of the final survey in Phase III of the study begins (see Figure 3.9). This includes an assessment of the critical areas of vulnerability and the current level of capability of the public sector supply chain.

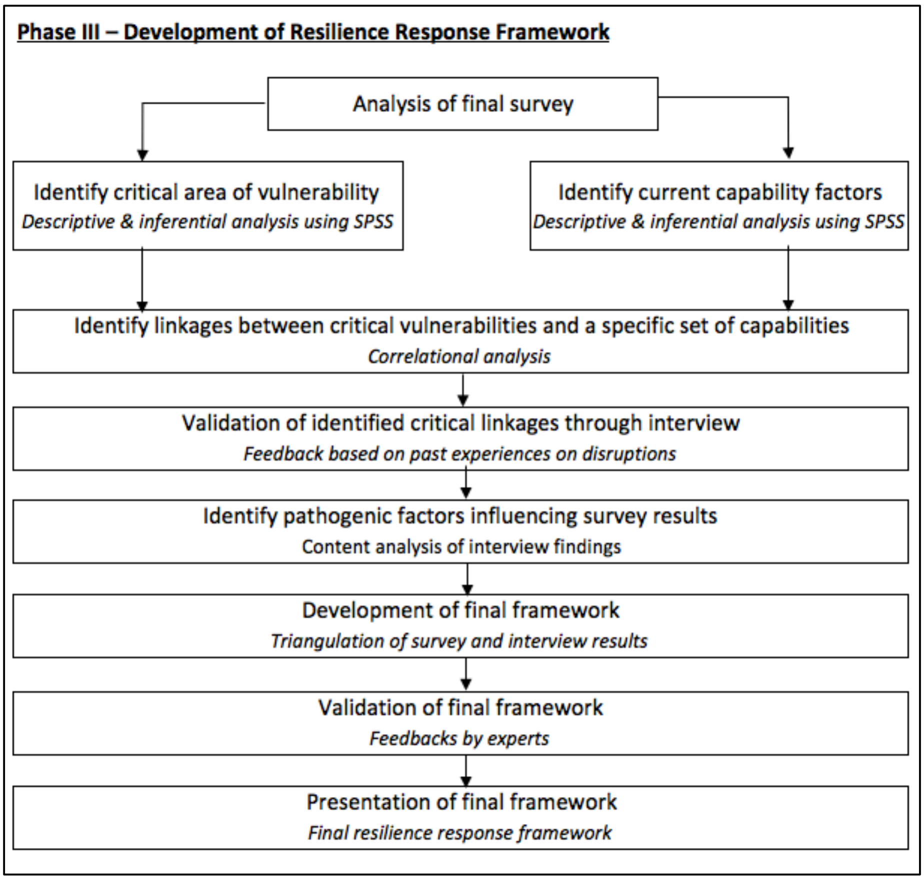

Figure 3.9: Research process Phase III – Development of Resilience Response Framework

The critical vulnerabilities and capabilities identified from the survey were used to develop the questions for the subsequent semi-structured interviews with 12 targeted respondents (Section 3.5.2.1). By highlighting the identified critical areas in the interviews, the researcher was able to validate the survey findings. The pathogenic influences, critical impacts and pathogenic mitigations of the critical vulnerabilities were also identified through the interviews, to understand the root cause of the problem and identify appropriate solutions accordingly. Overall, the data collected and analysed throughout all phases of this study contribute to the development of the final resilience response framework. Upon validation by the professional experts, the empirical results from the final phase of the study allow the researcher to fulfil the aim of developing a resilience response framework to build resilience of the public sector supply chain to disruptions in public projects. The results and analysis of the data collected from Phase III are presented in detail in Chapters 4, 5 and 6.

3.7 Ethical Considerations

Ethical approval for this research had been obtained from the researcher's previous university, the University of Salford's Ethics Panel (see document attached in Appendix G), and was verified by the researcher's current place of study, the University of Huddersfield. First, a letter requesting consent from the Malaysian Public Works Department to distribute questionnaires and conduct interviews with professionals engaged in delivering public projects was sent to the management office of PWD before the survey was conducted (see Appendix C). The letter ensured that the respondents understood the purpose of the study, their involvement in the study, and the possible benefits of taking part in the survey. The relevant contact details of the researcher for further inquiries were also included in the letter.

Once the researcher had gained the relevant consent from the managers, the questionnaires were sent out to relevant parties and a written consent was obtained from respondents who decided to participate, through a standard participant consent form (see Appendix C). A covering letter was also included with the questionnaire to provide relevant information to the respondents on the research background, the objectives of the questionnaire, how their responses would contribute to the research work, and the researcher's contact details.

For the semi-structured interviews, participants were given the interview questions beforehand to give them enough time to think about the subject matter and decide whether to be involved in the research study or not. As with the questionnaire, a signed standard consent form was obtained from participants (Appendix C).

In terms of data protection, data stored electronically is on a password protected computer and hard-copy data is stored in locked filing cabinets, accessed only by the researcher. The researcher also password protected the database and Excel spreadsheet containing the primary data on the researcher's own personal laptop; the data would be destroyed within three years of the researcher's graduate award. The interviews were transcribed as soft copy in the researcher's database and codified on the researcher's password protected personal laptop. As the data is coded, no names, addresses or specific references to individuals are held. All hard copy data is destroyed as per the standard procedures.

In disposing of the soft copy data three years after graduation, files on the researcher's personal laptop will be deleted and overwritten to ensure they are erased and disposed of securely. As for hard copy data, shredders will be used to physically destroy the papers in accordance with the required standard code of ethics. All publications will be written in such a way as to disguise the identity of the research participants involved, unless prior consent has been obtained from the individual involved.

The following chapter presents the data analysis of the questionnaire survey.

CHAPTER 4

DATA ANALYSIS OF QUESTIONNAIRE SURVEY

4.1 Introduction

Statistical analysis through SPSS was used to analyse the data collected in the questionnaire survey (Section 3.5.1.3). This chapter presents the results of the analysis of the questionnaire survey as part of the subsequent Phase III (Section 3.6.3). The development of the questionnaire survey and its validity and reliability were discussed in Section 3.6.2, under Phase II of the study. The main purpose of the questionnaire is to identify the critical vulnerability and capability factors of the public organisations and its supply chain members (referred to as private organisations) involved in public projects delivery. The method of analysis for the questionnaire follows that outlined in Section 3.5.1.3 (research methodology chapter).

The analysis of the questionnaire results from the total 105 respondents is presented below according to the five sections in the questionnaire (see Appendix C):

- Section 1 of the questionnaire involves close-ended questions on the respondents' general profile;
- Section 2 involves close-ended questions on the respondents' past experience of disruptive events in public projects;
- Section 3 involves the use of a 5-point Likert scale (1-strongly disagree, 2-disagree, 3-neither agree nor disagree, 4-agree, 5-strongly agree) to determine the degree of agreement or disagreement of the respondents with the statement relating to the supply chain vulnerability factors;
- Section 4 involves the use of the same 5-point Likert scale to determine the degree of agreement or disagreement of the respondents with the statement relating to the supply chain capability factors;
- Section 5 involves a 5-point Likert scale on the relative level of importance (range from not very important, moderately important, to critical) of the main vulnerability and capability factors.

4.2 Respondents' Profiles

Two main groups of respondents were sampled in the public sector supply chain: the professionals from the public organisations and the private organisations (parties engaged by the public organisations to undertake public projects). Based on the respondents' professional background as presented in Table 4.1, 51% came from the public organisations responsible for delivering and managing public projects, and 49% from the supply chain (25% consultants and 24% contractors) external to the public organisations, involved in public project delivery. The almost equal distribution among these two groups of respondents makes later statistic comparisons possible.

Table 4.1: Breakdown of Respondents' Organisation

Respondents' Organisation	Number of Respondents	Percent
Public Organisations	54	51%
Contract Consultant / Quantity Surveyor	3	3%
Civil and Structural Engineering Consultant	17	16%
Architecture Consultant	6	6%
Contractor	25	24%
Total	105	100%

In terms of the respondents' profession, more than half (55%) of the respondents are civil and structural engineers, as shown in Table 4.2. According to the PWD's official website, more than half of the civil and structural engineers out of the total professionals are employed in public sector projects (PWD, 2015). Some also act as project managers who manage the supply chain during public project delivery, making their insights valuable to this study. Other respondents include project managers (8%), architects (7%), quantity surveyors (5%) and contractors (20%). The other (8%) professional background in Table 4.2 includes project assistants and geographical information system executives.

Table 4.2: Breakdown of Respondents' Professional Background

Respondents' Profession	Number of Respondents	Percent
Project Manager	8	8%
Civil and Structural Engineer	55	52%
Architect	7	7%
Quantity Surveyor	5	5%
Contractor	21	20%
Other	9	8%
Total	105	100%

These professionals are significant to this study as they are responsible for the management and operational work of the supply chain and are at the frontline of the project team during the planning (25%), design (21%), tender (18%) and construction (36%) phases of projects, as tabulated in Table 4.3.

Table 4.3: Breakdown of Respondents' Involvement based on Project Phase(s)

Respondents' involvement in project phase(s)	Number of Respondents	Percent
Planning	54	25%
Design	47	21%
Tender	39	18%
Construction	80	36%
Total	220	100%

The majority of the respondents (80%) have more than 6 years of working experience in the construction industry, as shown in Table 4.4, with most of them involved in more than one project phase during public project delivery. These significant demographic characteristics therefore ensure that valuable insights and reliable data are obtained in assessing the supply chain's vulnerability and capability factors.

Table 4.4: Breakdown of Respondents' Work Experience in the Construction Industry

Respondents' Work Experience	Number of Respondents	Percent
Less than 3 years	12	11%
4-5 years	9	9%
6-10 years	35	33%
More than 10 years	49	47%
Total	105	100%

4.3 Respondents' Past Experience of Disruptive Events in Public Projects

Based on the respondents' past experience as reported in Figure 4.1, the survey results reveal that the public organisations put more emphasis on quality problems (26%) than did the contractors and consultants (13%) in addressing the frequent disruptions they often face. Conversely, contractors and consultants were more concerned with the failure of their key supplier or customer (17%) and their financial situation (16%). No disruptions due to loss of critical services were reported by the public organisations, suggesting that these occur more frequently in the contractors' and consultants' operations. The contractors' and consultants' operations also faced more severe weather conditions (12%) and transportdisruption (7%) than the public organisations (7% and 3% respectively). On the other hand, the public organisations faced more disruptions due to regulatory issues (12%) compared to the private organisations (9%). Both the public and private organisations gave the same ratings of 8% for disruption due to technological change.

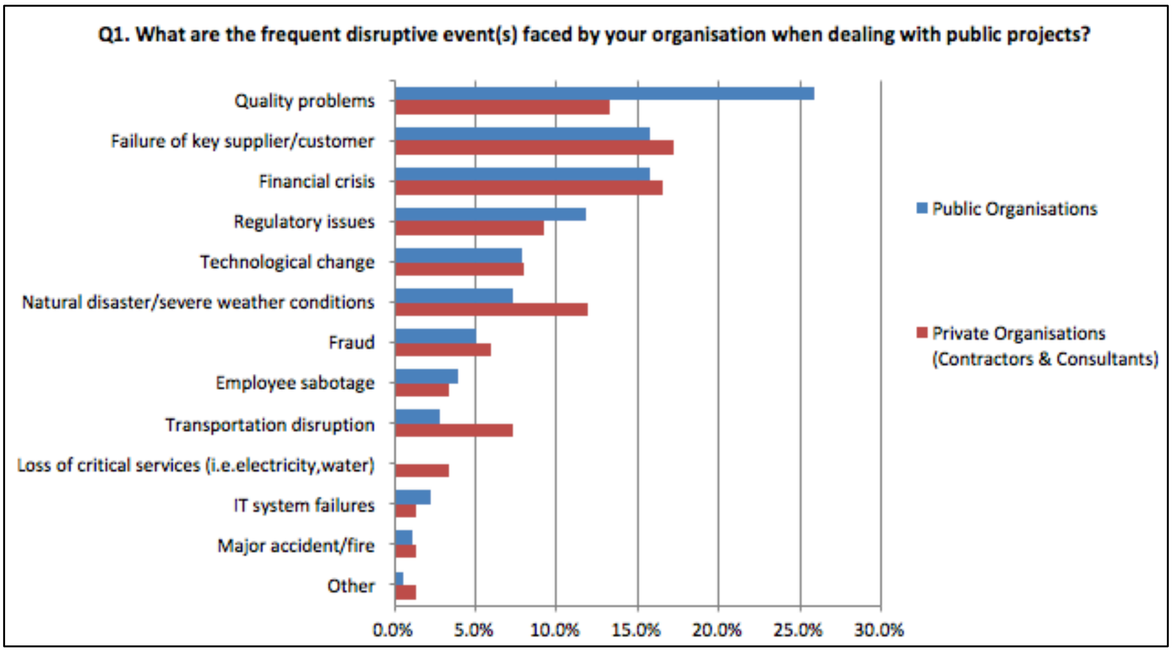

Figure 4.1: Frequent disruptive events experienced by respondents

The survey results show that a majority of the respondents from both the public and private organisations (56%) find that acute disruptions to project performance caused delay in delivering products or services to customers, as shown in Figure 4.2. However, there seems to be a gap in terms of the effect of disruptions on the quality of the public projects, with a higher rating (21%) given by the public organisations than that from the private organisations (7%). The public organisations (14%) were also more concerned about damage to their reputation than the private organisations (7%). On the other hand, the private organisations faced higher repercussion from disruptions on their internal performance and profitability measures (i.e. higher cost of operation (18%), loss of productivity (16%), and decrease in profit (15%)) compared to the public organisations. Only 13% of the public organisations rated loss of productivity, with 4% given to decrease in profit and the lowest, 3%, to loss of skilled workers.

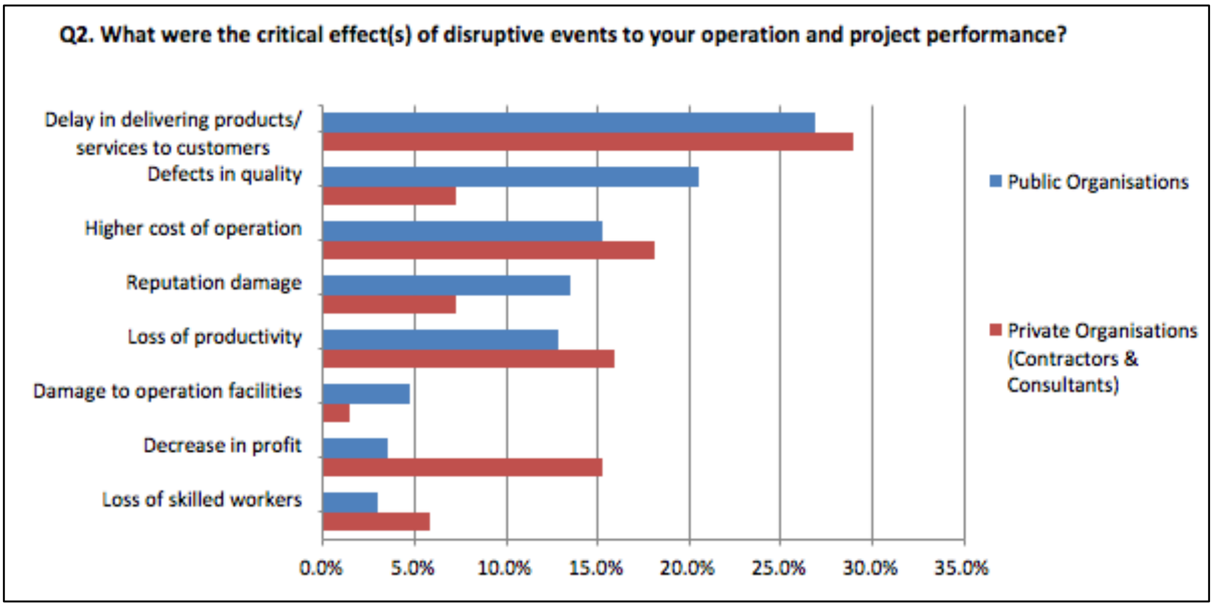

Figure 4.2: Critical effects of disruptive events

In terms of the level of frequency of disruptive events, a total of 65% of the private organisations (contractors and consultants) reported that they often or always face disruptions in dealing with public projects (see Figure 4.3). However, 33% of professionals from the public organisations claim that disruptions only occur sometimes in project delivery. The different perceptions of the frequency of disruptions suggest that the parties from the bottom tier of the supply chain (refer to Figure 2.4) face more frequent disruptions in project delivery than other parts of the chain. This is an important consideration as the disruptions might have a knock-on effect on the upper tier of the supply chain (i.e public organisations) if not managed properly.

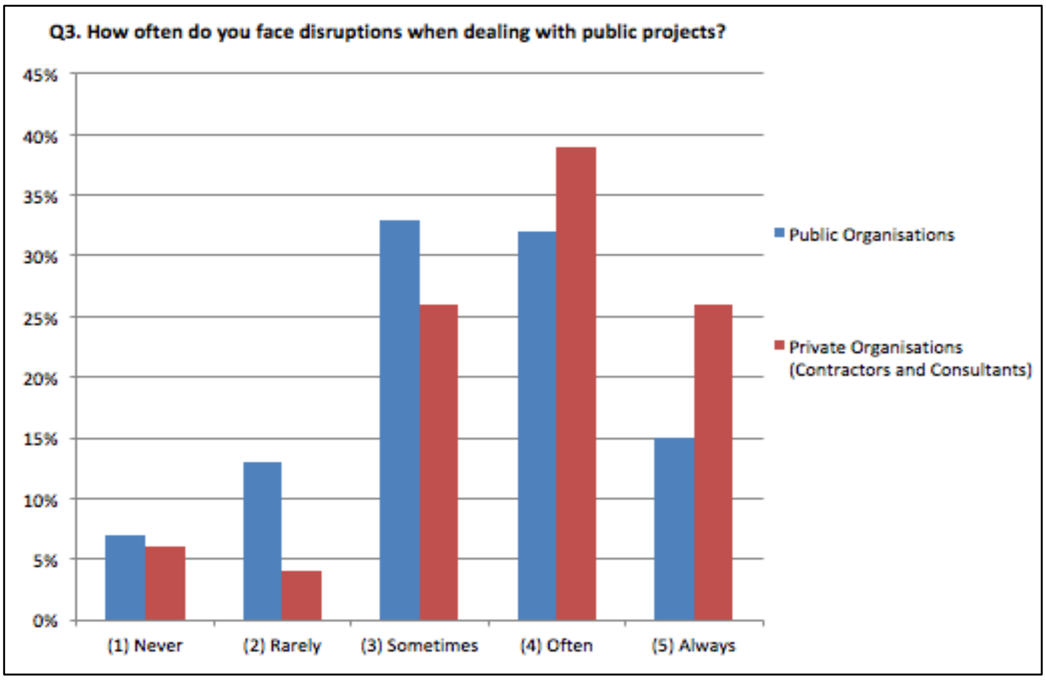

Figure 4.3: Level of frequency of disruptions faced by respondents

Based on the results presented in Figure 4.4, a majority of respondents from both the public organisations (63%) and contractors and consultants (39%) dealt with disruptions as part of business-as-usual. On the other hand, a total of 40% of the contractors and consultants found that the disruptions challenged them and were moderately or very disruptive. However, only 26% of the public organisations answered in this way. This shows how the disruptions have different levels of impact on different parts of the supply chain. Both the public and private organisations, however, agreed that the disruptions did not shut down their operation permanently, based on the number of ratings given for this option in Figure 4.4.

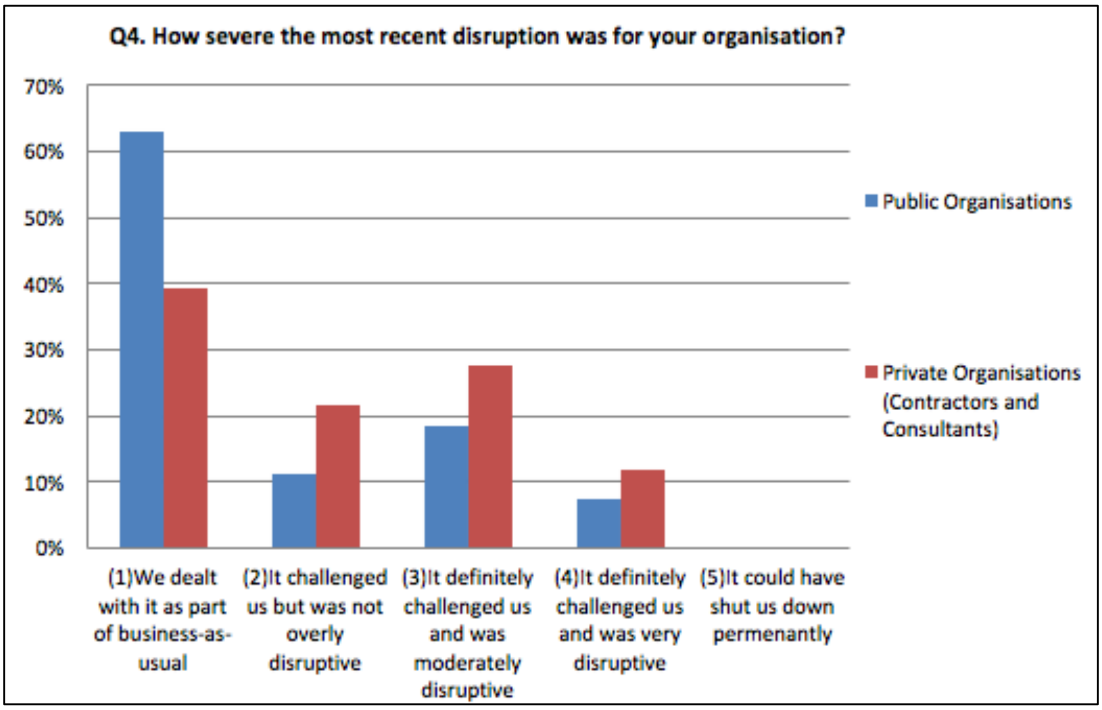

Figure 4.4: Severity of disruptions experienced by respondents

Comparison of Level of Frequency and Impact of Disruptions Between Groups of Respondents
Further Kruskal-Wallis tests as discussed in Section 3.5.1.3 were conducted on the results from question 3 on the level of frequency of disruptions (see Figure 4.3) and question 4 on the severity of impact of disruptions (Figure 4.4). For the purpose of this test, the answers to question 3 were computed as 1-never, 2-rarely, 3-sometimes, 4-often, and 5-always, and the answers to question 4 as 1-we dealt with it as part of business-as-usual, 2-it challenged us but was not overly disruptive, 3-it definitely challenged us and was moderately disruptive, 4-it definitely challenged us and was very disruptive, and 5-it could have shut us down permanently.

The reults of the Kruskal-Wallis test (Table 4.5) revealed a statistically significant difference in disruption frequency levels across the three groups of respondents (Gp1, n = 54: public organisations, Gp2, n = 25: contractors, Gp3, n = 26: consultants), χ^2 (2, n = 105) = 11.21, p = .004. Pairwise comparisons with adjusted p-values showed no significant differences in the disruption frequency between the public organisations and consultants (p = 1.00, r = .00). However, significant differences in the frequency level of disruptions were identified between the contractors and consultants (p = .018, r = .38) and the public organisations (p = .005, r = .36). The contractors overall recorded higher mean rank of 70.08 than the public organisations (mean rank = 47.68) and consultants (mean rank = 47.63). The discrepancy between the contractors' and the consultants' and public organisations' perceptions suggest that although all parties of the supply chain face disruptions in public projectsthose at the bottom tier of the supply chain, in this case the contractors, faced more frequent disruptions during public project delivery. This is an important consideration as the disruptions might have a knock-on effect on the upper tier of the supply chain if not managed properly.

Table 4.5: Level of Frequency and Impact of Disruptions in Public Projects Perceived Differently by Public Organisations, Consultants and Contractors using Kruskal-Wallis Test

	Mean Rank			Test Statistics		
	Public Organisations	Consultants	Contractors	Chi-Square	*df*	*P*-value
Frequency of Disruptions	47.68	47.63	70.08	11.213	2	0.004
Severity of Impact of Disruptions	47.22	47.77	70.92	13.419	2	0.001

In terms of the disruptions impacts, the Kruskal-Wallis test results in Table 4.5 revealed that there is a statistically significant difference in the impact of disruptions across the three groups, χ^2 (2, n = 105) = 13.42, p = .001. Pairwise comparisons with adjusted p-values showed that there was no significant difference in the impact between the public organisations and consultants (p = 1.00, r = .00). However, significant differences in the level of impact were identified between contractors and consultants (p = .010, r = .41) and the public organisations (p = .001, r = .39). The contractors overall recorded a significantly higher mean rank score (70.92) than the public organisations (mean rank = 47.22) and consultants (mean rank = 47.77), as per Table 4.5. This shows how the disruptions to public projects have different levels of impact on different parts of the supply chain, with greater disruption to the contractors' operations than to the consultants and public organisations.

In managing disruptions, the highest proportion of respondents (42% from the public organisations and 25% of the private organisations) reported that risk management is adopted by the firm to manage disruptions in public sector projects (see Figure 4.5). Apart from the traditional risk management approach, 16% of the public organisations also have disaster management in place to deal with disruptive events. This differs considerably from the case of the private organisations: only a small percentage (6%) employ disaster management in their operations, preferring emergency management (21%) and crisis management (13%). The major concern in the result here, however, is the fact that many of the private organisations (28%) do not employ any of these strategies in their operations, suggesting that they have no specific management plans in place to handle disruptions. In the public organisations, 15% of the respondents claimed to have no formal management system to reduce disruption.

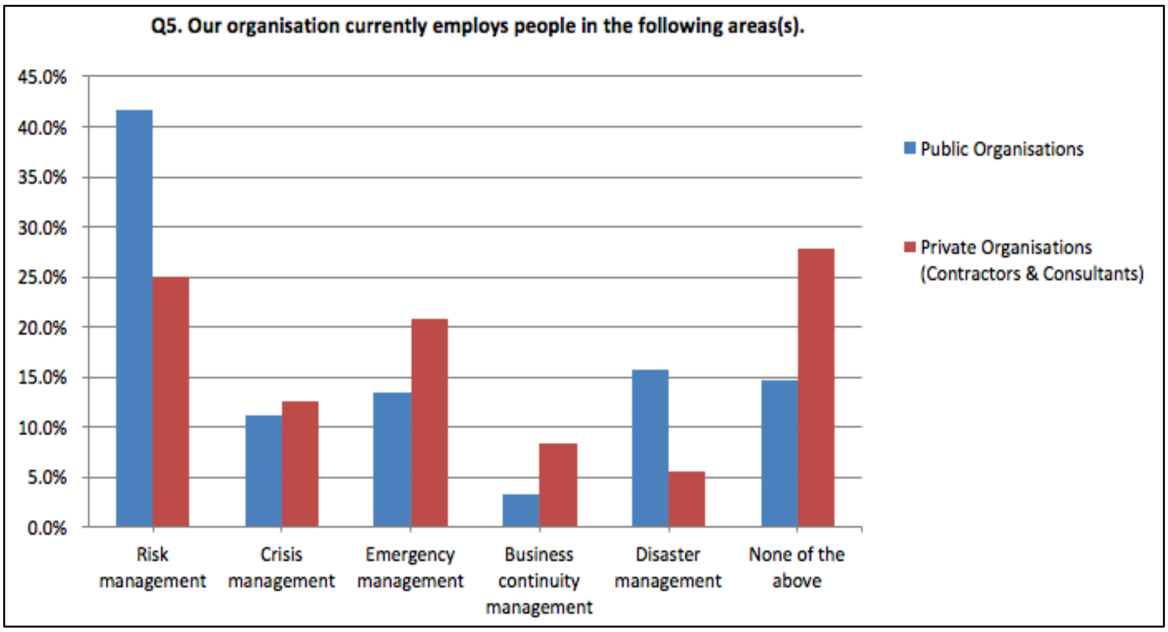

Figure 4.5: Current management of disruptive events

of the largest percentage of respondents from the public organisations believe that the best way to manage disruptions is through planning (35%), followed by collaboration with supply chain members (26%) and staff involvement (24%). Similarly, most of the contractors and consultants (38%) find that good planning will help the supply chain to anticipate, respond to and recover from disruptions in public projects. However, it can be seen from Figure 4.6 that, compared to the public organisations (14%), having insurance is perceived to be more important to contractors and consultants (19%) to recover from disruptions.

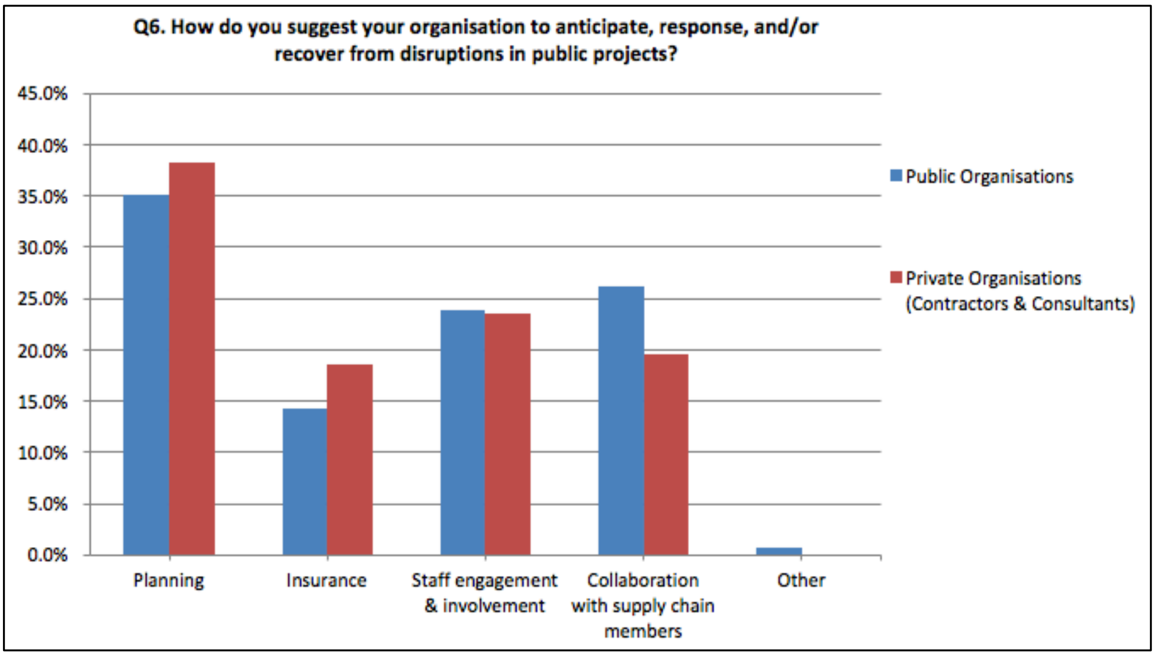

Figure 4.6: Suggestions for managing disruptions

4.4 Supply Chain Vulnerability and Capability Assessment

Supply Chain Vulnerability Assessment

Public Organisations

The results of the public organisations' vulnerability scores and rankings are presented in Table 4.6 (main factors) and Table 4.7 (sub-factors). As shown in Table 4.6, the top five critical vulnerability factors are political or legal pressures, management vulnerability, liquidity/credit vulnerability, strategic vulnerability and market pressures. The respondents from public organisations identified that they are widely exposed to political disruptions (3.76 average score) and are vulnerable to political or regulatory changes (3.56), as per Table 4.7. In terms of management vulnerability, the most significant sub-factors are the timing of business decisions (4.00), reliance upon information flow (3.74) and inadequate management oversight (3.41). Looking at the liquidity/credit vulnerability sub-factors, the public organisations are highly susceptible to financial policies and procedures (3.48) and the lack of financial resources (3.31). Finally, process vulnerability, environmental factors, supplier/customer disruptions and personnel vulnerability appear to be moderate vulnerabilities, and physical damage disruption is rated as a minor issue.

Table 4.6: Ranking of the Public Organisations' Vulnerability Main Factors

Rank	Main Vulnerability Factors	Factor Label	Average Score	Standard Deviation
1	Political/Legal Pressures	V6	3.66	0.78
2	Management Vulnerability	V2	3.58	0.48
3	Liquidity/Credit Vulnerability	V10	3.40	0.69
4	Strategic Vulnerability	V1	3.36	0.42
5	Market Pressures	V9	3.24	0.69
6	Process Vulnerability	V4	2.98	0.67
7	Environmental Factors	V7	2.96	0.63
8	Supplier/Customer Disruptions	V5	2.87	0.65
9	Personnel Vulnerability	V3	2.81	0.63
10	Physical Damage Disruptions	V8	2.62	0.65

Table 4.7: Ranking of the Public Organisations' Vulnerability Sub-factors

Rank	Vulnerability Sub-factors	Mean	Rank	Vulnerability Sub-factors (cont'd)	Mean
1	V2.2 Timing of business decisions	4.00	21	V7.4 Potential safety hazards	3.04
2	V6.1 Exposure to political disruptions	3.76	22	V4.2 Raw material availability	3.02
3	V2.3 Reliance upon information flow	3.74	23	V1.3 Innovation (competition)	2.96
4	V1.1 Degree of outsourcing	3.72	24	V7.1 Natural disasters	2.94
5	V1.6 Visibility of disruption to stakeholders	3.61	25	V8.1 Piracy & theft	2.94
6	V6.2 Political/Regulatory changes	3.56	26	V4.6 Distribution capacity	2.94
7	V1.2 Reliance upon specialty sources	3.54	27	V5.2 Supplier capacity	2.93
8	V4.1 Unpredictability of demand	3.52	28	V4.5 Production capacity	2.91
9	V10.1 Finance policies and procedures	3.48	29	V4.4 Reliability of equipment	2.87
10	V2.1 Inadequate management oversight	3.41	30	V4.3 Utilities availability	2.80
11	V5.5 Scale/extent of supply network	3.35	31	V5.3 Loss of key supplier	2.74
12	V10.2 Lack of financial resources	3.31	32	V4.8 Transportation disruption	2.72
13	V7.3 Public Reputation	3.28	33	V5.1 Supplier disruptions	2.69
14	V3.1 Human resources	3.26	34	V3.3 Loss of key personnel	2.69
15	V9.2 Price pressures (competition)	3.24	35	V5.4 Customer disruptions	2.67
16	V9.1 Fluctuations in prices	3.24	36	V8.2 Accident in plant	2.59
17	V1.5 Complexity	3.20	37	V7.2 Health pandemic	2.57
18	V2.4 Budget overruns	3.19	38	V3.2 Labor disputes	2.50
19	V1.4 Concentration of capacity	3.13	39	V8.3 Terrorism & sabotage	2.31
20	V4.7 Product quality problem	3.09			

Private Organisations

The vulnerability scores and rankings of the contractors and consultants are presented in Table 4.8 (main factors) and Table 4.9 (sub-factors). The contractors and consultants are seen to be facing vulnerabilities arising from market pressures, management vulnerability, liquidity/credit vulnerability, political/legal pressures and strategic vulnerability. Table 4.9 shows that contractors and consultants are facing market pressures from strong price competition and severe price fluctuation (both ranked in the top ten vulnerability sub-factors) caused by the construction market and economy. As market pressure is external to the supply chain network and beyond the contractors' and consultants' control, important resilience measures must be taken to sustain their place in the market. As in the public organisations, timing of business decisions is ranked as the sub-factor (3.84) with the susceptibility, followed by the high reliance on information flow (3.67) under the main factor of management vulnerability. In terms of liquidity/credit vulnerability, the sub-factor that contributes to the high ranking is financial policies and procedures (3.67). However, contrary to the public organisations, the lack of financial resources (3.06) is rated low by the private organisations, as per Table 4.9. As with the public organisations, environmental factors, supplier/customer disruptions, process vulnerability, and personnel vulnerability are rated as moderate and physical damage disruptions are not an issue.

Table 4.8: Ranking of the Private Organisations' Vulnerability Main Factors

Rank	Main Vulnerability Factors	Factor Label	Average Score	Standard Deviation
1	Market Pressures	V9	3.59	0.78
2	Management Vulnerability	V2	3.44	0.74
3	Liquidity/Credit Vulnerability	V10	3.36	0.76
4	Political/Legal Pressures	V6	3.33	0.66
5	Strategic Vulnerability	V1	3.29	0.46
6	Environmental Factors	V7	3.11	0.63
7	Supplier/Customer Disruptions	V5	2.91	0.64
8	Process Vulnerability	V4	2.88	0.56
9	Personnel Vulnerability	V3	2.79	0.77
10	Physical Damage Disruptions	V8	2.63	0.77

Table 4.9: Ranking of the Private Organisations' Vulnerability Sub-factors

Rank	Vulnerability Sub-factors	Mean	Rank	Vulnerability Sub-factors (cont'd)	Mean
1	V2.2 Timing of business decisions	3.84	21	V10.2 Lack of financial resources	3.06
2	V10.1 Finance policies and procedures	3.67	22	V8.1 Piracy & theft	3.04
3	V2.3 Reliance upon information flow	3.67	23	V4.2 Raw material availability	3.04
4	V1.2 Reliance upon specialty sources	3.63	24	V4.8 Transportation disruption	3.02
5	V9.2 Price pressures	3.61	25	V7.4 Potential safety hazards	3.00
6	V9.1 Fluctuations in prices	3.57	26	V5.2 Supplier capacity	2.98
7	V1.1 Degree of outsourcing	3.47	27	V5.1 Supplier disruptions	2.80
8	V6.2 Political/Regulatory changes	3.35	28	V7.2 Health pandemic	2.78
9	V7.1 Natural disasters	3.33	29	V4.6 Distribution capacity	2.78
10	V5.5 Scale/extent of supply network	3.33	30	V4.5 Production capacity	2.78
11	V7.3 Public Reputation	3.31	31	V4.4 Reliability of equipment	2.78
12	V6.1 Exposure to political disruptions	3.31	32	V5.4 Customer disruptions	2.76
13	V4.1 Unpredictability of demand	3.29	33	V4.7 Product quality problem	2.69
14	V1.4 Concentration of capacity	3.27	34	V3.2 Labor disputes	2.67
15	V1.3 Innovation (competition)	3.20	35	V5.3 Loss of key supplier	2.65
16	V2.1 Inadequate management oversight	3.14	36	V3.3 Loss of key personnel	2.65
17	V1.5 Complexity	3.10	37	V4.3 Utilities availability	2.61
18	V2.4 Budget overruns	3.10	38	V8.2 Accident in plant	2.49
19	V1.6 Visibility of disruption to stakeholders	3.08	39	V8.3 Terrorism & sabotage	2.37
20	V3.1 Human resources	3.06			

Supply Chain Capability Assessment

Public Organisations

Based on the data presented in Table 4.10, the public organisations scored adaptability as their strongest capability factor. This essentially means that the public organisations are able to modify operations in response to disruptions, particularly in areas such as learning from experience through continuous improvement programmes (3.69), adapting new technologies to their operations (3.63), and process improvement by constantly striving to reduce their operation time in project delivery (3.52), all in the top ten capability sub-factors (see Table 4.11). Nevertheless, despite these strengths, the public organisations' ability to seize advantage from disruptions is still weak, based on the reported low ranking of this sub-factor in the adaptability category (ranked 34 from 44 overall sub-factors in Table 4.11). This was followed by security capability, showing that the public organisations have good security defences against deliberate intrusion or attack on their facilities, equipment, digital information and employees. The public organisations also seem to have strong market position, due to their long-term relationships and effective communication with their clients; both scored in the top 10 capability sub-factors. Their strong reputation for quality (ranked 11 of 44 capability sub-factors) is also critical in surviving the threats of the competitive construction market. The public organisations, however, have yet to control a significant share of the market (a bottom 10 capability sub-factor), an area that can be further improved on over time.

At the other end of the spectrum, the public organisations have low capability scores in collaboration, capacity, flexibility, efficiency and financial strength, as shown in Table 4.10. In terms of flexibility, four out of five sub-factors of this construct were ranked in the bottom ten capability sub-factors in Table 4.11. They rated the ability to quickly move orders to alternative suppliers and reallocate jobs between different people or departments as the lowest sub-factor under the flexibility construct (ranked 41 of 44 overall capability sub-factors). The public organisations' finished products or designs are not flexible to change (in the bottom five capability sub-factors), which could be an issue considering the reported high unpredictability of demand shift by clients (a top ten vulnerability sub-factor in Table 4.7). On the other hand, the public organisations greatest strength under the flexibility construct is their access to many alternative suppliers for key inputs (a top 10 capability sub-factor in Table 4.11). Suppliers here are considered as the external organisations that provide the services required for operations, such as contractors, consultants and nominated sub-contractors. However, it was reported that collaboration with their supply chain members is still significantly poor (the weakest main capability factor). In terms of capacity, the public organisations reported to significantly low excess capacity of materials, equipment and personnel to quickly boost output if needed (the lowest capability sub-factor in Table 4.11). Redundant capacity such as backup energy sources and access to alternative facilities (ranked 31 and 33 respectively) are also still poor and need to be improved.

Table 4.10: Ranking of the Public Organisations' Capability Main Factors

Rank	Main Capability Factors	Factor Label	Average Score	Standard Deviation
1	Adaptability	C5	3.52	0.49
2	Security	C11	3.47	0.58
3	Market Position	C10	3.44	0.58
4	Dispersion	C8	3.43	0.52
5	Visibility	C4	3.42	0.69
6	Recovery	C7	3.42	0.59
7	Anticipation	C6	3.38	0.56
8	Financial Strength	C12	3.36	0.55
9	Efficiency	C3	3.27	0.62
10	Flexibility	C1	3.20	0.57
11	Capacity	C2	3.14	0.57
12	Collaboration	C9	3.12	0.55

Table 4.11: Ranking of the Public Organisations' Capability Sub-factors

Rank	Capability Sub-factors	Mean	Rank	Capability Sub-factors (cont'd)	Mean
1	C5.4 Learning from experience	3.69	23	C12.3 Financial reserves & liquidity	3.33
2	C5.3 Alternative technology development	3.63	24	C11.1 Access restriction	3.33
3	C11.2 Employee involvement in security	3.61	25	C4.2 Products, Assets, People visibility	3.31
4	C8.4 Geographic dispersion of markets	3.59	26	C3.3 Product variability reduction	3.31
5	C4.1 Business intelligence gathering	3.57	27	C12.2 Portfolio diversification	3.31
6	C10.3 Customer relationships	3.54	28	C7.1 Crisis management	3.31
7	C5.1 Process Improvement	3.52	29	C8.1 Distributed decision-making	3.30
8	C10.4 Customer communications	3.52	30	C6.5 Recognition of opportunities	3.30
9	C7.3 Consequence mitigation	3.50	31	C2.3 Backup energy sources	3.28
10	C1.2 Multiple sources	3.48	32	C3.1 Labor productivity	3.26
11	C10.2 Brand equity	3.48	33	C2.2 Redundancy (assets, labor)	3.26
12	C6.3 Deviation, Near-miss analysis	3.48	34	C5.2 Seizing advantage from disruptions	3.24
13	C6.4 Contingency planning	3.46	35	C1.5 Fast re-routing of requirements	3.22
14	C6.1 Monitoring early warning signals	3.46	36	C10.1 Market share	3.22
15	C11.3Cyber-security	3.46	37	C6.2 Forecasting	3.20
16	C12.1 Insurance	3.44	38	C1.3 Alternate distribution channels	3.20
17	C7.2 Resource mobilization	3.44	39	C3.2 Asset utilization	3.09
18	C8.3 Decentralization of key resources	3.43	40	C1.1 Product commonality	3.07
19	C8.2 Distributed capacity & assets	3.41	41	C1.4 Multi-sourcing	3.02
20	C3.4 Failure prevention	3.41	42	C9.3 Risk sharing with partners	3.00
21	C9.1 Communications - internal, external	3.39	43	C9.2 Postponement of orders	2.98
22	C4.3 Collaborative information exchange	3.37	44	C2.1 Reserve capacity	2.87

Private Organisations

Similarly, the contractors and consultants reported adaptability as their strongest capability factor, as presented in Table 4.12. The high adaptability scores of both the public and private organisations indicate that they are able to adapt to disruptive events, perhaps explaining why so many respondents reported that they dealt with disruptions as part of business-as-usual (see Figure 4.3). As with the public organisations, elements of the adaptability capability such as process improvements, learning from experience and alternative technology development are all of high strength in the private organisations, scoring in the top ten capability sub-factors (Table 4.13). However, unlike the public organisations, the private organisations also excel at seizing advantage from disruptions in public projects (ranked 12 of 44 capability sub-factors). They also have a higher visibility score (3.80) than the public organisations (3.42), which includes the ability to gather business intelligence information on the future trends of the industry (ranked 4), the ability to consistently exchange information with their supply chain members (ranked 5) and their awareness of the current status of their resources and operations (ranked 13) in delivering public projects. Financial strength is also a strong capability of these private organisations, and is led by insurance coverage (the second strongest capability sub-factor) followed by financial reserves (ranked 14 of 44 sub-factors in Table 4.13). The diversification of their financial portfolio, however, is still weak and need improvement (ranked 28) to mitigate vulnerabilities such as unpredictability of demand by client (ranked 13 of 41 vulnerability sub-factors in Table 4.9) and threats from competitive innovations (ranked 16 of 41 vulnerability sub-factors).

However, despite having high visibility of their operations and good financial strength, collaboration among supply chain members is relatively poor, as reflected through the low collaboration score of respondents from both the public organisations and the contractors and consultants (see Tables 4.11 and 4.12). This is a significant issue as collaboration among supply chain members is important in handling disruptions in public projects. Based on the data in Table 4.13 below, like the public organisations, the contractors and consultants were found to have low ability to postpone orders when their operation is hampered by disruptions (2.98 average score) and low risk sharing with partners (3.20) (both in the bottom three of the capability sub-factors). The contractors' and consultants' level of flexibility is also poor, with four out of the five elements of the flexibility construct ranked in the bottom ten of the overall capability sub-factors. The survey shows that although these private organisations have several alternative suppliers (ranked 18 of 44 capability sub-factors), their ability to quickly relocate orders or reallocate jobs between different people when necessary is still weak (ranked 34 of 44 capability sub-factors). This could also contribute to the low scoring of their collaboration capability factor in Table 4.12. This might be problematic considering the high unpredictability of demand faced by the contractors and consultants (ranked 13 of 41 vulnerability sub-factors in Table 4.9) and the market pressures (the highest vulnerability factor in Table 4.8). The contractors' and consultants' ability to quickly increase capacity of storage and distribution (ranked 37 of 44 capability sub-factors in Table 4.13) and quickly re-route materials or products when necessary (ranked 41) are also areas that need to be improved under the flexibility construct. As with the public organisations, the private organisations' finished products are also inflexible to change (39 of 44 sub-factors). The contractors and consultants also have low scores in their capacity capability factor, as shown in Table 4.12. Factors such as multiple redundant resources (i.e access to alternative facilities and equipment for backup) and reserved capacity of materials, equipment and labour, are areas of concern, ranking in the bottom ten of the overall 44 capability sub-factors in Table 4.13. Backup utilities such as electricity and water for operation, on the other hand, is a moderate capability (ranked 22).

Table 4.12: Ranking of the Private Organisations' Capability Main Factors

Rank	Main Capability Factors	Factor Label	Average Score	Standard Deviation
1	Adaptability	C5	3.84	0.58
2	Visibility	C4	3.80	0.60
3	Financial Strength	C12	3.72	0.52
4	Security	C11	3.62	0.51
5	Efficiency	C3	3.61	0.64
6	Market Position	C10	3.60	0.50
7	Dispersion	C8	3.55	0.57
8	Anticipation	C6	3.54	0.52
9	Recovery	C7	3.54	0.56
10	Capacity	C2	3.46	0.57
11	Flexibility	C1	3.43	0.62
12	Collaboration	C9	3.27	0.53

Table 4.13: Ranking of the Private Organisations' Capability Sub-factors

Rank	Capability Sub-Factors	Mean	Rank	Capability Sub-Factors (cont'd)	Mean
1	C5.1 Process Improvement	3.98	23	C8.2 Distributed capacity & assets	3.59
2	C12.1 Insurance	3.96	24	C9.1 Communications	3.57
3	C5.4 Learning from experience	3.86	25	C3.1 Labor productivity	3.57
4	C4.1 Business intelligence gathering	3.86	26	C11.3 Cyber-security	3.55
5	C4.3 Collaborative information exchange	3.80	27	C11.1 Access restriction	3.53
6	C5.3 Alternative technology development	3.80	28	C12.2 Portfolio diversification	3.51
7	C11.2 Employee involvement in security	3.78	29	C8.1 Distributed decision-making	3.51
8	C10.4 Customer communications	3.76	30	C8.4 Geographic dispersion of markets	3.51
9	C7.3 Consequence mitigation	3.76	31	C3.2 Asset utilization	3.49
10	C10.3 Customer relationships	3.75	32	C6.4 Contingency planning	3.49
11	C3.3 Product variability reduction	3.75	33	C7.2 Resource mobilization	3.47
12	C5.2 Seizing advantage from disruptions	3.73	34	C1.4 Multi-sourcing	3.47
13	C4.2 Products, Assets, People visibility	3.73	35	C2.2 Redundancy (assets, labor)	3.43
14	C12.3 Financial reserves & liquidity	3.69	36	C7.1 Crisis management	3.37
15	C10.2 Brand equity	3.69	37	C1.3 Alternate distribution channels	3.37
16	C6.5 Recognition of opportunities	3.67	38	C2.1 Reserve capacity	3.35
17	C3.4 Failure prevention	3.65	39	C1.1 Product commonality	3.35
18	C1.2 Multiple sources	3.61	40	C6.2 Forecasting	3.33
19	C6.3 Deviation, Near-miss analysis	3.61	41	C1.5 Fast re-routing of requirements	3.33
20	C8.3 Decentralization of key resources	3.59	42	C9.3 Risk sharing with partners	3.20
21	C6.1 Monitoring early warning signals	3.59	43	C10.1 Market share	3.20
22	C2.3 Backup energy sources	3.59	44	C9.2 Postponement of orders	3.06

Comparisons of vulnerability and capability scores between the public and private organisations

Further detailed comparative statistical tests (as presented in Figure 3.6 in Section 3.6) were conducted between the public and private organisations' vulnerability and capability scores, as shown in Tables 4.14 and 4.15 respectively. The Mann-Whitney U test reveals that the public organisations are significantly more vulnerable to political or legal pressures (mean rank = 59.81) than are the private organisations (mean rank = 45.79): U = 1009.5, z = -2.43, p = .015, r = .24. It can also be observed that the public organisations are statistically significantly more vulnerable to the sub-factor exposure to political disruptions (mean rank = 60.29) than are the private organisations (mean rank = 45.28), as per Table 4.14. Nevertheless, no significant differences in score between the public and private organisations were identified for the vulnerability sub-factor changes in government regulations (U = 1139.0, z = -1.67, p = .094, r

= .16) under the political or legal pressures construct, suggesting that the contractors and consultants are also to some degree affected by changes in government regulations. Further assessment of other vulnerability sub-factors shows that the public organisations are also statistically significantly more vulnerable to the sub-factor visibility of disruption to stakeholders (mean rank = 61.13) and product quality problem (59.64) compared to the private organisations (44.39 and 45.97 respectively).

Table 4.14: Results of Vulnerability Factors Perceived Differently between Public and Private Organisations using Mann-Whitney U Test

	Mean Rank		Test Statistics		
Vulnerability Factors	Public Organisations	Private Organisations (Contractors and Consultants)	Mann-Whitney U	Z	*P*-value
<u>Main Factors</u>					
Political/Legal Pressures	59.81	45.79	1009.50	-2.425	0.015
Market Pressures	46.68	59.70	1035.50	-2.275	0.023
<u>Sub-Factors</u>					
Visibility of disruption to stakeholders	61.13	44.39	938.00	-2.992	0.003
Product quality problem	59.64	45.97	1018.50	-2.422	0.015
Exposure to political disruptions	60.29	45.28	983.50	-2.692	0.007
Natural disasters	46.32	60.07	1016.50	-2.468	0.014
Price pressures	47.17	59.18	1062.00	-2.165	0.030

On the other hand, the private organisations are significantly more vulnerable to market pressures (mean rank = 59.70) than are the public organisations (46.68): U = 1035.5, z = -2.28, p = .023, r = .22. It can be observed from Table 4.14 that under this construct, the private organisations are significantly more susceptible to the sub-factor price pressures (59.18) than the private organisations (47.17). Natural disasters, a sub-factor of environmental factors, were also perceived as a critical vulnerability by the private organisations (mean rank = 60.07), compared to the public organisations (mean rank = 46.32).

In terms of the capability factors, Table 4.15 shows that there are statistically significant differences in scores between the public and private organisations in five of the overall 12 main capability factors. The Mann-Whitney U test reveals that the private organisations have significantly higher capability scores for capacity (mean rank = 61.90), which includes greater strengths in the areas of reserve capacity (62.16) and backup energy sources (59.03) compared to the public organisations (44.35 and 47.31 respectively). On the other hand, Table 4.15

reveals that the public organisations have a statistically significantly lower overall efficiency level (mean rank = 45.21) than the contractors and consultants (61.25). This includes areas such as labour productivity (47.66), asset utilisation (46.33), and product variability reduction (45.68), indicating inconsistency in the quality of the public organisations' operation. The public organisations also have a significantly lower level of financial strength (mean rank = 45.07) than the private organisations (61.39), which includes significant low scores in the areas of insurance and financial reserves (43.07 and 46.17 respectively) under this construct.

Table 4.15: Results of Capability Factors Perceived Differently between Public and Private Organisations using Mann-Whitney U Test

	Mean Rank		Test Statistics		
Capability Factors	Public Organisations	Private Organisations (Contractors and Consultants)	Mann-Whitney U	Z	*P*-value
Main Factors					
Capacity of Resources	44.59	61.90	923.00	-2.981	0.003
Efficiency of Operation	45.21	61.25	956.50	-2.738	0.006
Visibility of Supply Chain Operation	45.20	61.25	956.00	-2.775	0.006
Adaptability in Responding to Challenges	45.70	60.73	983.00	-2.574	0.010
Financial Strength	45.07	61.39	949.00	-2.818	0.005
Sub-Factors					
Reserve capacity	44.35	62.16	910.00	-3.191	0.001
Backup energy sources/communications	47.31	59.03	1069.50	-2.165	0.030
Labor productivity	47.66	58.66	1088.50	-1.999	0.046
Asset utilisation	46.33	60.06	1017.00	-2.473	0.013
Product variability reduction	45.68	60.75	981.50	-2.785	0.005
Business intelligence gathering	47.34	58.99	1071.50	-2.228	0.026
Products, assets, people visibility	46.65	59.73	1034.00	-2.381	0.017
Collaborative information exchange	46.40	59.99	1020.50	-2.530	0.011
Process improvement	44.72	61.76	930.00	-3.363	0.001
Seizing advantage from disruptions	45.00	61.47	945.00	-3.019	0.003
Recognition of opportunities	46.42	59.97	1021.50	-2.513	0.012
Insurance	43.07	63.51	841.00	-3.947	0.000
Financial reserves & liquidity	46.17	60.24	1008.00	-2.632	0.008

The Mann-Whitney U test also reveals (Table 4.15) that the private organisations have a statistically significantly higher capability score in the visibility of their supply chain operation (mean rank = 61.25) than the public organisations (45.20). Evidently, all sub-factors under this construct were identified by the private organisations to be strengths, with significantly higher scores in their business intelligence gathering (mean rank = 58.99), products, assets and people visibility (59.73) and collaborative information exchange (59.99), as per Table 4.15. The private organisations are also highly adaptable in terms of continuously improving their process (mean rank = 61.76) and seizing advantage from disruptions (61.47) compared to the public organisations (44.72 and 45.00 respectively). It is therefore not surprising that they also had a significantly higher score in the capability sub-factor of recognition of opportunities (mean rank = 59.97) than the public organisations (46.42), as shown in Table 4.15.

Level of Agreement on the Vulnerability and Capability Factors

Spearman's coefficient of rank correlation was used to test the level of agreement or disagreement among the different groups of respondents (the public organisations, consultants and contractors) on the vulnerability and capability factors, as discussed in Section 3.5.1.3. Table 4.16 presents the results of the Spearman rank correlations and the significance level between the different pairs of groups of respondents. The results show a significantly high level of agreement between the consultants and contractors in ranking the vulnerability and capability factors, approximately 82% and 89% respectively. Indeed, it would be expected that the consultants and contractors have similar views on the ranking of the vulnerability and capability factors as both parties represent the private organisations. The public organisations also seem to have relatively good agreement with the consultants and contractors in ranking the vulnerability factors, approximately 78% with the consultants and 77% with the contractors. As these parties are within the same public sector supply chain, it is reasonable to have positive agreement on the supply chain vulnerability factors.

Table 4.16: Spearman Rank Correlation

Groups of Respondents	Vulnerability		Capability	
	Spearman rank correlation coefficient	Significance level	Spearman rank correlation coefficient	Significance level
Consultants - Contractors	0.818	0.01	0.891	0.01
Public Organisations - Consultants	0.782	0.01	0.595	0.05
Public Organisations - Contractors	0.773	0.01	0.670	0.05

However, there seem to be conflicting views on the capability factors, with the lowest degree of agreement between the public organisations and consultants in ranking the capability factors, approximately 59%. Similarly, contrary opinions on the capability factors could also be observed in Table 4.16 between the public organisations and contractors, approximately 67%. The results therefore imply that there are opposing views on the level of capability between the public and private organisations. Certainly, the statistical comparison test between the public and private organisations' capability scores (Table 4.15) show significant differences in the scores of five of the main capability factors and 13 of the capability sub-factors between the two groups of respondents.

Comparisons of vulnerability and capability scores between the organisations with explicit disruption management strategies and organisations without disruption management strategies

Next, the vulnerability and capability scores were tested against those organisations that have explicit disruption management strategies and those without. The respondents were grouped by their answers to their current disruption management approach (Figure 4.5): those who indicated they have none of the abovementioned strategies were grouped as being without explicit disruption management strategies, and the remaining respondents as organisations with explicit disruption management strategies. The Mann-Whitney U test in Table 4.17 reveals that the vulnerability and capability scores were found to be significantly different at the 95% confidence level between the two groups.

Table 4.17 shows that the organisations with no explicit disruption management strategies were vulnerable to more of the main factors assessed in the survey (personnel vulnerability, process vulnerability, supplier or customer disruptions) than those adopting specific disruption management strategies. The latter had the higher capability scores in areas such as labour productivity (mean rank = 57.26), contingency planning (57.39), distributed decision-making (57.30) and cyber-security (57.09). The results suggest that having a formal disruption management approach (i.e. risk management, disaster management, crisis management) could help to reduce the level of susceptibility to the critical vulnerability factors, and improve organisations' capabilities in responding to disruptions in construction projects.

Table 4.17: Results of Vulnerability and Capability Factors Perceived Differently between Organisations with Explicit Disruption Management Strategies and Organisations without Disruption Management Strategies using Mann-Whitney U Test

	Mean Rank		Test Statistics		
Vulnerability and Capability Factors	Organisations with disruption management strategies	Organisations without disruption management strategies	Mann-Whitney U	Z	*P*-value
Vulnerability Factors					
Personnel Vulnerability	48.64	62.52	874.00	-2.193	0.028
Process Vulnerability	48.90	61.94	893.00	-2.041	0.041
Supplier/Customer Disruptions	47.97	63.97	826.00	-2.514	0.012
Technology Vulnerability	48.88	61.98	891.50	-2.104	0.035
Political/Legal Pressures	48.99	61.74	899.50	-2.050	0.040
Environmental Factors	47.01	66.06	757.00	-3.000	0.003
Physical Damage Disruptions	48.07	63.76	833.00	-2.487	0.013
Liquidity/Credit Vulnerability	48.74	62.29	881.50	-2.212	0.027
Capability Factors					
Labor productivity	57.26	43.70	881.00	-2.290	0.022
Contingency planning	57.39	43.42	872.00	-2.419	0.016
Distributed decision-making	57.30	43.62	878.50	-2.292	0.022
Cyber-security	57.09	44.08	893.50	-2.250	0.024

4.5 Importance of Vulnerability and Capability Factors

Importance of Vulnerability Factors

Figures 4.7 and 4.8 present the importance of vulnerability factors as perceived by the public and private organisations respectively. From Figure 4.7, the public organisations are found to consider management vulnerability and strategic vulnerability as critical vulnerability factors that should be mitigated, possibly because they are highly susceptible to these two factors (ranked 2 and 4 respectively out of the 10 factors in Table 4.6). However, despite their low vulnerability scores for process vulnerabilit' and personnel vulnerability (ranked 6 and 9 respectively), they perceived these factors as highly important, and to be improved in the public sector supply chain, as depicted in Figure 4.7. On the other hand, political or legal pressures and liquidity or credit vulnerability were perceived to be of moderate importance to the public organisations, albeit both are critical (top three vulnerability factors in Table 4.6). Lastly, environmental factors, physical damage disruptions and market pressures were of minor importance to the public organisations, possibly because they were perceived as external factors beyond the public organisations' control.

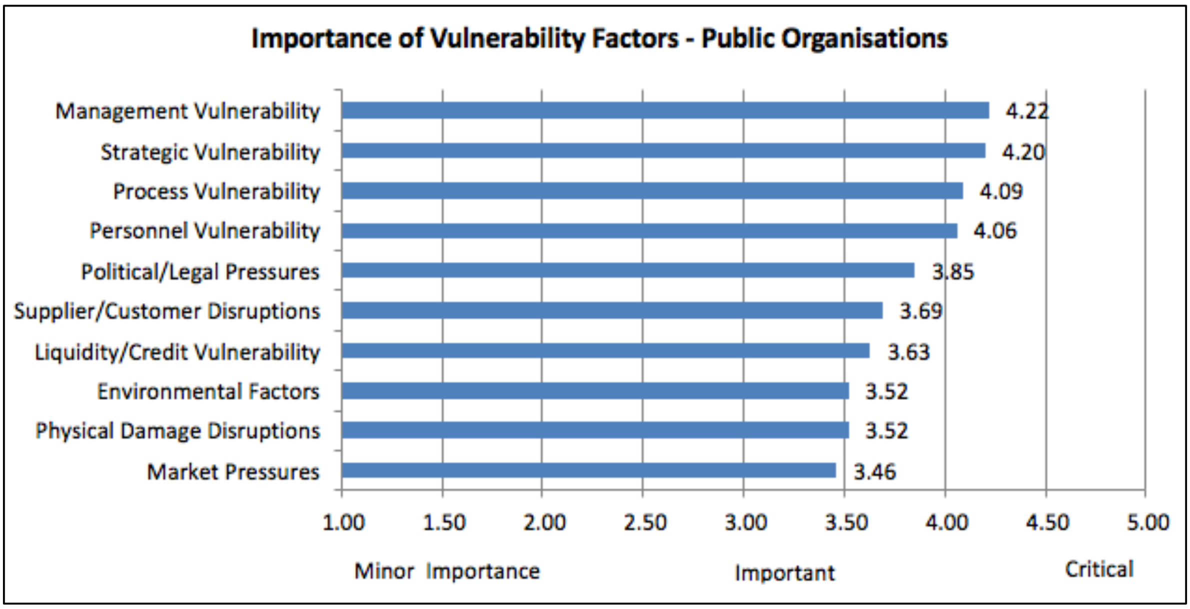

Figure 4.7: Importance of vulnerabilities by the public organisations

As did the public organisations, the private organisations prioritised management vulnerability and strategic vulnerability as the top important factors to be improved in the supply chain (see Figure 4.8). However, unlike to the public organisations, they also prioritised supplier or customer disruptions as one of the top factors to be mitigated, despite their low vulnerability to this factor indicated in Table 4.8. Understandably, being commercially driven, the private organisations place great importance on their customers and supply chain members in order to maintain their position in the market. On the other hand, the public organisations perceived market pressures and political/legal pressures to be of low importance in spite of being highly vulnerable to such external pressures (both in the top five vulnerability factors in Table 4.8). Similarly, liquidity or credit vulnerbility is of moderate importance to the private organisations even though it is one of the top three critical factors to which they are highly vulnerable (see Table 4.8).

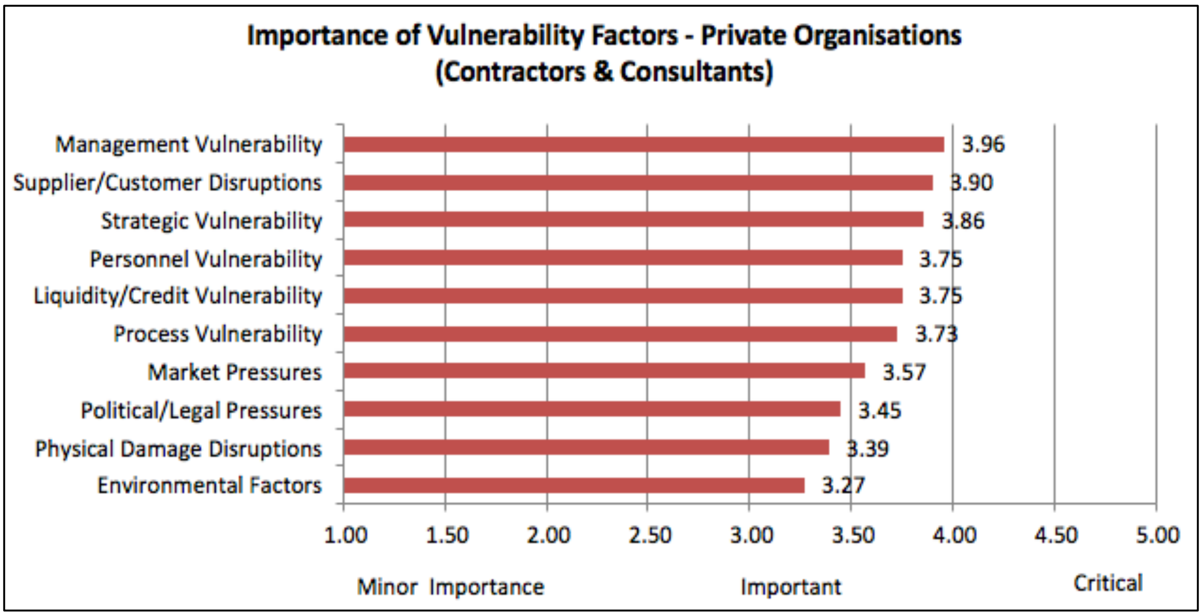

Figure 4.8: Importance of vulnerabilities by the private organisations

On the other hand, although the private organisations are not highly vulnerable under process vulnerability and personnel vulnerability (ranked 8 and 9 out of 10 factors in Table 4.8), they placed moderate and high importance on these factors in Figure 4.8. Overall, it can be observed from Figure 4.8 that, like the public organisations, the private organisations give higher priority to internal factors within their organisations and the supply chain network than to external factors such as physical damage disruptions and environmental factors.

Importance of Capability Factors

The public and private organisations' perceived importance of capability factors are depicted in Figures 4.9 and 4.10 below. The public organisations gave higher priority to efficiency, financial strength, recovery and anticipation as the important factors on which to build their resilience to disruptions. Understandably, they had received moderate scores on these factors (see Table 4.10) and recognised the importance of these capabilities in mitigating their critical areas of vulnerability such as political pressure, inadequate management and financial vulnerability (see Table 4.6). Meanwhile, collaboration, flexibility and capacity were identified as being of moderate importance (Figure 4.9) even though these factors were ranked as the bottom three capability factors of the public organisations (see Table 4.10). At the opposite end, five low importance capability factors perceived by the public organisations (Figure 4.9) (security, market position, dispersion, visibility and adaptability) had been their top strengths (see Table 4.10). The results therefore suggest that the public organisations might have developed these capabilities and hence given them lower priority.

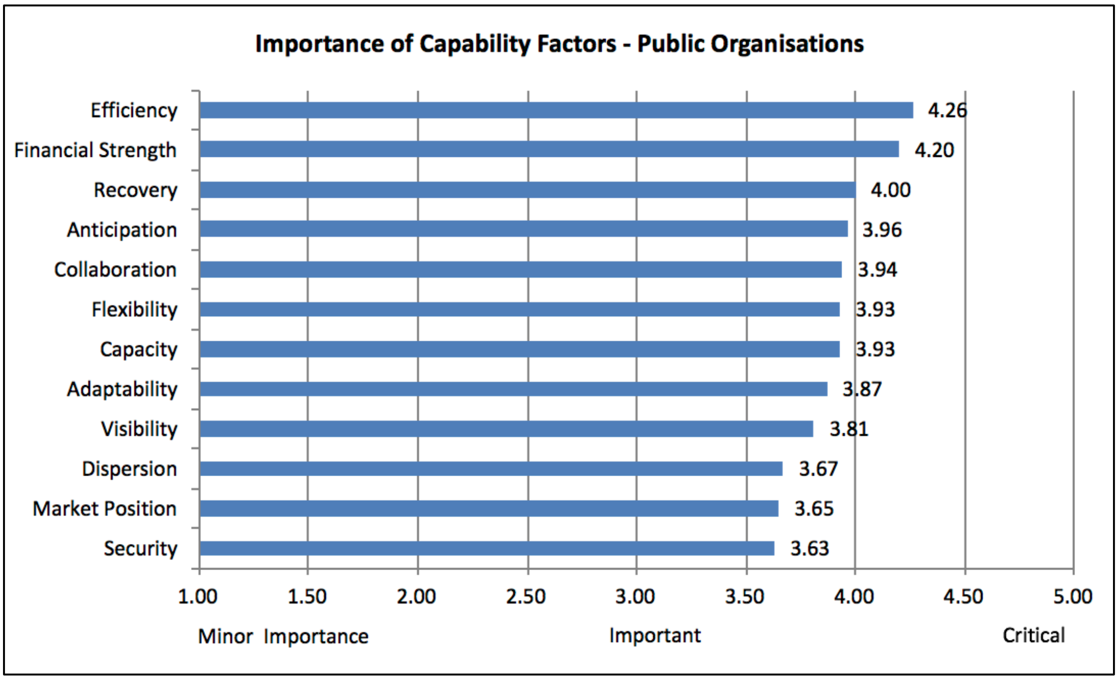

Figure 4.9: Importance of capabilities by the public organisations

Looking at the private organisations' results in Figure 4.10, although they were strong in financial strength and efficiency (top five capabilities in Table 4.12), these factors were perceived as critically important factors to be improved in building resilience to disruption. It can therefore be seen that, despite their strength in these areas, significant financial reserves and high efficiency of operations are important and need continuous improvement in responding to disruptive events. However, one could also argue that the private organisations might have overutilised their resources in improving their financial strength and efficiency instead of mobilising their resources for other capability factors in which they were still weak. This is followed by the high importance of flexibility and capacity factors, which is reasonable as the private organisations had received low scores in both of these areas (bottom three capability factors in Table 4.12).

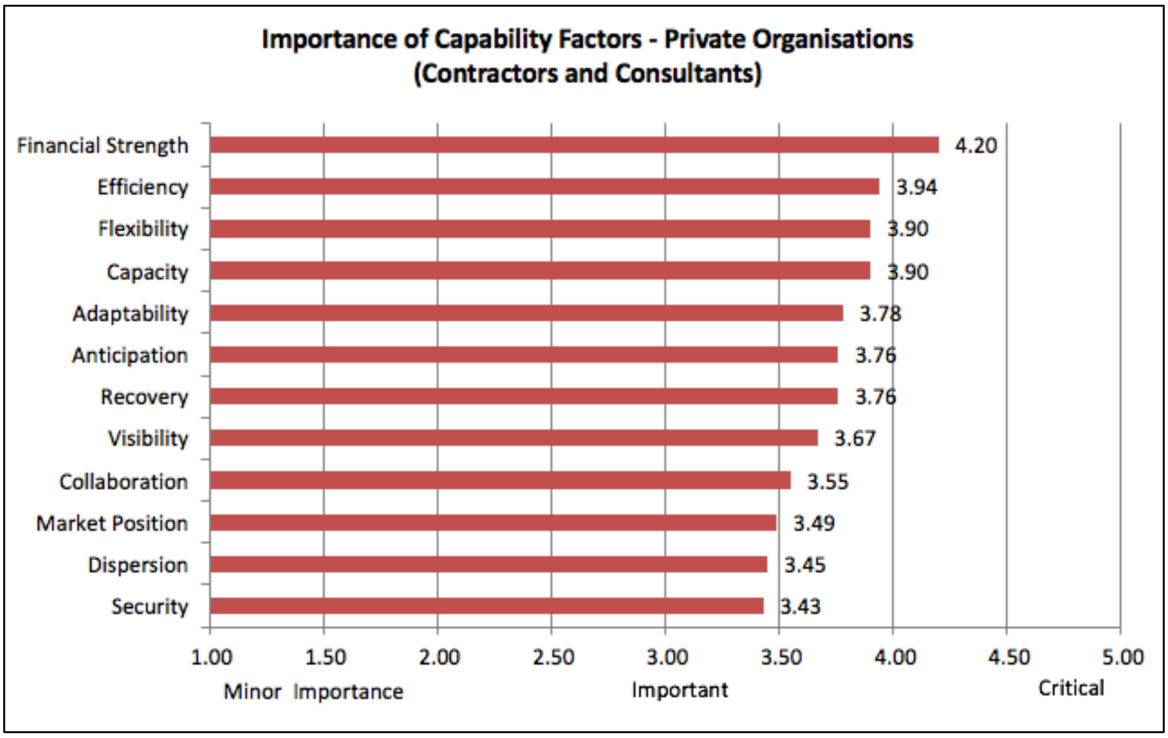

Figure 4.10: Importance of capabilities by the private organisations

On the other hand, the private organisations placed low priority on improving market position (Figure 4.10), which is of concern as they face strong market pressures (see Table 4.8) and have moderate strength in this factor (Table 4.12). Collaboration was also given moderate importance although it was the lowest capability factor of the private organisations reported in the earlier Table 4.12. Lastly, as in the public organisations, security was perceived as the least important factor.

Prioritisation of Vulnerability and Capability Factors

A scatterplot was computed from the results of the vulnerability scores (see Tables 4.6 and 4.8) and the importance of vulnerability (Figures 4.7 and 4.8) of the public and private organisations, as depicted in Figure 4.11. The scatterplot is divided into four quadrants: high vulnerability but low importance factors, high vulnerability and high importance factors, low vulnerability and low importance factors, and lastly, low vulnerability but high importance factors. It can be observed from Figure 4.11 that three of the private organisations' vulnerability factors (political or legal pressure, strategic vulnerability, management vulnerability) fell within the high vulnerability and high importance quadrant while the remaining three (personnel vulnerability, process vulnerability, supplier or customer disruptions) lie within the low vulnerability and high importance quadrant. Similarly, the private organisations have the same factors grouped within the high vulnerability and high importance quadrant as the public organisations, although 'environmental factors' also fell within the high vulnerability and high importance quadrant. Overall, the vulnerability factors that lie within the quadrant of high vulnerability and high importance in Figure 4.11 are identified as the critical vulnerabilities that need to be mitigated by both public and private organisations in the public sector supply chain to build resilience to disruptions. However, this does not mean that the low vulnerability factors that were given high importance should be neglected; the scatterplot in Figure 4.11 should be treated as a guide for the public and private organisations to prioritise spending on those vulnerability areas which they want their organisations or supply chain members to alleviate.

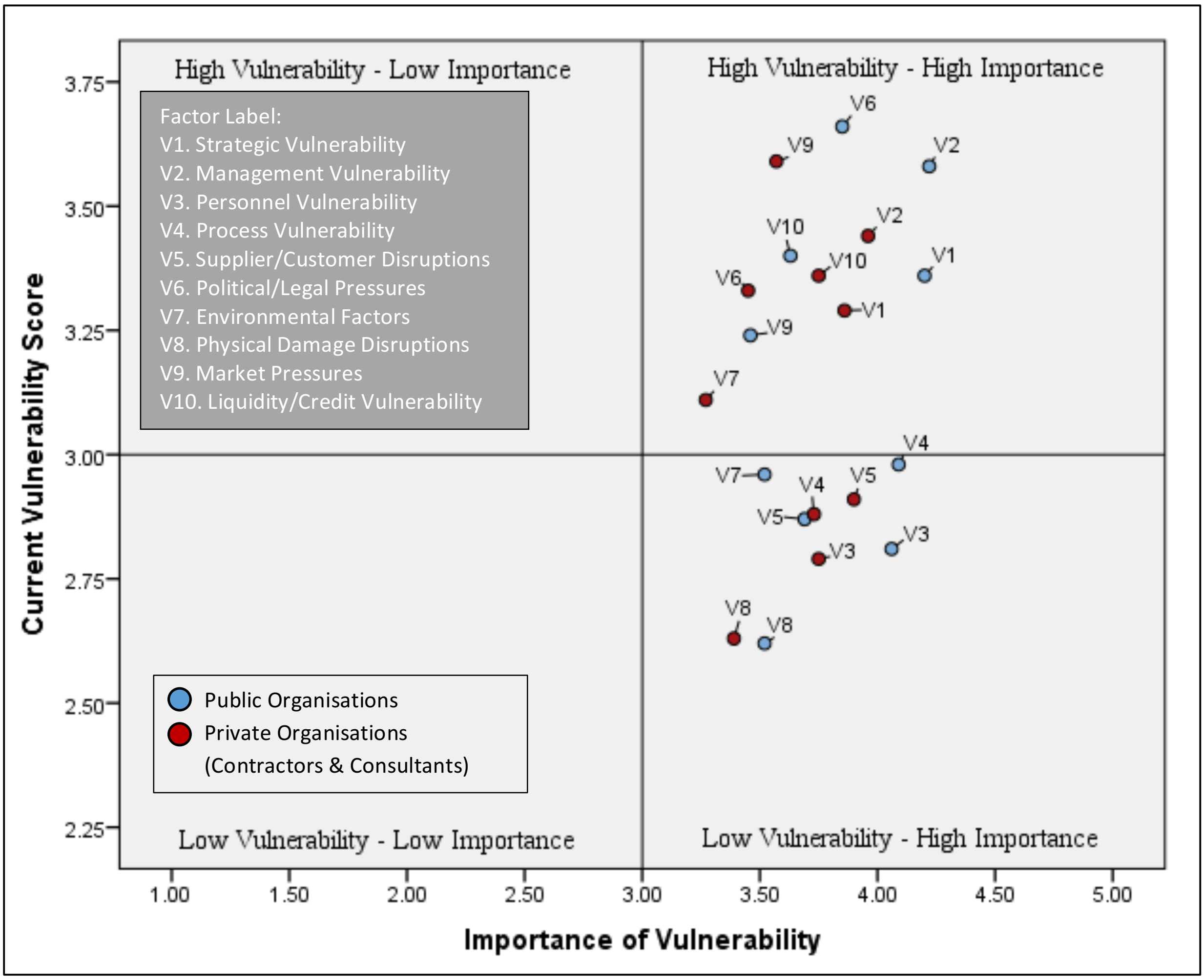

Figure 4.11: Critical vulnerability factors

The scatterplot in Figure 4.12 presents the prioritisation of capability factors based on the results of the capability scores (see Tables 4.10 and 4.12) and importance of capability (Figures 4.9 and 4.10) of the public and private organisations. In this case, the capability factors that lie within the quadrant of low capability but high importance are identified as the critical capabilities that need to be improved to mitigate their vulnerabilities and build resilience to disruptions. The gap between the public and private organisations' levels of strength can be clearly observed in the scatterplot. In this case, Figure 4.12 shows that the majority of the public organisations' capability factors lie within the low capability and high importance quadrant, only 'adaptability' and 'security' fell under the high capability and high importance quadrant.

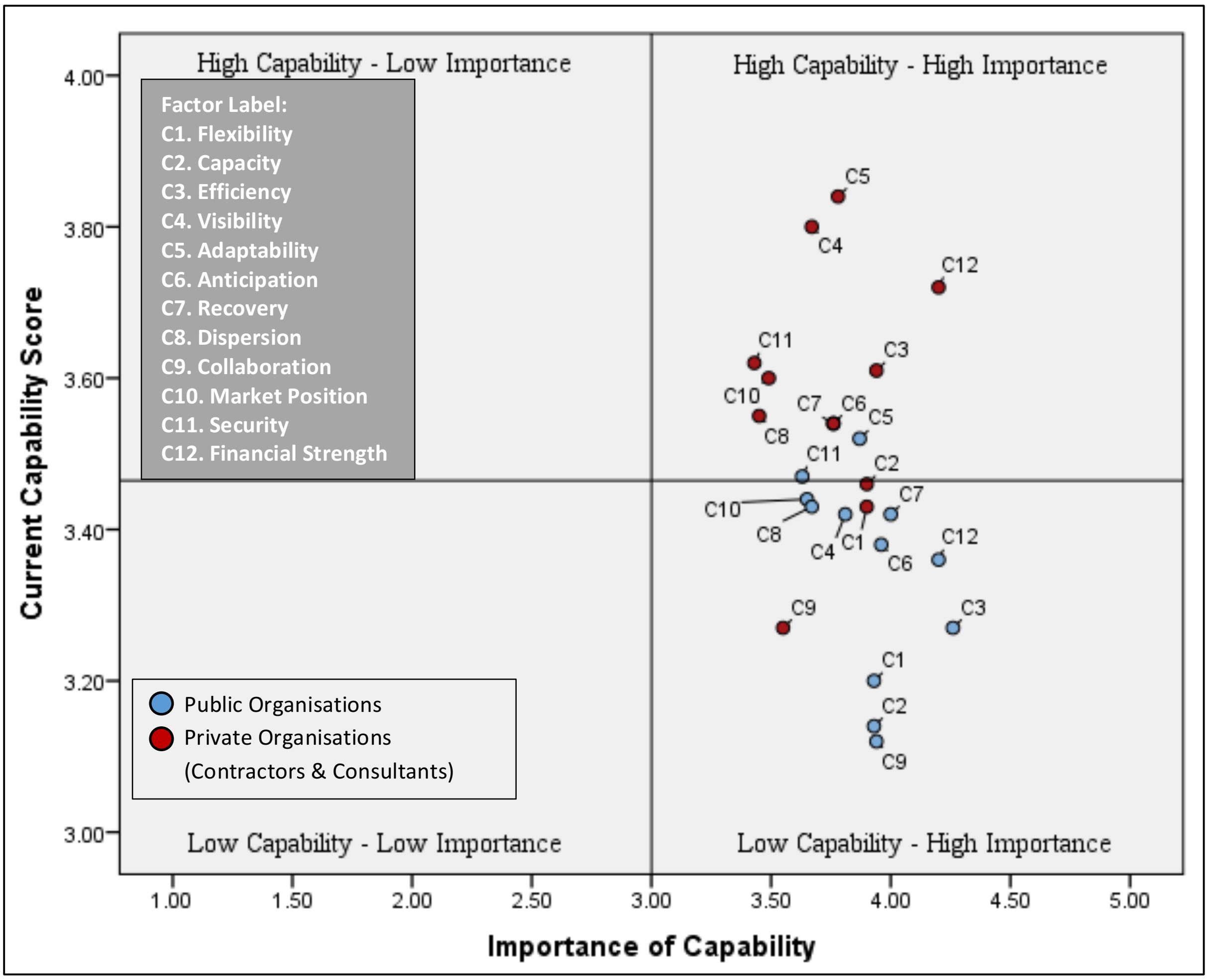

Figure 4.12: Prioritisation of capability factors

In contrast, the majority of the private organisations' capability factors lie within the high capability and high importance quadrant, and only three capabilities (flexibility, capacity and collaboration) under the low capability and high importance quadrant. This shows that although the public organisations are highly adaptable and have strong security measures, they still need to improve most areas of the capability factors in order to reduce their vulnerabilities identified in Table 4.6 and be on a par with their supply chain members' (i.e. private organisations') capability level. This includes improving their strengths in factors such as finance, collaboration and capacity. On the other hand, although the private organisations have high strengths in most of the capability factors, they might be eroding profits by investing in areas of high capabilities that are moderately important such as visibility and adaptability. Overall, the scatterplot in Figure 4.12 allows the public and private organisations to prioritise spending their resources on the capabilities that they want their organisations or supply chain members to improve in order to build their resilience to disruptions in public projects.

4.6 Correlation Analysis

The next step of the analysis is the identification of critical linkages between the vulnerability and capability factors through correlation analysis (n=105). As the data involves slightly skewed distributions, the non-parametric correlation analysis of Spearman rho was computed to identify statistically significant correlations ($p < 0.01$, $p < 0.05$ and $p < 0.10$) between the vulnerability and capability scores, as presented in Table 4.18. Some of the vulnerability factors listed in this table positively correlate with capability factors, that is low vulnerabilities are matched with low capabilities and high vulnerabilities with high capabilities. For instance, respondents that face severe threats from environmental factors might have developed strong capabilities in developing the necessary recovery measures, hence employing a well-balanced resilience in this area. On the other hand, negative correlations exist when high vulnerabilities are matched with low capabilities and vice versa. For instance, respondents might have low levels of capacity to mobilise resources, causing them to be highly vulnerable to any political or regulatory changes. Both significant positive and negative correlations are therefore taken into account in this study as the main purpose of the correlation analysis is to identify significant relationships that exist between the vulnerability and capability factors regardless of the direction of the relationship. The critical linkages, however, were subject to further validation by respondents through the subsequent semi-structured interviews.

Table 4.18: Critical linkages of public sector supply chain vulnerability and capability factors

Vulnerability Factors	Linked Capability Factors
V1.Strategic Vulnerability	*No specific linkages*
V2.Management Vulnerability	C1.Flexibility** C3.Efficiency*** C10.Market Position*
V3.Personnel Vulnerability	C3.Efficiency*
V4.Process Vulnerability	C3.Efficiency**
V5.Supplier/Customer Disruptions	*No specific linkages*
V6.Political/Legal Pressures	C2.Capacity** C3.Efficiency* C11.Security*
V7.Environmental Factors	C2.Capacity** C4.Visibility*** C5.Adaptability*** C7.Recovery* C8. Dispersion* C12.Financial Strength*
V8.Physical Damage Disruptions	*No specific linkages*
V9.Market Pressures	C2.Capacity** C12.Financial Strength***
V10.Liquidity/Credit Vulnerability	C3.Efficiency**

*** Correlation is significant at the 0.01 level (2-tailed)
** Correlation is significant at the 0.05 level (2-tailed)
* Correlation is significant at the 0.10 level (2-tailed)

The overall linkages identified in the Table 4.18 are also presented in the supply chain vulnerability and capability matrix for further validation, as depicted in Figure 4.13.

<u>Public Sector Supply Chain Vulnerability and Capability Matrix</u>

	V1.Strategic Vulnerability	V2.Management Vulnerability	V3.Personnel Vulnerability	V4.Process Vulnerability	V5.Supplier/ Customer Disruptions	V6.Political/ Legal Pressures	V7.Environmental Factors	V8.Physical Damage Disruptions	V9.Market Pressures	V10.Liquidity/ Credit Vulnerability
C1.Flexibility		x								
C2.Capacity						x	x		x	
C3.Efficiency		x	x	x		x				x
C4.Visibility							x			
C5.Adaptability							x			
C6.Anticipation										
C7.Recovery							x			
C8.Dispersion							x			
C9.Collaboration										
C10.Market Position		x								
C11.Security						x				
C12.Financial Strength							x		x	

Figure 4.13: Supply chain vulnerability and capability matrix

4.7 Summary

This chapter has presented the findings from the questionnaire survey based on the total 105 respondents from the public and private organisations. They include the respondents' general profiles, the perceived frequent disruptive events in public projects and their critical impacts, the management approach to current disruptions adopted by the respondents, and finally, the main assessment of the supply chain's vulnerability and capability. The chapter also compared the public and private organisations' critical vulnerability and capability factors through the Mann-Whitney U Test, and the level of agreement between the public organisations, contractors and consultants in rating these factors. Finally, critical linkages between the vulnerability and capability factors were presented through correlation analysis.

The key findings from this chapter will be discussed in further detail in Chapter 6. The results of the survey will be triangulated with the findings identified in the interviews in the following Chapter 5. Overall, this chapter fulfilled part of Objective 3 (see Section 1.4) of the study, in analysing the emergent vulnerability and capability factors of the public sector supply chain in coping with supply chain disruptions. The results will help the researcher to achieve the aim of developing the resilience response framework to improve the public sector supply chain's resilience to disruptions in public projects.

CHAPTER 5

DATA ANALYSIS OF INTERVIEWS

5.1 Introduction

As part of Phase III of the research (see Figure 3.9), this chapter looks at the analysis of results from the semi-structured interviews conducted with 12 construction professionals involved in delivering Malaysian public sector projects (see research method in Section 3.5.2). During the interviews, each respondent described examples of recent disruptive events they had faced in delivering public projects, including their impacts on operations. They also described their organisation and supply chain's actions in dealing with the disruptions (see guidelines of interview questions in Appendix D) and explained what they believe had caused them. This was to fulfil Objective 4 (see Section 1.4).

This chapter presents the four critical pathogens (refer Section 2.7) that emerged from the interviews as causing disruptions: *practice, circumstance, convention* and *organisation*. A further pathogenic influence of *behaviour* was also identified (see Section 5.8). Examples from the disruptive events highlighted by the respondents are used to describe these critical pathogens. It is worth noting here that some of these pathogens overlap due to their interdependence in causing the disruptive events. Along with the pathogens, the critical vulnerability factors presented in the survey results in Chapter 4 (political or legal pressures, market pressures, management vulnerability, liquidity or credit vulnerability and strategic vulnerability) were identified in the interviews as part of the validation of the survey results. These vulnerabilities, however, are discussed in detail in Chapter 6, with examples from the interview data.

5.2 Respondents' Background

The 12 respondents interviewed were five professionals representing the public organisations, three engineering consultants representing the external private organisations working with public projects, and four contractors engaged by the public organisations (see sampling method in Section 3.5.2.1). Each respondent had over 20 years of experience working in public projects and was therefore able to provide insightful data of the current real-world scenario of disruptions in public projects. Their background is presented in Table 5.1.

Table 5.1: Background information on respondents

Experts	Professional Background and Responsibilities
Expert PO1	A project manager and principal assistant director with civil and structural engineering background from the public state department. He also designs and advises on infrastructure works such as roads and bridges. He is involved mostly at the planning and design phase of the project, before the project goes to tender.
Expert PO2	Superintending officer and senior assistant director from the public state department. She has a background in civil and structural engineering and is responsible for managing and overseeing construction works on-site. She has been involved in building projects, but is currently supervising roadworks and infrastructure projects.
Expert PO3	A civil and structural engineer from the Head of Project Team (HOPT) in the main public works department's headquarter in Kuala Lumpur. He is mainly involved in government 'sick projects' and acts as an advisor in recovering the projects to get back on track. He is currently dealing with many public building works, but has experience dealing with infrastructure works.
Expert PO4	A principal assistant director and civil and structural engineer from HOPT who is an expert in work scheduling. He is involved in the planning phase of the public projects. His tasks include preparing the risk management plan, and liaising with public works department's design team in capturing the client's brief on the project. He has experience in building works, but is currently working with consultants on Mass Rapid Transit projects.
Expert PO5	A principal assistant director and project manager who represents the public organisations during the construction phase. He ensures construction works on-site meets the expected timeline in the schedule and helps to coordinate the team on-site. He has a background in civil and structural engineering and is mainly involved in building works.
Consultant CS1	A senior civil and structural engineer from a small-sized consultant engineering firm (20 employees). She prepares design drawings for the public state department from planning to design phase and is mainly involved in roadworks. Her firm also engages specialists to assess traffic management plans for the roadworks. She assists PWD in responding to public road users' complaints.
Consultant CS2	A civil and structural engineer from a medium-sized consultant engineering firm (more than 50 employees). She prepares design drawings for tender and consults public works department on the structural designs of the infrastructure works. She also assists public works department in acquiring land and in dealing with contractors' enquiries on roadworks design.
Consultant CS3	A civil and structural engineer from a medium-sized family-owned consultancy (more than 50 employees). He deals mostly with the structural design of public buildings. He prepares the design drawings for public sate department during design, and also provides a quantity surveying service to estimate the design works.
Contractor CO1	A main contractor from a large construction company involved in construction, contract administration, quantity surveying, trading and training services (more than 100 employees). He has experience working in public infrastructure and building construction works, and has also worked as a sub-contractor and supplier through his company's departments.

Contractor CO2	A main contractor from a medium-sized construction company (more than 50 employees). His past experience includes both public and private projects, and is experienced in dealing with international projects. He is currently focusing on two public projects.
Contractor CO3	A main contractor who is also the CEO of his small company (20 employees). He directly manages his company's finance and the construction works on-site. His company is mainly involved in government and semi-government projects (government-owned company projects).
Contractor CO4	A main contractor from a small family-owned company (less than 20 employees). The company has run for more than 20 years through his father, and has been a supplier and sub-contractor in past public projects. He is currently working as the main contractor on two public projects.

5.3 Pathogenic themes

As previously discussed in Section 3.5.2, the computer software package Nvivo (version 11) was used to conduct the content analysis. The recorded interviews were transcribed and uploaded in the software to identify the major themes from the interview data. In this case, predetermined pathogenic themes from existing literature (Busby and Hughes, 2004) were used to classify the data. The emergent theme of *behaviour* was also identified from the interviews, and was included in the analysis. Figure 5.1 presents the coding structure developed on the critical pathogenic influences that contribute to the occurance of supply chain disruptions in public projects.

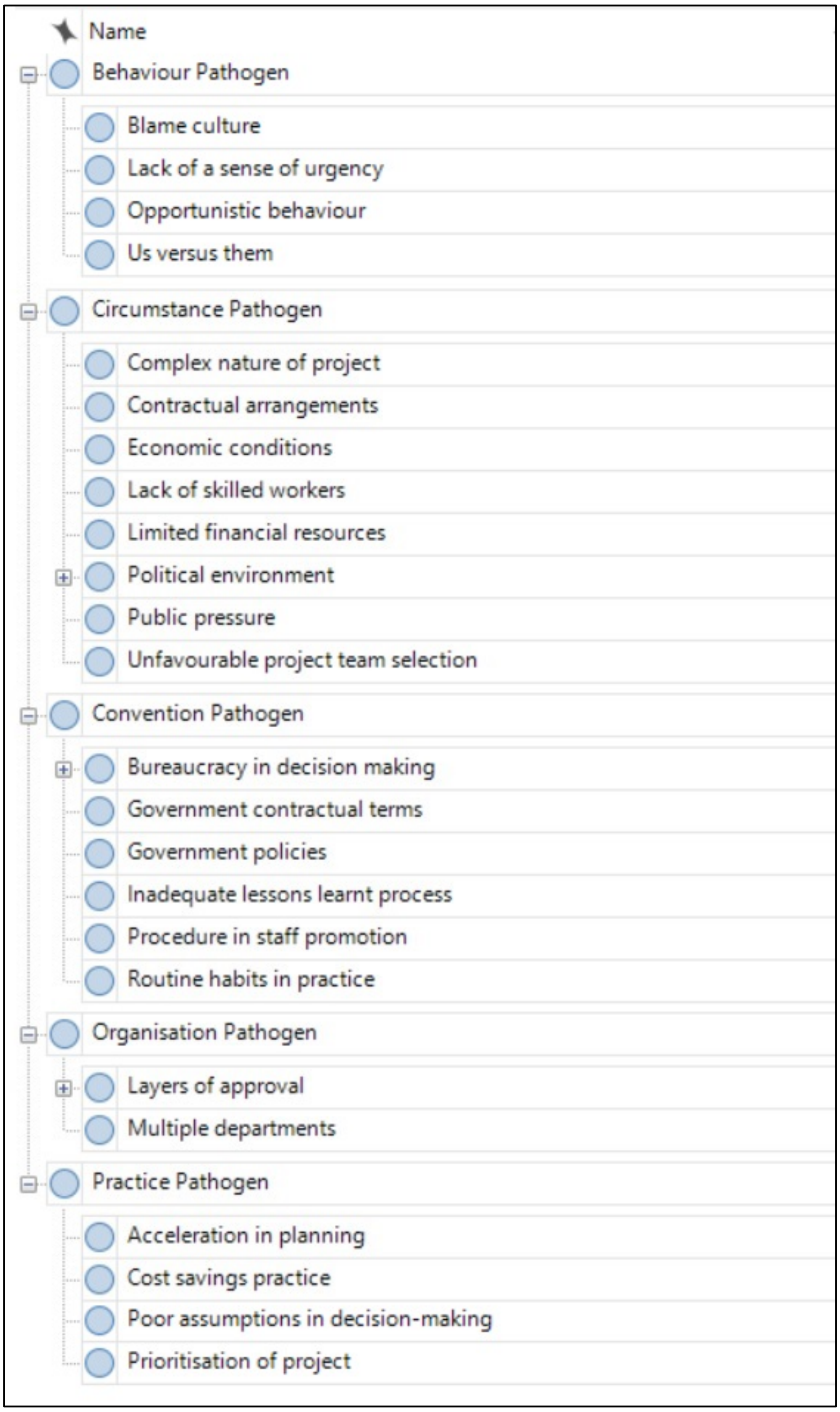

Figure 5.1: Coding structure of critical pathogenic influences

The output in Figure 5.1 above highlights five critical pathogens that emerged from the interviews: *practice, circumstance, convention, organisation* and *behaviour*. The cognitive map of these pathogens were developed following the analysis of the interview, as shown in Figure 5.2 below.

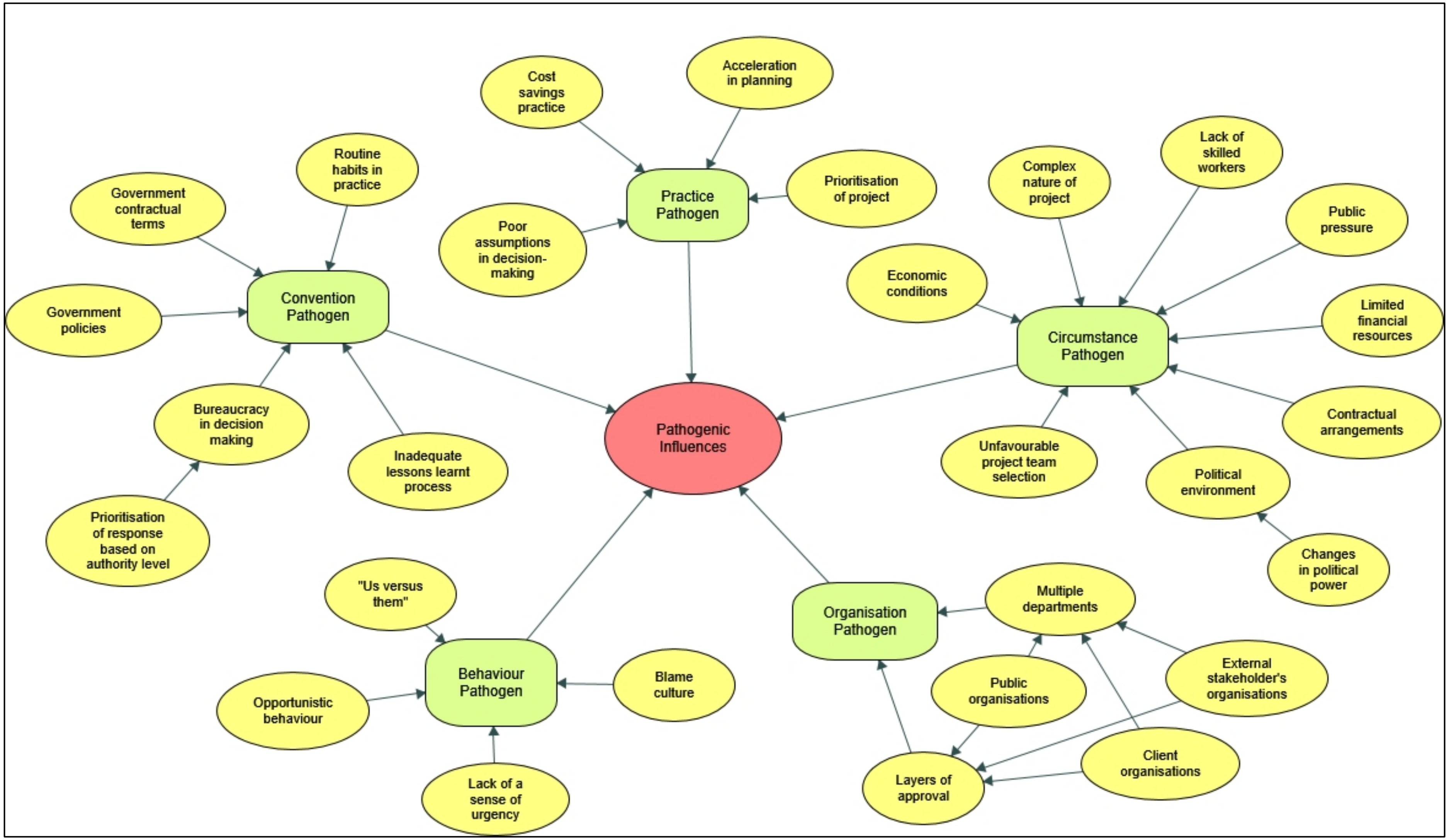

Figure 5.2: Cognitive map of the critical pathogenic influences

The critical pathogenic influences in Figure 5.2 are further discussed below.

5.4 Practice pathogen

The practice of poor assumption during decision making has caused significant disruptions to the public projects, This is prevalent especially in public infrastructure projects delivery. Understandably, given the nature of highly complex engineering projects, many assumptions have to be made during the initial planning and design phase. This evidence is based on Consultant CS1's experience in dealing with a bridge project. In this case, the public organisations initially wanted to utilise an existing bridge and upgrade it into a main road instead of building a new road, in order to reduce costs. Although this practice was seen as a way to save money, the initial estimates for the existing bridge failed to consider the high traffic load that would come when the bridge became a main road.

> The existing bridge is used mainly by the local people to commute to their plantation farm. If we were to modify this existing bridge to become the main road, there would be significantly more traffic. These costs unfortunately were not captured during the award stage.

The consultant stated that the estimates were based on basic upgrading works which were not sufficient to the project. Further inspection, simulation and projection of the traffic load over 10 to 20 years had to be conducted by additional specialists to ensure the bridge could carry the expected high loading, which subsequently added to the budget. It can be seen here that poor assumption by the public organisations on the costs of reusing the bridge had increased their vulnerability to budget overruns. In making such decision to save costs, additions to the design and resources when reusing the bridge went unnoticed throughout the planning stage, causing a significant increase in the project budget. This shows that the practice of satisfying cost-saving goals could result in being pathogenic to the public organisations. In this case, the public organisations' decision to conform to the lower-cost solution of reusing the existing bridge instead of building a new one further increased the budget due to the current condition of the bridge. The consultant's practice of outsourcing work to assess the bridge could also be pathogenic to the project budget as additional external parties need to be engaged to execute the design work.

Expert PO2 addressed a similar pathogenic practice of poor assumption in decision making. During the construction of a roadwork project, a utility was discovered on-site that could not be replaced because of high costs. She believes that this was caused by carelessness in terms of the planning and design work, as the parties involved did not actually visit the site during the planning and design phase. The practice of poor assumption by looking at design drawings in the initial phase without actual verification on-site had a pathogenic effect on the subsequent construction phase of the project. However, Consultant CS2 argued that such carelessness in assumption can not be predicted as an error until an actual disruption occurs on-site. It was noted that while some risks can be identified earlier, underground utilities such as water pipes and piling can only be identified later during excavation on-site.

> Because we are dealing with a very long highway, we can not afford to survey all 50 points of the site due to the limited cost and time imposed by the public organisations. So we can map only 7 to 8 points or locations in our design. (CS2)

Thus, it might be that the public organisations not wanting to spend much money and time on the planning phase contributed to their vulnerability to the utility disruption in the first place. Expert PO1 also acknowledged that despite having a project management plan, the public organisations usually rushed things and did not work according to plan. This acceleration in delivering plans is usually due to the added pressure by top management, leading to the consultant proceeding with tentative assumptions based on the limited time and resources available for producing the final design. Examples of these disruptions and the pathogens that contributed to their occurrence are represented in Figure 5.3a below.

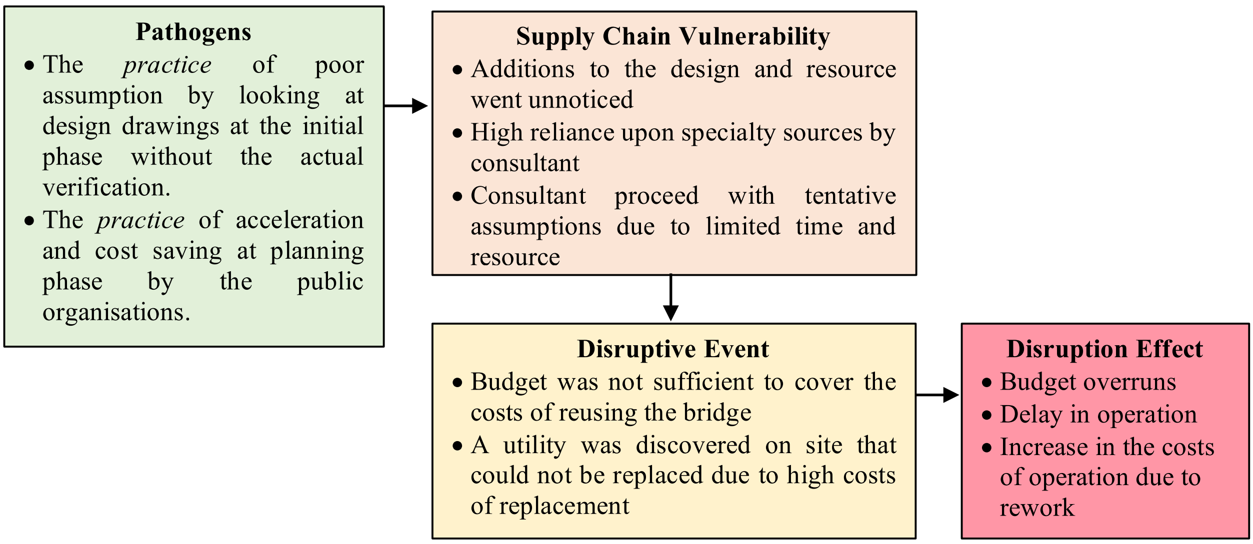

Figure 5.3a: Underlying *practice* pathogen that caused disruptions

On the other hand, Expert PO3 stated that sometimes disruptions arise from the bottom tier of the supply chain (i.e. sub-contractors, suppliers). He highlighted that even though the public organisations have identified the list of qualities or the checklist of specifications beforehand, the team or sub-contractors selected by the contractors may not comply with the government standard. This is attributed to the fact that the sub-contractors want to cut costs, for higher profit. This shows that the practice of cost saving is prevalent not just in the contractor's operation but also by the sub-contractors at the bottom tier of the supply chain. This act is perceived as pathogenic to the project manager as it could ultimately disrupt the quality of the final product. Furthermore, the practice of cost saving by sub-contractors was also perceived as pathogenic to Contractor CO4. He stated that the main contractor ultimately bears the loss when they outsource their work to such incompetent sub-contractors or suppliers, as the schedule and timeline are under the control of the main contractor. He further argued that it was hard to predict that the cost saving act by his sub-contractors could lead to disruption in his operations, until his sub-contractors made the actual mistakes on-site. Consequently, this pathogen of cost saving by sub-contractors causes loss of productivity and profit on the contractor's side and affect the public organisations' ability to get the best value of money from the project due to the poor quality of work. Nevertheless, Contractor CO2 found that such pathogen arising from sub-contractors can ultimately be controlled by the main contractor by ensuring timely payment to the sub-contractors.

The practice of prioritising projects by their prominence in the public organisations was also perceived as pathogenic to the consultant's operations. Consultant CS2 reflected on cases where such prioritisation had halted the design phase of another public roadwork project. The consultant emphasised that as the same people in the public organisations handle multiple projects at a time, the projects have to be narrowed down and prioritised. The project that the consultant was specifically involved in, however, was not under the priority category, further drawing out the decision-making process. The slow decision-making process had subsequently caused disruptions and delay to the design process of over a year, when initially the consultant was supposed to be contracted for only one year. This also caused loss of productivity on the consultants' side of the work. The consultant expressed their predicament that they still needed to continue with the design despite the halt of this phase as they still needed to submit a monthly progress report to the public organisations to show progress. For the consultant, this was a waste of time, as necessary design work could have been done during that time if the public organisations had made a decision. This shows how the public organisations' practice of prioritising projects is seen as pathogenic to the consultants as it could disrupt their ability to design the roadwork progressively and on time. Indeed, Expert PO2 from the public organisation also highlighted the fact that as a superintending officer (SO), she has several projects to manage and can not dedicate her full time to a single one. Hence, it appears that the pathogenic practice of prioritisation of projects was preceded by the public organisations' poor utilisation of additional resources, as the same professionals in the firm handled multiple projects at a time and their consultant was left waiting for a response. This ultimately affected the project team's efficiency in delivering the project on time. The subsequent construction phase of the roadwork project then faced significant delay because the preceding design work had been halted.

The summary of the pathogens that contribute to the supply chain's vulnerabilities from the abovementioned cases are highlighted in Figure 5.3b below.

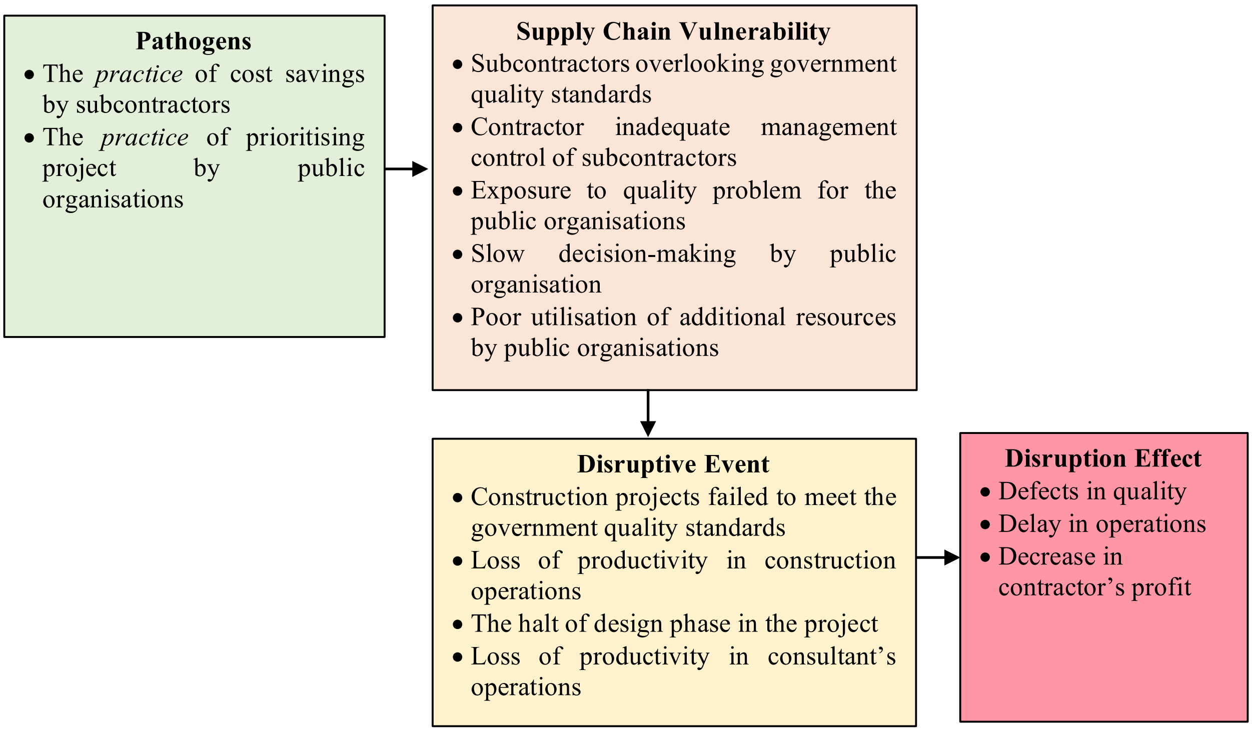

Figure 5.3b: Underlying *practice* pathogen that caused disruptions

Next, the *circumstance* pathogen highlighted by the respondents is discussed below.

5.5 Circumstance pathogen

The circumstances arising from the unstable political environment in which the projects are operating were identified as one of the main underlying latent conditions for disruption. Expert PO1 acknowledged that,

> If you look at the list of risk priorities in public infrastructure projects, in terms of ranking, the first project priority is always political. Second rank in terms of priority is probably safety, followed by traffic capacity and so on. This is unfortunately the risk we have to take.

Indeed, disruption due to political influence is inevitable in public projects, thus the reason it has always been considered as one of the public projects' risks. However, the pathogenic effects of political influence are sometimes not always obvious until actual disruptions or deficiencies arise in the supply chain operations. For instance, Contractor CO1 expressed his concern at the circumstance when nominated sub-contractors were selected directly by the public organisations,

> It is like a forced marriage. The public organisations tender, but we have to sign the sub-contractors under us. That itself is a disruption.

In this case, the direct appointment of the sub-contractors by the public organsiations was due to the political influence during the tender evaluation process. This shows that the circumstance of unfavourable project team selection, that could be linked with the political environment, is perceived as pathogenic to the contractor. The project team's vulnerability to political disruptions could ultimately disrupt the public project delivery due to poor collaboration and ineffective teamwork. Changes in political power were also identified as pathogenic to Contractor CO4's operations. Based on this contractor's experience, following the change to the political party that governs the state where the site was located, the existing government authority protested and closed down their services in that state. Subsequently, this caused significant delay in the approval of land acquisition. The contractor explained that,

> We submitted our plan for land acquisition but they did not process the plan we submitted for two years; they gave us a lot of excuses for not processing it and made it difficult for us to get their approval.

This shows how the political change had ultimately disrupted progress causing the roadwork project to suffer. Expert PO2 agreed that,

> When it comes to government, we have a lot of political effect, we have to check and deal with a lot of things that have to do with monetary and political issues, especially during elections.

Hence, even though the external political parties are not directly related to the project, such political changes could still disrupt the public organisations' and contractor's operation. This shows the high vulnerability of the public organisations and its supply chain to unstable political environment in delivering public projects.

The circumstance of the nature of infrastructure projects that involve complex design is also pathogenic to the project team. This is prevalent in Consultant CS2's experience, especially in identifying the location of existing underground utilities in mapping the roadworks (as discussed in Section 5.4). The consultant explained that,

> We do not want to disrupt the energy and water supply to the public as this will have a social and economic impact, making it even more difficult to carry out the project.

Similarly, land acquisition for roadworks was perceived as a difficult process due to its complexity. According to the consultant, when a small road is expanded to a wider road, additional land has to be acquired for access by the public organisation. However, when roads are widened, nearby buildings will be affected, as will plantation farms. The public organisations have to compensate for the losses incurred by the owners of the palm trees based on the projected future profit that should have been generated from these plantations. The consultant stated that land acquisition for infrastructure projects itself can take 12 to 18 months. This shows how the circumstance of the complex nature of infrastructure projects could also send pathogenic effects to the local community and the agricultural economy if the projects' land acquisition is not managed wisely.

Furthermore, the public organisations and their supply chains were highly vulnerable to public scrutiny. For instance, the public organisations have to deal with constant reports or complaints from road users. In dealing with these complaints, Expert PO2 highlighted the public organisations' dilemma that, apart from satisfying the road users' requirements, they also have to satisfy the client who provides the money for the roadworks. Under the client's budget, some of the objectives must be compromised and not all objectives can be fulfilled. However, Expert PO2 believes that when such roadwork projects become the local people's problems, this could subsequently have a social impact. This shows that the nature of public infrastructure projects and its exposure to the public can also be pathogenic to the public organisations as it could have both social and economic impacts. Furthermore, both Expert PO2 and Consultant CS1 highlighted that although they are used to public complaints, such circumstance of public scrutiny become pathogenic when recovering from disruptive events in public projects. Consultant CS1 had faced circumstances whereby they were pressured by the public and media to resolve the collapse of a roadwork quickly within two days. This was deemed as an unrealistic timeline by the consultant, as further testing and road diversion have to be made when a road collapses. The consultant also found that in this case, the client did not always understand the process needed to resolve the issue, putting further significant pressure on the project team. This has resulted in the slow operations of the project team as they have to constantly response to media and make further justifications to the client in their recovery measures. It can also be seen here that the high visibility of disruptions in public projects to the public organisations' stakeholders, including both the client and the local people, could also cause reputational damage to the public organisations. Overall, the *circumstance* pathogens discussed above are summarised in Figure 5.4a below.

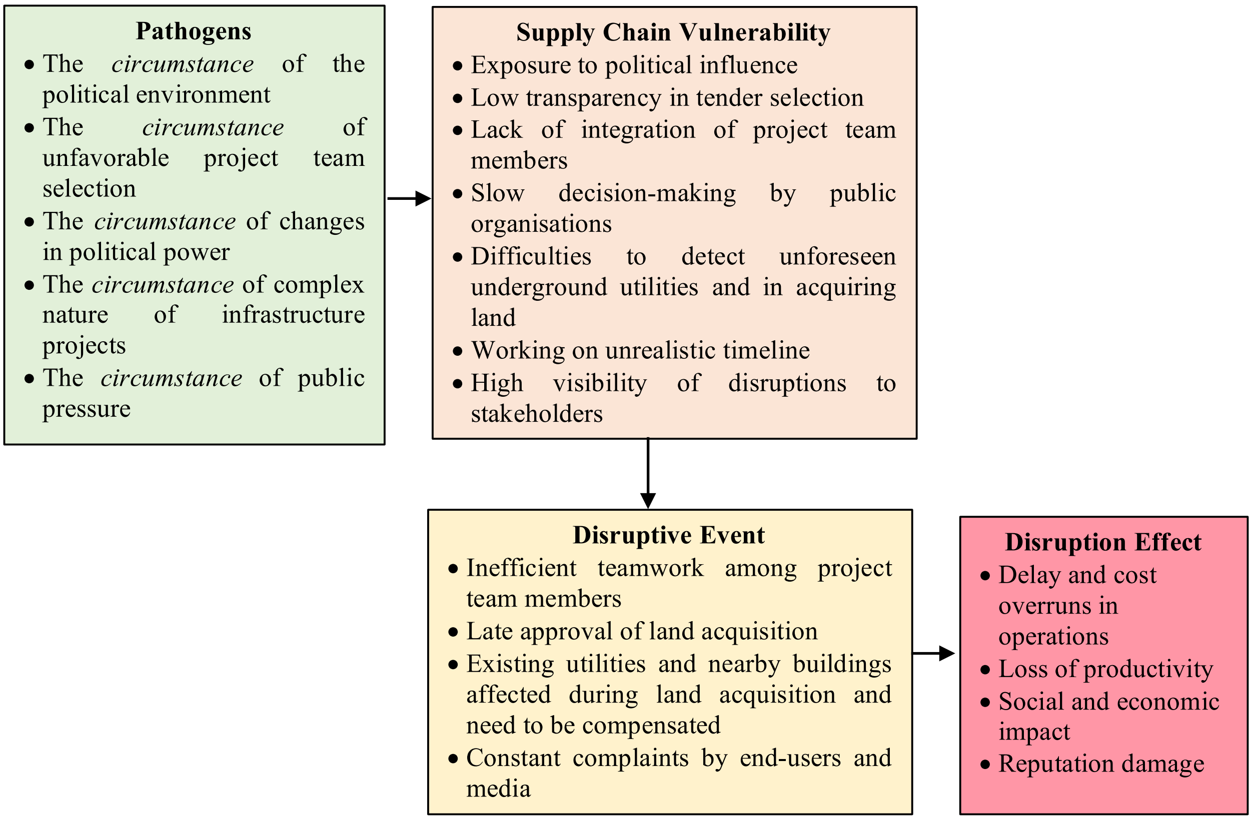

Figure 5.4a: Underlying *circumstance* pathogen that caused disruptions

The financial circumstances of the public organisations were also deemed as pathogenic by Expert PO1, as they limit the design standards. He stated that the public organisations' design team usually has to accept optimisation rather than maximising the design standards. The engineer explained,

> We have to optimise the design based on the available budget without compromising safety. Apart from safety, we can slightly improve the capacity as well and that is sufficient. Even if we produce the best design, in the end, the ministries do not have the sufficient resource or budget, hence we cannot continue with the design.

The lack of financial resources had led to the reduced standard of design in the public projects, which could subsequently affect the quality of the completed buildings or infrastructure works. This in turn, could make the public organisations highly exposed to further public scrutiny due to the quality of works. The circumstance of limited financial resource by the public organisations could also result in late payment to the contractors and their contracting parties (further discussed in Section 6.2.1). On the other hand, Contractor CO1 had also faced significant financial disruptions due to economic circumstances. The Prime Minister's announcement of the rise in oil prices had affected the contractor's operation with a projected immediate loss of RM28 billion. This is because when the price of oil increases, the price of bitumen increases, and when the bitumen price increaseds, the cost of materials and transport will also increase significantly. The major increase in the oil price had subsequently caused transportation disruption to the contractor's operation, as the transport cost for the material was even more expensive than the material itself. In this case, the contractor had to absorb all the losses due to the current procurement arrangement with the public organisations, as in the turnkey contract there is no Variation of Price (VOP). This shows how the pathogenic effect of the current circumstance of economic pressure and contractual arrangement was indeed critical to the contractor, causing substantial loss of profit. The low risk sharing arrangement between the contractor and the public organisations also made it harder for the contractor to recover from such disruptions, eventually having to mobilise resources by cutting down on the sub-contractors to reduce losses.

The circumstance of contractual arrangements was also highlighted by the respondents. Expert PO2 explained that when there were incompetent people in the project team, as the SO she could not simply remove them due to contractual matters. For example, disruptions arose from the incompetence of the external consultant engaged, who failed to communicate with the utility company to relocate the existing utilities on-site before the contractor could commence work. In this case, under the terms of the contract Expert PO2 could not simply dismiss the consultant. Subsequently, she decided to call in another response team from the contractor's side to help expedite the process of utility relocation by directly dealing with the utility company themselves, without waiting for the consultant. On the other hand, Expert PO5 observed that some of the contractual payment arrangements between the main contractor and their sub-contractors or suppliers could result in the bottom tiers of the supply chain not receiving adequate payment. He explained that,

> The contract is supposed to be back to back, meaning what the government pays to the main contractor, the supplier will get. But the supplier's contract with the contractor is not back to back, it's a different contract, so that's why it becomes a problem. If the contract is back to back, it'll be easier because whatever payment the government gives, the supplier will receive it. So that's one of the issues.

Subsequently, this caused a significant delay in acquiring the material because the supplier wanted to wait until the price was stable before proceeding with the order. Hence, inconsistent contractual terms among the contractors and their team of sub-contractors could result in cascading delayed payment among the parties in the bottom tiers of the supply chain.

Furthermore, the circumstance of lack of skilled workers was perceived to be pathogenic to the contractors, as it resulted in their high dependency on foreign workers. Contractor CO2 explained that there are cases where disruptions arise due to the poor quality of workmanship of the foreign workers on-site, causing further reworking of their operations. He added,

> The beginning of hiring foreign workers is always a problem, one of the problems. They usually can't cope with the energy levels needed in construction. What we can do is just train them. After a few months, only then do they have the energy to work hard.

This affects the level of productivity of the workers on site. Contractor CO2 found a further big loss when the foreign workers who have been well trained in Malaysia return to their home country,

> Malaysia is like a training centre, we take foreign workers from Indonesia, Bangladesh, and when they are well trained after some years, they go back to their own country, so it's a bit of a loss. For instance, in this one job, we took foreign workers from Bangladesh; from no knowledge we trained them until they were good at their job within two years. At last, they have to go back, so we face a loss. And maybe they will go to another country to work, so that country will get the benefit from it, right? It's not easy to develop that skill.

This resulted in the further loss of skilled workers to the local construction industry. Overall, it can be observed that although the contractor could overcome the high reliance on foreign workers by training them on-site, over time, this could be pathogenic to the contractor as more skilled foreign workers leave the country. This has resulted in the contractor having to repeatedly engage and train new workers in subsequent projects, which adds time and money to their operations.

Overall, the abovementioned underlying *circumstance* pathogens are summarised in Figure 5.4b below.

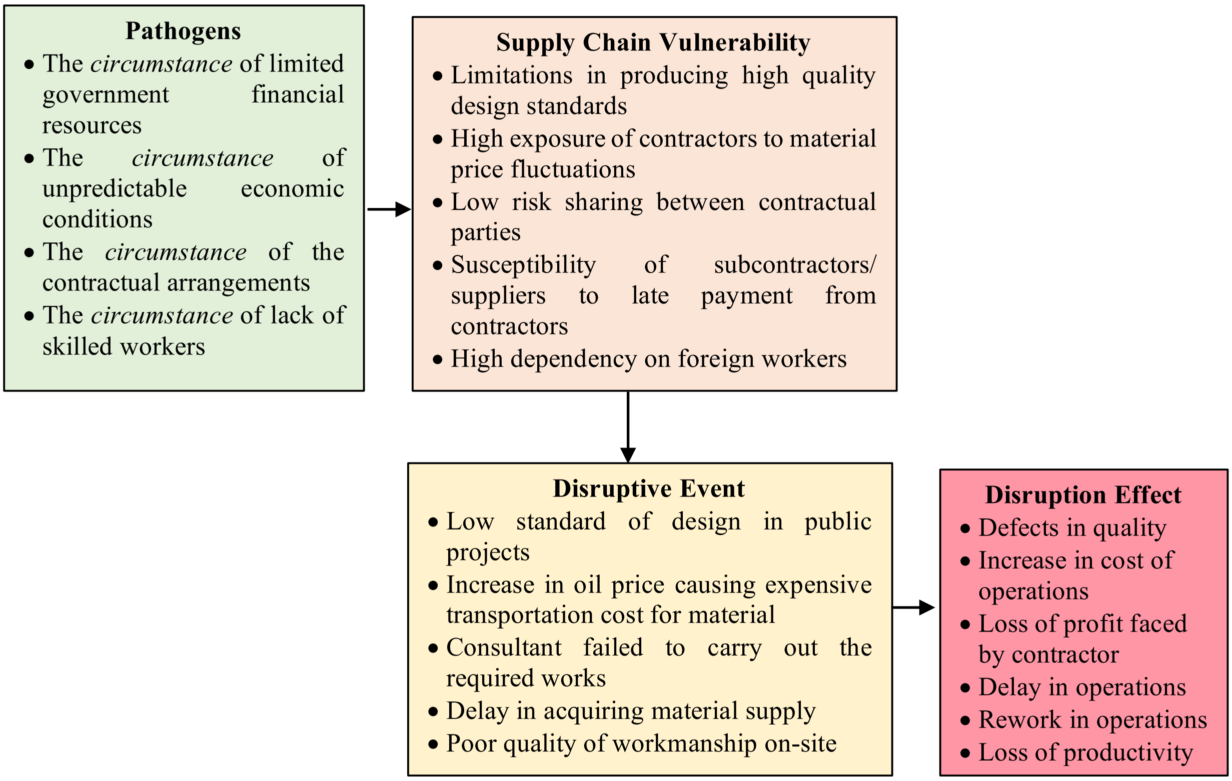

Figure 5.4b: Underlying *circumstance* pathogen that caused disruptions

Next, the *convention* pathogen arising from standards and procedures is discussed below.

5.6 Convention Pathogen

Pathogens arising from standard procedures were also reported to have contributed to the supply chain's vulnerability to disruptive events. The majority of the respondents interviewed found that the late decision making in the public sector supply chain is due to the unnecessary bureaucracy in the decision-making process. In most cases, such hierarchical decision making resulted in project team members prioritising their response to parties according to their level of authority. For instance, Contractor CO1 pointed out that,

> As a contractor, you can't do anything when dealing with the public organisations team. They prefer to hear from their own personnel. They do not entertain contractors. Government to government basis is different, it is easier. But when the contractor or consultants come to deal with the public organisations, it is harder and will take a lot of time.

He further argued that although the public sector supply chain is accustomed to such bureaucracy in practice, the public organisations' habit of prioritising responses by the level of authority power is not helpful when a prompt reply is needed during disruptions. On the other hand, Expert PO3 argued that similar cases arise when the public organisations' representatives deal with the contractors on-site. He recalled his visits to the government sick projects (i.e. projects that faced more than than three months' delay),

> When I go to visit each sick project, I advise that we need to redo the scheduling: they have to revise their programme, increase manpower and machinery. The contractors listen but they don't do it, so the project becomes problematic. So lastly, I tell them, I don't want to see this new problem any more, unless I have instructions from the authority. Because I don't have the top authority, the top-most authority is from another division. So it's different from when I go to a project site where I have been given the authority from the top number one director. Whatever I say or advise, it's like I'm his representative, and the contractor follows my instructions.

In this case, in saving the sick projects, Expert PO3's advice to the contractors usually does not work, as the contractors refuse to adhere to his instructions. Similarly, Expert PO4 pointed out that even as the public organisation's main scheduler on-site, he has no authority when it comes to handling the design work on-site. The suppliers usually want to deal with the people from the public organisations' design department, instead of with the scheduler appointed. He further addressed his concern that,

> The design team has not yet made their decision, it takes a long time. They are not used to the timeline and are unaware of the problems on-site, so to them, like time is not of the essence. So the problem lies with me at the site.

This could also be attributed to the poor distribution of decision making in the public organisations (further discussed in Section 6.3.3). Similarly, Consultant CS2 faced difficulties in dealing with external stakeholders involved in public projects. This is because they will only respond and provide necessary information if the direction comes from the public organisations. She added that in such cases,

> We have to ask the public organisations' help sometimes, "Sir, can you help us because the sub-consultant does not want to answer the phone". So they will go and make the phone call. In dealing with external parties, if we are from public organisations, they will entertain us. If it comes from the private organisations, they do not really accept us. So whatever it is the public organisations sometimes become the middle person to speed up the process.

Hence, in this case, it was faster for the consultant to retrieve external data from the stakeholders through the public organisations' request. This shows that when disruptions occur, the convention of only responding to directions from a higher level of authority is perceived by the respondents as pathogenic, as it could cause a slow response and late decision making, as described in these cases.

Furthermore, Expert PO3 identified that the public organisations' convention of recording their lessons learnt from disruptions without the opinion of other supply chain members involved in the project could be pathogenic to subsequent public projects. In this case, Expert PO3 argued that,

> There's no point in us just getting our public organisations project team during the lessons learnt, because we end up saying the other side was at fault. Usually when we do lessons learnt, these problems are the contractor's fault, and this one is indeed the consultant's fault, but there are our faults in some part of it. We have to accept that some of the problems arise from our team as well. We have to learn from our mistakes, or else it is a blaming game, and we kept asking other parties to improve, but not entirely improve together. So we must contribute to the improvements.

He added that such lessons learnt by the public organisations are not documented properly and do not reveal their true weaknesses. He believes that the public organisations should listen to the contractor's and consultant's sides of the stories in documenting the lessons learnt. Indeed, such poorly recorded lessons learnt could be pathogenic as the public organisations would be repeating the same mistakes in following projects. This is evident in the case highlighted by Expert PO4. One of the outcomes from the lessons learnt in the public project in which he was involved was about the procurement arrangement that caused the significant delay. He explained that,

> The public organisations want to write the outcome as, "it should have been a conventional contract". It is always like that, when they fail doing design and build because of their incompetence, they say they always prefer the conventional way. If you ask people like me, because I deliver 10 packages of design and build (D&B), it's no problem, 'cause I understand it, I would prefer D&B. I would argue that D&B can be delivered very fast. And even the pre-construction period I can do it within 8 months. It is easier to control.

It can be observed here that the public organisations failed to admit that their competence level on design and build was rather low. Expert PO4 added that,

> Using conventional contracts in the next projects still doesn't solve the delay. Let's say if it's conventional, one problem is the time, if you still can't control the design changes due to end-user, there'll still be variation order (VO), once there's VO, there's extension of time.

Hence, the main outcome of the lessons learnt on using conventional contracts in the next projects could be pathogenic to the public organisations as in fact they take longer time to deliver compared to design and build. Indeed, Expert PO1 found that despite having the lessons learnt recorded, the public organisations usually returned to their routine practice and usual habits. He acknowledged that, We attended workshops for the lessons learnt. But in the end, we do not follow the lessons we learnt from these workshops. We usually go back to our usual practice that we are comfortable with even though it has been proven that it is the wrong way of delivering the project.

It can be observed here that the public organisations are reluctant to change their conventional habits or adapt to new methods. This could be pathogenic to the public organisations as they are continually exposed to the same risk of disruptions. Indeed, Expert PO5 concluded that, even though the public organisations are tied in to their conventional procedures, public project performance can be improved if the public organisations are brave enough to accept changes in their procedures. Figure 5.5a below presents the summary of the pathogens discussed above.

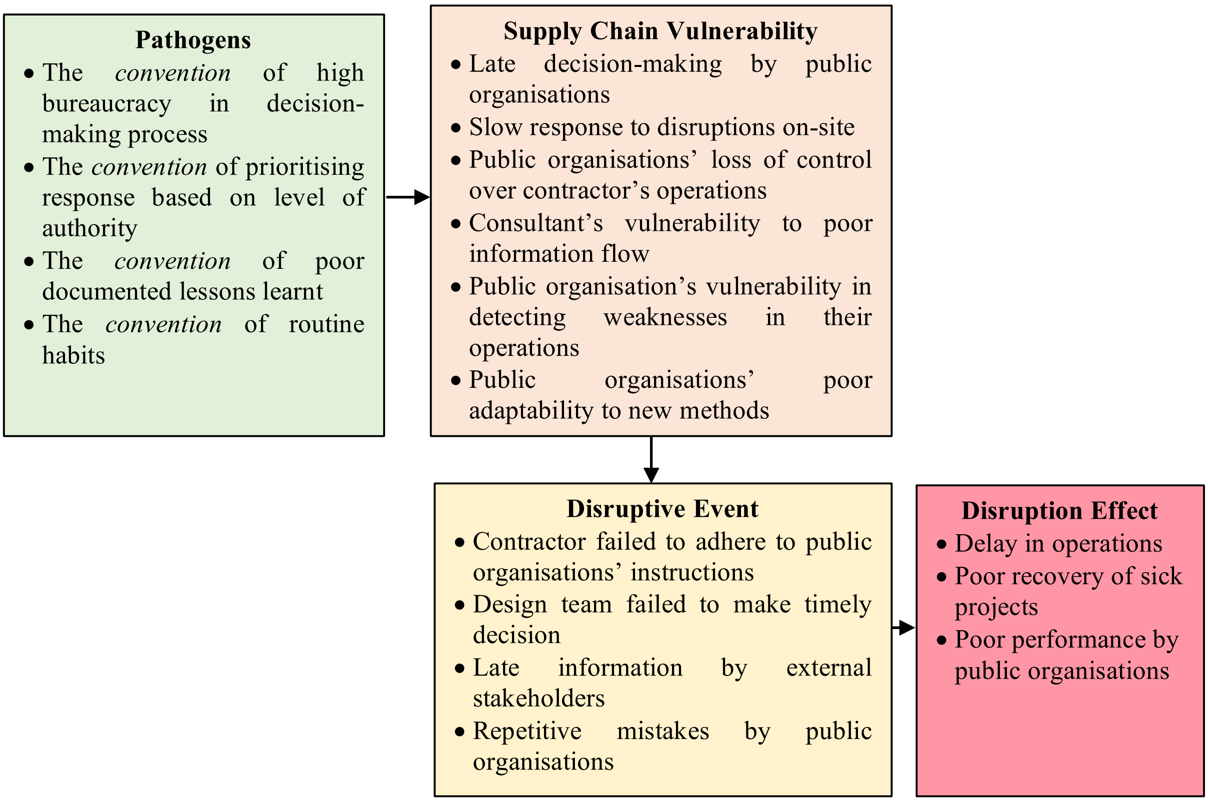

Figure 5.5a: Underlying *convention* pathogen that caused disruptions

Another pathogenic convention that was highlighted by one of the respondents is the public organisations' procedure in promoting staff immediately. For instance, Expert PO2 cited a case where there was a change in the SO representative in the project,

Sometimes we do not have a choice, when working with the government, the SO representative could not stay for long in a project, as they will be promoted. Based on our regulations, once we are promoted we have to move immediately. They will give us two weeks to move. So if the SO representative has to move, and the new SO representative is incompetent, it will become a disaster. Sometimes the project is already almost complete, but the SO has to move. That is the government regulation. That is another factor, the government system.

Hence, this convention of quick changes of staff was perceived as pathogenic to Expert PO2 as it disrupts the progress of the public projects. In this case, waiting for the new SO to adapt to the project and its team members resulted in further delay in the public project delivery.

In other cases, weaknesses were identified in the public organisations' contractual terms with the utility companies (water and electricity). One of the contractual conditions set by the public organisations for roadwork projects is that any identified existing utilities on-site are required to be relocated by the utility companies at their own cost. However, Contractor CO1 argued that this obligation resulted in the utility companies having no sense of urgency to move their facilities, causing delay to the contractor's operations. He added that,

> So for the utility companies, it's not urgent to do the relocation, they'll do it at the end of the year, because there's no penalty, the government does not penalise utility. How the government builds the utility company later on I'm not sure, but they are too lenient, when actually they can charge or penalise utility companies for late relocation.

Similarly, Contractor CO1 highlighted the drawback of one of the public organisations' contractual terms with the contractors. For instance, in a turnkey project, there is a clause in the public organisations' contract on the contractor's design proposals, whereby any savings from the proposals go to the public organisations. He explained that,

> That clause is not fair to me. So why would I want to initiate savings on alternative design solutions? They should have a 50-50 distribution of the savings gain.

On the other hand, the contractor has to bear the financial loss for any weaknesses arising from their design proposals. It should be noted here that parties should know well in advance their obligations and responsibilities when signing a contract (Love et al., 2011), hence should understand the risks allocated to them. However, in this case, the contractual terms might be perceived as pathogenic to the contractor due the lack of incentives by the public organisations to motivate the contractor to save costs in the projects. Similarly, Contractor CO2 pointed out that even in design and build contracts, all the savings go to the government. For example, the contractor instanced a project where there were eight different embankment designs for the eight different bridges that needed to be constructed even though all span were all the same length, because the designs of the embankments came from different design teams. In the end, upon approval of the SO, the contractor decided to select one particular design for all the bridges to save time and costs. However, due to the contractual terms, such savings from the value engineering go to the public organisations. Contractor CO2 added that,

> A lot of these value engineering things can sometimes be done to save costs for both parties. But the public organisations must be open-minded to accept the proposed changes.

He found that the public organisations' contract is rigid and without the flexibility to accommodate such design improvements. This could therefore result in the public organisations missing out on potential cost savings solutions in public projects.

Furthermore, Contractor CO3 found the government terms on the use of 80% of Industrialised Building System (IBS) content in public building projects to be pathogenic to the contractors' operations. Although there are many benefits from adopting IBS (i.e. less waste on-site), the contractor argued that the government's delivery of the plan in transitioning the local construction industry from labour intensive to highly mechanised was too rushed. He indicated the frequent problems in the implementation of IBS projects, such as the poor quality of the IBS components provided by suppliers, the monopolisation of price by IBS suppliers, and the poor handling of IBS components on-site due to the contractor's inexperience. Contractor CO3 believes that,

> If the government wants to make the transition, it must be some sort of evolutionary process, not a one-shot policy. You should start actually at what, 40% IBS for certain types of building, then go higher and higher. If you're building a hospital, it's a complicated and complex building, right? And of course the IBS will become very expensive because you have to tailor it to the hospital. But if you're building a school, then it is very cheap.

Hence, while the use of IBS could improve the efficiency of operations in public projects, poor implementation of the IBS provision could result in negative impacts on the contractor's operations. The government should deliver the IBS plans gradually to allow some time for the contractors and the rest of construction professionals to adapt.

Overall, the *convention* pathogens discussed above are depicted in Figure 5.5b below.

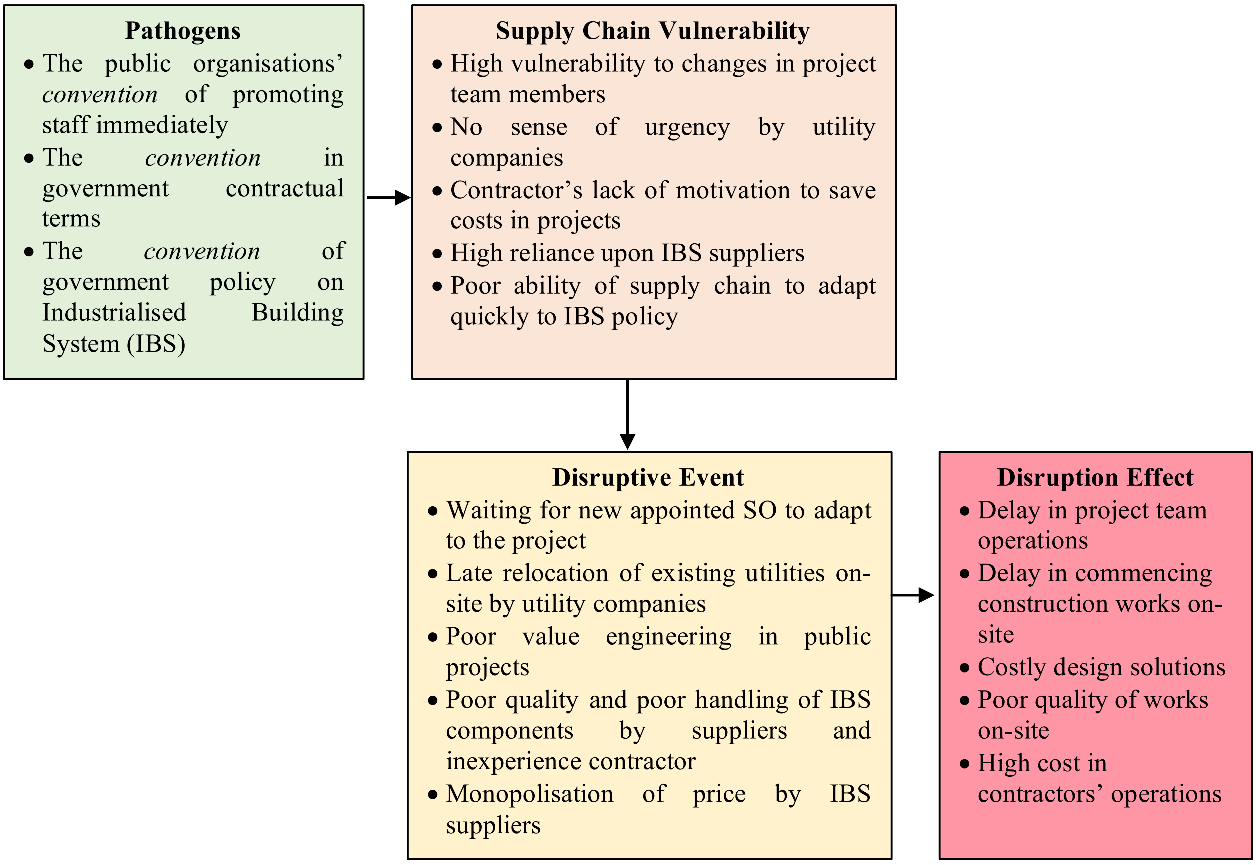

Figure 5.5b: Underlying *convention* pathogen that caused disruptions

The *organisation* pathogen is further discussed in the following section.

5.7 Organisation Pathogen

The majority of the respondents (PO1, PO2, PO5, CS1, CS3, CO2, CO3) found that the structure of the public organisations resulted in late decision making. For instance, the various departments handling tasks in different phases (i.e. planning, design, tender) of the projects make it harder for the project team to identify any problems arising from deficiencies in their operations. As discussed in Section 5.6, the late approval process is attributed to bureaucratic decision making. In this case, discrepancies exist between the team who do the planning and the project management at the public works department's main headquarters (Head of Project Team, HOPT), and the team who do the design and tender works (Head of Design Team, HODT) and the team who manage the construction works on-site (state organisations). Expert PO2 pointed out that,

> These things can sometimes be problematic as all tasks in the project are done by different departments. For us in the state organisations, we usually face the problems on-site when HOPT and HODT do not perform.

Hence, any problems arising from the operations of the planning (HOPT) and design (HODT) teams in the public organisations could cascade down to the state organisations if not rectified beforehand. Consultant CS1 added that this organisational structure has resulted in unclear roles between the departments in the public organisations as each is led by different managers, causing delay in their operations. It also causes confusion for the contractors and consultants, especially those who are still not familiar with the public organisations' system, in navigating through their process and identifying the key person in charge to report to when disruptions arise. Expert PO1 pointed out that usually when disruptions arise during construction,

> If the state representatives cannot solve the problems on-site, they will go to the HOPT office to solve it. Sometimes they can't solve them because of their own capacity, but mostly because of the limitations in the contractual agreement that requires decision with approval from higher authority in HOPT.

This makes it difficult for the public organisations to respond quickly during disruptions. Moreover, multiple departments in the client's organisation were also deemed as pathogenic to the project team's operations. Expert PO5 said,

> Within the client itself there are a lot of layers of authority that need to approve the contractor's proposal on materials, etc. A lot of stages. Starts with the bottom team, then goes to another administration stage, their head administrator, and he has to satisfy the secretary board, and then it goes to the main director, then the secretary has to go back to the other stage to report the decision. So that's why it becomes slow sometimes. We previously estimate that this decision making will only take three months, but because of these layers of authorities, it now goes beyond those three months.

Understandably, it is common for such large organisations such as the public and client organisations to have multiple departments working on different tasks. However, it could also be pathogenic to the project team operations if the system could not produce a fast response. Expert PO5 found that simplifying the different levels of approval would save time in public project delivery, especially when a quick response is needed during disruptions. On the other hand, the majority of the respondents who deal with external stakeholders such as the utility companies also find it difficult to navigate through their systems. This is prevalent especially in public roadworks projects, as necessary information on existing utilities on-site are required by the consultants and contractors. Consultant CS1 shared her experience in dealing with utility companies,

> During the design phase, in order to get information on existing pipes on-site, we have to make an appointment with the utility providers, which takes a lot of time because the provider has a lot of departments that deal with different things. For instance, for the energy provider, they have different levels, 11Kv, 33Kv, 275 Kv and so on, which are all from different departments. They also have several projects to deal with, so we have to know when they are available. To get their confirmation after we have done the site visits takes a lot of time.

Similarly, Consultant CS2 stated that the various departments within the utility companies resulted in confusion for the consultants in terms of submitting documents to the right person, causing delay in the consultants' operations. She added that,

> Sometimes, there is no coordination between the utilities' district departments and the main utilities headquarters. It does not mean that the information or resources that are available at the headquarters are available at the district departments and vice versa. The communication between them internally also takes time. So unfortunately, we have to wait.

It can be seen here that the consultants rely heavily on a continuous information flow from the utility companies, affecting any deficiencies arising from these external companies' operations. Overall, these cases show that the pathogen of multiple layers of approval in organisational structure is prevalent not just in the public organisations' system but also in other stakeholders' organisations such as the client's and utility companies'. This makes the public sector supply chain highly vulnerable to late decision making.

The *organisation* pathogens discussed above are presented in Figure 5.6 below.

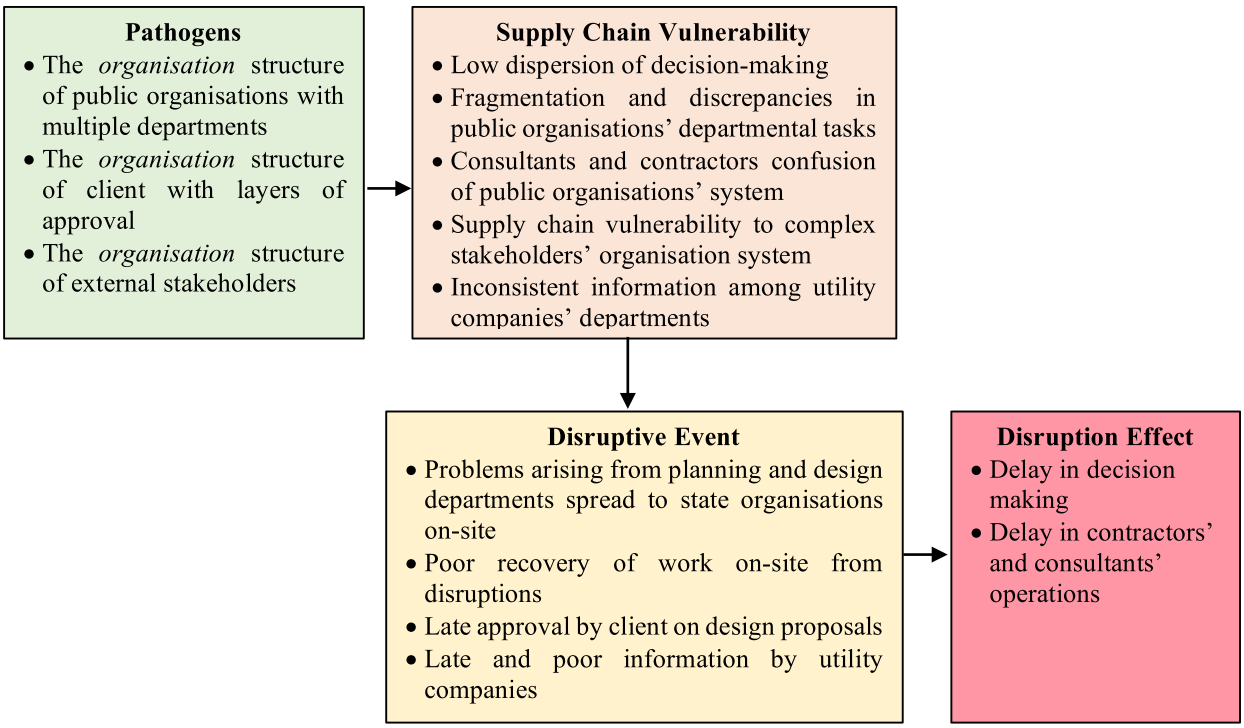

Figure 5.6: Underlying *organisation* pathogen that caused disruptions

The following section presents the emergent theme of *behaviour* pathogen identified in the interviews.

5.8 Behaviour Pathogen

Various types of behaviour were identified in the interviews, including opportunistic behaviour by contractors, which was seen as pathogenic to the consultant and the public organisations. For instance, according to Consultant CS1, the contractors tend to use unsettled land matters as an excuse to claim for extension of time (EOT) for roadwork projects, whatever their reason for not starting work on-site. However, this consultant claimed that,

> When we go on-site, we can clearly see those areas where the contractor can already start their work, also known as the 'green areas'. It is only those 'red areas' that are still unsettled and they are not able to touch yet. The contractor wanted to wait until all the areas are 'green' and all the existing utilities relocated before he started work on site, which is not necessary. He was able to justify and use the land matters as an excuse to get the EOT three times.

The consultant found that this illustrates poor planning by the contractor in terms of the sequence of commencing work on-site. The contractor's act of taking advantage of the unsettled land matters eventually caused the contractor to be penalised by the public organisations for liquidated damages due to the late completion of the overall project. It also caused the contractor to face a significant loss of profit. Contractor CO1 acknowledged that, for contractors, with every disruption comes an opportunity because as a contractor, problem means money. He explained that he managed to recover from financial losses in a recent project by taking advantage of the work sequence, technicalities and the specifications of the project, which he justified as,

> I took advantage of alternative specifications to cut cost but I never break the law, I only bend the law. It is like if we take a ruler and bend it as much as we can but never break it.

Nevertheless, Expert PO1 identified this act as pathogenic,

> The contractor usually finds an area where they can cut their costs, they will try hard to do that to make a profit. This affects the quality of the work.

This opportunistic behaviour can in some cases be seen as pathogenic by other parties, but in the case of the contractor, this behaviour of taking opportunities was seen as reaction to recover from disruptive events.

The behaviour of external parties' lack of a sense of urgency also makes the project team vulnerable to disruptions. Expert PO2 stated that it is easier to gather the internal project team to mitigate the problem when disruptions occur, but when it involves external parties (i.e. utility providers and other stakeholders), there is no sense of urgency in responding to disruptions. There were cases where a utility provider simultaneously constructed their cables right next to the public projects' site. Expert PO2 explained that,

> They just started constructing about 30% of their cable, but they almost hit our embankment area that we want to construct. But these people are just lazy and simply do whatever they want to do. So I have to call them up, send a formal letter, call for a utility meeting. I have to urge them to make them understand that they have to be fast, because the moment they touch my line of area, I can not proceed with the work on-site, and the contractor will claim for EOT. Usually when I call for a meeting, some of them just take it easy, they do not come even after several warnings.

Hence, when the public organisations depend on external parties, it will be difficult to adhere to the project timeframe as they do not have the same sense of urgency as the project team. Expert PO2 believes that things like this cannot be avoided,

> I can control my team, but I can not control the utility providers because I am not their boss. It is not an easy task, it is really challenging.

This attitude of no sense of urgency results in a substantial waste of time and money to the public organisations. There were also cases where disruptions arose through the contractor's attitude of delaying small works. Expert PO5 claimed that sometimes the public project is 98% to 99% complete, and yet the contractor is not able to finish it off. He believes that this delay is not because of the money, but is due to their attitude: "they were too lazy to finish one or two things". It can be seen here that the contractor's attitude is perceived as a risk to the public organisations. Expert PO5 believes that this attitude is the most problematic risk as it is hard to alter someone's behaviour. Naturally, the public organisations can not hand over an unfinished project to the client. In this case, due to the sluggish attitude of the contractor, the public organisations had to engage a third party just to complete the remaining 0.1% of the project, for minor things such as planting grass.

The respondents also identified a common "us versus them" attitude among project team members; conflicting behaviours among parties is one of the main pathogens contributing to the vulnerability of the project team to disruption. Contractor CO1 pointed out that,

> It is usually the case where the client goes, "oh, I am the client, listen to me", the contractor says, "oh, I am the contractor, I have got to make profit, I do not want any losses", and for the

> consultants, "oh, I am the policeman here!" and they only observe our mistakes. Sometimes the public organisations also have this attitude, "oh, you are just a contractor, what do you know, I am from the public organisation, I have authority". That is problematic as well.

This divergence usually leads to problems as each party has their own priorities. Nevertheless, it is important for the contracting parties to arrive at a certain agreement so that the project can be delivered effectively. This shows poor collaboration and risk sharing between the contracting parties. Furthermore, the blame culture is prevalent in public projects, which results in a poor level of sharing information among parties who do not trust each other. For instance, Contractor CO3 stated that during risk management meetings, contractors usually do not share all the information about risks on their side with the public organisations, because they do not want to be blamed by other parties if such risks occur. This was evident in Contractor CO4's case,

> Everyone will find a way to blame another party when disruptions happen. So when the pillar cracks, the client blames the contractor and says we stole some of the steel, and then asks us to hack back the concrete to check if there's steel in it, and there is steel in it. And then test the concrete because they are scared that we might lie about the concrete properties. Another test. So the victim is the contractor.

Consultant CS3 also expressed his views on the blame culture when design failure occurs,

> People say, when the building design is beautiful, the architect gets the credit; they won't mention us, the civil and structural (C&S) engineers. The C&S engineer is behind the scene and won't get credit for it. But when the building collapses or faces design failure, the engineering consultant will be blamed first. It's just the culture.

Similarly, Expert PO2 pointed out that disruption due to design changes usually end up with arguments and blaming other parties for not considering the matter beforehand, causing further time and cost overruns. She observed that,

> If there's one party that's not committed to the project, this person is usually the weakest link. We can break at any time because of this particular person. We're like a chain, the moment the chain breaks, we face disaster. We cannot let incompetent people stay for long, we have to settle it quickly because the 'disease' can be transmitted and spread like cancer to other parties in the team. So we have to eliminate that. Anyone's problem is everyone's problem.

Indeed, Rice and Caniato (2003, p. 22) stated that "the supply network is inherently vulnerable to disruptions, and the failure of any one element in it could cause the whole network to fail". This shows that ultimately, everyone plays a part from the upper tiers to the bottom tiers of the supply chain, as this will influence the level of resilience of the supply chain to disruptions. Expert PO2 found that attitude is the most problematic risk as it is hard to mitigate someone's behaviour. On the other hand, all three consultants and two out of the four contractors (CO3 and CO4) argued that they could foresee the public organisations' behaviour from their past experience in dealing with public projects. Thus, this risk of behaviour is included as a potential problem in their risk management plans. Consultant CS2 found that,

> We can try to minimise the risks, but we can not eliminate them entirely, because after all we are human; you can control your quantity of concrete or the size of your bar, but you cannot control the person that operate the things.

Indeed, it is hard to control inappropriate acts by people who are in direct contact with the operations. Such acts are also known as 'active failures' by Love et al. (2011); when combined with the pathogens they can cause significant problems and have an adverse impact on project performance. This shows that the problem exists and lies within the behaviour of the contracting parties. However, behaviour has not been classified as a pathogen in past studies (Busby and Hughes, 2004; Love et al., 2011) but rather was considered as one of the triggers that could cause the pathogens to arise. However, in treating the pathogens as subjective interpretations (i.e. what the respondents considered as being pathogenic) in this study, the researcher believes that behaviour is one of the main pathogens that was constantly raised by the respondents as an underlying condition that makes projects susceptible to disruption. Indeed, Reason (1990) recognised that behaviour is difficult to change, but believed that the conditions under which people work can be improved and remedied before disruption occurs. Understanding the behaviour of the project team could therefore help in mitigating other pathogens identified in this study.

Overall, the *behaviour* pathogens discussed above are presented in Figure 5.7 below.

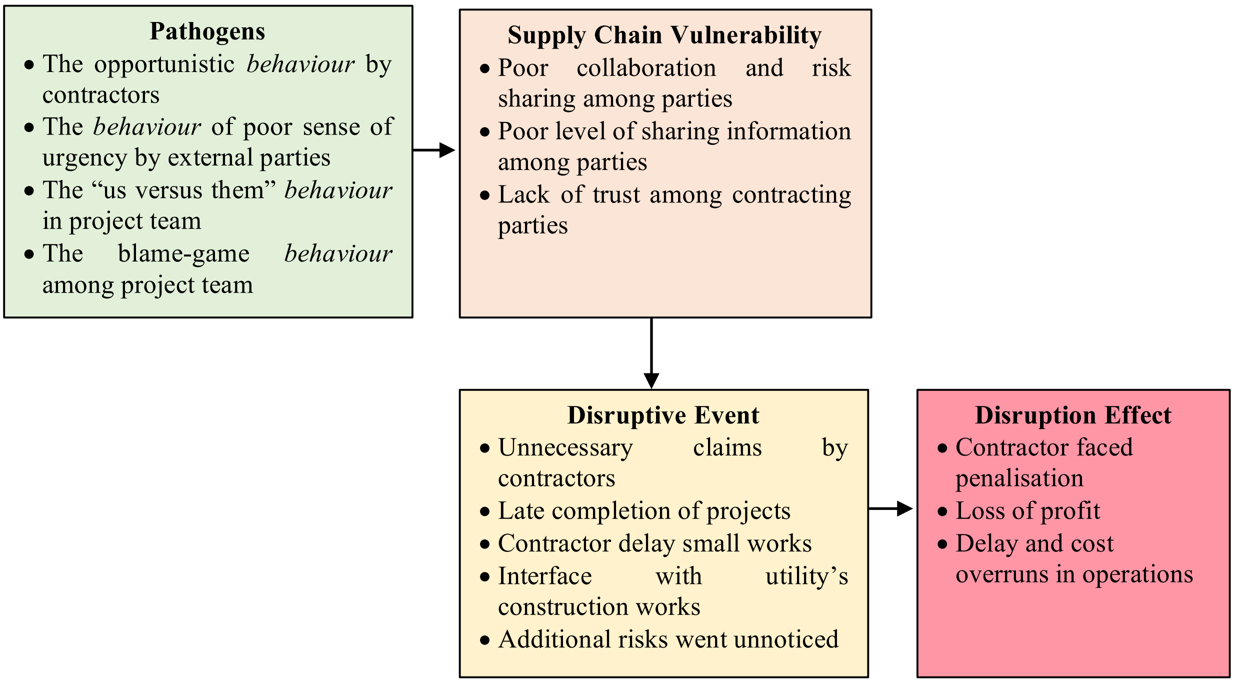

Figure 5.7: Underlying *behaviour* pathogen that caused disruptions

5.9 Summary

This chapter discussed the relevant pathogens and vulnerability of public organisations and the supply chain to disruptions in public projects. Pathogens identified from the interviews were people's deliberate practice, the circumstance the project operates in, the convention of government standards and regulations, and the organisational structure. In this case, the *practice* of poor assumptions at the planning and design phase disrupts the subsequent construction phase of the project. The inadequacy of these assumptions is not realised until an actual failure occurs on-site. The current *circumstances* of political interference and poor financial and economic conditions also result in unfavourable project team selection, limited quality standards and a significant loss of profit faced by the contractor. The established *convention* in the government system on the other hand, such as hierarchical decision making, the lessons learnt process, and their contractual terms, make them reluctant to change, remaining highly exposed to potential disruptions in public projects. The *organisation* structure that involves multiple departments and hierarchical decision-making processes causes fragmentation in the project delivery, making it harder for the project team to deal with the public organisations. Additionally, *behaviour* was identified as pathogenic by the respondents, whereby opportunistic behaviour by the contractor, lack of a sense of urgency by stakeholders, and conflicting behaviours among parties, affect project performance.

It was also observed through the interviews that the pathogens identified could be interrelated. The interview findings show that the *circumstance* (i.e. political environment, economic conditions, lack of skilled workers) in which the public sector supply chain operates influences individual *practice* (i.e. poor assumptions in decision making) and *behaviour* in response to such a project environment. Existing *organisational* structure and established *convention* in government procedures also influences their management in operational and strategic decision making. The findings of this study on the practice and circumstance agree with previous studies (Busby and Hughes, 2004; Love et al., 2011). However, unlike these studies, the nature of the *task* performed was not identified as pathogenic to our respondents, although an emergent theme of *behaviour* was identified as pathogenic instead. Overall, the identification through these interviews of the pathogenic influences gave the researcher a good understanding of the areas in which the parties are vulnerable.

The triangulation of the findings identified in the interviews and the questionnaire survey (Chapter 4) are discussed in Chapter 6.

CHAPTER 6

DISCUSSION OF RESULTS

6.1 Introduction

This chapter presents the discussion on the triangulation of data from both the questionnaire and interview analysis. It discusses the key findings identified in the questionnaire survey results (Chapter 4), with justification from the interview findings (Chapter 5) and the literature. It begins by examining the public sector supply chain's past experiences in dealing with disruptive events, based on the survey analysis (Section 4.3): the frequent disruptive events and critical effects of acute disruptions in public projects, the level of frequency and severity of these disruptions, the current disruption management approach employed by the organisations, and the respondents' proposed suggestions for managing disruptions. This is followed by a summary of Section 4.4: analysis of the public sector supply chain's critical vulnerabilities and capabilities. Finally, the final framework of this study and its validation are presented to highlight the key findings and propose related resilience measures. This is in line with Objective 5 (Section 1.4), in developing a resilience response framework to improve supply chain performance in meeting its resilience goals to mitigate against disruptive events in Malaysian public sector projects.

6.2 Supply Chain's Past Experiences of Disruptive Events in Public Projects

The following is based on the analysis presented in Section 4.3 on the respondents' past experiences in dealing with disruptions. Respondents from the questionnaire includes 54 number of respondents from the public organisations, and 51 respondents from the private organisations engaged by the public organisations to carry out the public projects (see respondents' profile in Section 4.2).

6.2.1 Frequent Disruptive Events in Public Projects

Quality problems

The survey results in Figure 4.1 revealed that only 13% of the contractors and consultants considered quality problems to be the most frequent cause of disruptions faced in public projects, as against 26% of the public organisations. The emphasis of the latter on quality is due to the influence of the Malaysian Construction Industry Development Board's (CIDB) aim to improve the quality of work, through their Construction Industry Master Plan (2006-2015). This seems rational given the importance placed on the functionality of the final product, chiefly public buildings and infrastructure, as pointed out by Expert PO2,

> …for us who represent the client, it is more the technical and quality issues that are important as we want to provide the road and facilities for the public, for the safety of the public.

One of the consultants (CS3) interviewed observed the discrepancy between the public organisations' and contractors' emphasis on quality in their design,

> There is a difference between the designs proposed by the contractor and the public organisations' design team. For the contractor's version, they will give a proposal based on their cost effectiveness and time effectiveness because of the profit, but for the public organisations' design team, they will provide a proposal based on quality and technical effectiveness, and whether the design can save costs. So apart from cost, quality is very important to the client.

Indeed, the researcher's review of the literature (Abdul-Rahman, 1997; El-Sayegh, 2008; Sambasivan and Soon, 2007) confirmed the public organisations' concern with quality, highlighting acute disruptive events caused by poor workmanship on-site, often the contractors' fault. However, the contractors and consultants surveyed took quality for granted and did not perceive it as a key or frequent cause of disruption in public projects. An expert from the public organisations (PO3) explained that,

> Sometimes the disruption arises from the contractors when they select their team. The team they choose sometimes does not care to comply with our quality standards. As long as they construct the building, they do not care about whether they follow the concrete grade specification, the right formwork. This effects the quality of the work. This is because they want to cut cost. So contractors usually find areas where they can cut their costs, they will try to do that the best that they can to make a profit. But the public organisations already identify the quality or checklist of things that we want.

This shows the diverse goals between the public organisations and contractors in terms of prioritising quality versus cost, which could affect public project performance.

Failure of key customers

On the other hand, the contractors and consultants seem to have experienced several episodes of acute disruptions caused by their key supplier or customer (17%). Both contractors (CO2 and CO3) and consultants (CS1 and CS2) seem to be in agreement in raising the issue relating to the failure of their key customers, in this case, the public organisations who, they claimed, always make frequent design changes and take a long time in finalising their decisions, causing disruption to the design and construction operations,

> Due to added pressure by the client or higher authorities, the public organisations get stressed and keep asking us to review the designs many times, and up until the last minute, we are still reviewing drawings. (CS2)

> Clients like to follow their heart and change designs as and when they like, and want it immediately, like tomorrow. So it depends, everyone is forced to work against an unrealistic deadline. (CO3)

The analysis of the supply chains and the different perspectives of the public and private organisations (contractors and consultants) suggests diverse concerns relating to the perceived cause of acute disruptions. Ironically, considering that the public organisations blame quality problems on the contractors' deficiencies, and that the private organisations blame failure oo their customers (i.e. the public organisations) as the most frequent disruptions in public projects, this suggests a possible issue of *trust* between the two groups of respondents.

Failure of key suppliers

In terms of the failure of key suppliers, the result of this study is consistent with data obtained in similar studies conducted in other developing countries such as Vietnam (Le-Hoai et al., 2008) and Nigeria (Aibinu and Odeyinka, 2006), whereby shortage of materials due to unreliable suppliers and sub-contractors' or suppliers' slow mobilisation of materials was perceived to be in the top five most frequent causes of delay and cost overruns in local construction projects. Suppliers here are referred to as external organisations that supply the materials, information or services required for the respondents' operations. One of the contractors (CO2) stated that,

> Usually what happens with suppliers is the delay during supply. Their reason usually is because the material is imported from other countries and the shipping caused delay. So the supply to site is late because some suppliers acquire resources from outside the country. When the supply to site is late, it will affect our construction completion date.

Another contractor (CO3) addressed his experience in dealing with inconsistencies in the quality of the materials imported by their suppliers,

> ….usually the material or sample that we initially approved was good, the ones we test are the correct ones from the supplier in China. But later when the actual material arrives on site, the quality is different. That is the problem when dealing with imported materials. Such as imported steel, the sample that the supplier sends sometimes has a different composition from that delivered to site; the material property that arrives on-site differs.

A consultant (CS1) also addressed frequent disruptions due to the failure of their key supplier of information (the utility organisations), It does not necessarily mean that the information that the utility provider gave is correct, it is usually a 50-50 scenario. When we receive such data from them on the mapping of existing cables on site before we started designing the roadworks, we usually comment and check the same data over three times to ensure whether it is correct. This inconsistency in the information provided causes delays to our design work. Sometimes we are forced to make our own assumptions.

On the other hand, the acuteness of this factor might also be due to the effect of the supply chain relationships with private clients (see supply chain network in Figure 2.4) where the same key suppliers or customers might pose a threat of disruption, resulting in interdependent impacts on other supply chains. This is evident in the case highlighted by Contractor (CO3),

…one other thing that affects our construction is, as we are a developing country, when we want to implement something, our raw material actually is not there, for example, steel bars. So at the end of the day when all the public and private projects overlap or clash, especially with a mega-rail project like Mass Rapid Transit that begins at the same time as our government hospital project, the demand for steel becomes very high. At the end of the day the supplier increases the price. There is no consistency.

Given that the contractors and consultants could be doing one public project with several private projects involving international suppliers, the failure of any supplier or customer arising from not only the public but also the private sector-initiated supply chains could disrupt all the contractors' operations.

Financial crisis

Financial crisis was highlighted by both the public (16%) and private organisations (17%) as one of the most frequent disruptive events faced. As discussed in Section 2.2.1, the volatility of the Malaysian economy indeed affects the construction industry's operation. According to Contractor CO1,

When the oil price increases, the material and transportation prices increase. For this recent public project, we had financial problems due to the increase in oil price, and I had to absorb all the losses.

Contractor CO3 pointed out similar issues on how the devaluation of the Ringgit Malaysia against major currencies affected their financial cash flow,

So the problem that we are facing now is the currency that goes up and down, that is very bad. There are a lot of building components that are actually affected by the currency such as steel. So when we tendered for the hospital project, the exchange rate was RM3.20 to 1 US dollar. But now it is 4 US dollars, an 80 cents increase. If we consider the cost of equipment, say RM50 million, this means we are losing almost RM32 million. You see? If the currency goes up 20 or 30 cents it is still reasonable, but no, an 80 cents increase is high.

Payment issues due to financial constraints on the public organisations is also a problem in public projects. Interviewees from the different sectors held similar opinions,

> …the public organisations made late payments to the contractor. The contractor claimed today, but only received payment 12 months later. (CS3)

> The public organisations usually do not pay on time. Even if I worked like mad it does not guarantee that I will receive timely payment from the public organisations. (CO4)

> Sometimes we have to compromise on the objective based on the available budget, so not all objectives are achieved. Even if we produce the best design, in the end, the client does not have sufficient resources or budget, hence we cannot continue with the design. So we have to find an alternative solution. (PO1)

Similarly, a joint study by CIDB and University Malaya in 2006 had identified that payment issues were severe and a source of major concern to the construction industry; the majority of the 333 contractors surveyed faced delays in receiving payments during project delivery (CIDB, 2006). Subsequently, this late payment caused delay of the contractor's work progress due to the inadequate cash flow to support the construction expenditures (Sambasivan and Soon, 2007, Abd. Shukor et al., 2010), thus threatening the overall success of the construction project (Alaghbari et al., 2007). Financial problems such as delayed payments and financial difficulties in construction are also prevalent in other developed and developing countries such as in Vietnam (Le-Hoai et al., 2008), Jordan (Sweis et al., 2007), Nigeria (Aibinu and Odeyinka, 2006), Hong Kong (Lo et al., 2006), Kuwait (Koushki et al., 2005) and Ghana (Frimpong et al., 2003), making it imperative for the construction supply chain to improve their resilience to such financial disruptions.

Regulatory issues

The next most frequent disruption faced by both groups of respondents was regulatory issues (11%). This is reasonable as all public projects come under government rules and regulations; approval from different levels of the public organisations are needed before projects can be implemented, as pointed out by Expert PO3,

> …our strategy is tied up to contractual terms, politics and procedure. So we could not just alter things like that; if we want to do something that is out of the procedure, we have to go one step higher by meeting with the higher level authority or minister.

Another expert from the public organisation (PO1) and consultant organisation (CS1) contended that some of the government procedures that take a long time could be disruptive to the public project, especially when recovering from a disruptive event (e.g. design changes, change of budget),

> When design changes occur, the design itself is easy and can be completed quite fast. But this process does not involve the design only, it involves revising the Bill of Quantities (BQ) and contract, there is a procedure for this. We have to coordinate with other parties and agencies and that usually take a lot of time. (PO1)
>
> To increase the allocated budget of a project is not an easy process. The public organisations have to prepare all the necessary documents to justify the increase in budget and request additional money from the relevant authorities. The decision will take a long time as it will go back and forth from the higher manager to us, the consultant. Procedurally, the public organisations usually request 10 working days for the higher level directors to make a decision. But in most cases, it takes a longer time than that. (CS1)

This shows how strict government regulations can hinder the project team members' operations in reacting to and recovering from disruptive events. This result, however, differs from similar studies (Le-hoai et al., 2008; Sambasivan and Soon, 2007; Lo et al., 2006) where obstacles from government regulations were not highlighted. Nevertheless, considering that the public organisations in this study are service providers for the government and are bound by its policy, treasury circulars, technical instructions and specifications, it is rational that strict regulations could restrict the supply chain's operations. The report by the CIDB (2008) highlighted a similar problem, where the government's unfavourable legislation and inefficient bureaucratic practices were the subject of complaint by local construction industry players in Malaysia, affecting public project delivery.

6.2.2 Critical Effects of Acute Disruptions in Public Projects

Delay and cost overruns

Based on Figure 4.2, the majority of the organisations found that the most critical effect of disruptions on project performance was delay in delivering products or services to customers (56%) and higher cost of operations (33%). This is consistent with the literature, where the frequent cost and time overruns have been stressed (Sambasivan and Soon, 2007; Abdul-Rahman et al., 2006; Ng et. al., 2001). Similarly, the survey conducted by Ahmad et al. (2009) on delays in the Malaysian construction industry revealed that the majority of their respondents had encountered delays in their projects 10 to 40% in excess of the actual contract duration. Another report also found that 80% of government projects faced significant delay (Joshi, 2009). Indeed, the issue of delay and cost overruns is evidently a concern shared across the respondents in this study. The factors that contributed to time and cost overruns, such as the frequent disruptive events (i.e. quality problems, failure of key suppliers), could arise from any part of the supply chain, including client, public organisations and contractors. For instance, two experts from the public organisations pointed out how disruption due to the client's constant design changes had caused significant delay and cost overruns to their operations,

> …due to delay in decision making we rescheduled and we gave the client another deadline to finalise their decisions on the design. But they have still have not finalised the design , and this has caused delay to the overall construction works and discrepancies in costs. (PO1)

> …during the initial phase of the project, there is also delay due to the client's requirement that caused us to keep revising the design. This affects a lot of other things. For instance, there were additional changes to the interior design's (ID) lighting works. So basically, even though in terms of the work programme the ID works can be conducted at the end, the information needs to be gathered much earlier. Because after they agree, only then can we fabricate the lights at the factory, which takes time. (PO6)

It is worth noting here that the client could also be affected by additional professional fees and possibly a reduced return in their investments when projects face such significant delays (Endut et al., 2009). It is also evident here that late decision making by the client could affect the public organisations' timely decision making on subsequent work. It was therefore not surprising that Expert PO4 and Contractor CO1 reported significant delays due to the late decision making on the public organisations' side in some public projects,

> …the public organisations delayed for about five to six months in appointing the contractor. They ended up giving the appointment letter in just an ad-hoc manner. Like in a forced way, they had to do it because it was too late. That caused the substantial delay to the subsequent works. (PO4)

> The project was delayed for three years due to late land acquisition by the public organisations. That was really slow, the original contract was three years, but the project was completed in six years with significant high cost overruns. (CO1)

It might be the case here that the frequent disruption by regulatory issues previously reported by the public organisations had caused the length of time it took for approvals and decision making. Apart from the client and public organisations, delay could also arise from the bottom tiers of the supply chain, such as the contractors and suppliers, as highlighted by Consultant CS3,

> …the bridge project faced delay about one year due to the contractor's mismanagement in terms of their communication with their team on-site. The procurement of the material from the suppliers was also really late, which had caused significant time overruns during construction.

Indeed, past researchers (Koushki et al., 2005; Frimpong et al., 2003) shared similar views that construction projects often faced delays in the procurement and arrival of material on-site, holding up the overall completion date. In most cases, surplus material was also on site after project completion (Abdul-Rahman and Alidrisyi, 1994), causing significant construction waste. It is therefore reasonable that the failure of key supplier was perceived by the contractors and consultants to be the most frequent disruptive event in the survey, as previously discussed (see Figure 4.1). The critical effect of delay and cost overruns due to external parties was also evident in the disruptions highlighted by the contractors,

> …the utility companies delayed their operation in relocating the existing utilities on-site because for them, it is not urgent. But for the public organisations, it is urgent and for us, the contractor, it is urgent. If they do not do the relocation, we cannot proceed with our work on site and the project faces delay. That is the conflict. (CO1)

> We faced severe disruptions due to design failure by the consultants engaged. It becomes a big problem to contractors when design fails, it is not a minor problem. The worst thing was that the structural design failure was identified after everything had been completed. So the project was put on a halt and we had to demolish the building and redo it. That is the worst disruption I have ever faced. The project faced delay for a long time, delayed for five years, and of course, the costs exceeded the budget tremendously. (CO4)

This shows how timely and costly it is for not just the public organisations but for the contractors as well to get the public projects back on track once disrupted. Hence, albeit the various scale and magnitude of disruptive events, the critical effect is definitely felt across the supply chain. This is a great concern as about 17.3% of 417 public projects in Malaysia were considered 'sick projects' in 2005, facing more than three months of delay or, even worse, being abandoned (Sambasivan and Soon, 2007). Furthermore, when delay occurs, disputes often arise between the public organisations and the contractor on the contractual terms in deciding whether the contractor is entitled to claim for the extra cost incurred. Certainly, delay is considered a major cause of construction claims (Abdul-Rahman et al., 2006) that affect both the public organisations' and contractor's finance. The duration of the construction projects is either extended or accelerated when delay occurs, contributing to the critical effect of cost overruns (Sambasivan and Soon, 2007), as reflected in the survey results. Ultimately, the findings imply that the public organisations are still vulnerable in managing and controlling the costs, design and scope of public projects, seriously exposing their supply chain to the critical effect of time and cost overruns. The interdependencies between the supply chain's operations also make it imperative for all parties to work together in building their resilience to such disruptive events in an effort to improve public project performance.

Defects in quality

Surprisingly enough, as with the previous results on frequent disruptions, the contractors and consultants did not find defects in quality as one of the critical effects of disruptions (7%), despite the assertion in previous studies that the risk of disruptions could hamper the quality of construction projects (Ibrahim et al., 2010; Le-Hoai et al., 2008; Pratt, 2000). The public organisations, however, have a different view on this and placed higher pressure on defects in quality (21%) as one of the major effects of disruptions. This is possibly due to the fact that as a public government body, any delay, quality problem or other disruption faced by these organisations has a significant impact on their reputation in the public's eyes. For instance, when public roadworks face quality problems, the public organisations are hit by constant complaints from the local road users, as reflected by Expert PO1,

> For instance, the ELITE highway that collapsed has still not been settled. Media coverage of the case and complaints by the public put pressure on us to resolve the issue quickly. We ended up suffering because the public put pressure to us to settle this within two days, which is unrealistic.

It is indeed difficult to meet the high expectations of quality in public projects. The same expert added that most of the times, the locals underestimate the amount of work that has to be done in recovering from such quality defects. This includes diverting the traffic, engaging contractors to do the recovery, and improving the overall quality of the road. He further argued that,

> …such quality problems become a social problem, not technical any more because people do not understand why we have to design the road a certain way. When we talk with people in the same field it is easier, but as a user, their perspectives are different. All they know is that they want to drive to their destination quickly, they are not considerate. We have to compromise on certain aspects, and not everybody is happy.

This is one of the reasons why maintaining quality is important to the public organisations. Furthermore, as previously discussed, quality problems often arise due to deficiencies of operations in the construction phase. Expert PO2 emphasised how defects in quality could result from the inconsistencies of material provided by the suppliers,

> …let's say the material is made off-site. Like in this project now, the suppliers send the completed mixed concrete on-site, but how are you going to control the quality? We have this problem that because the suppliers want to make money, they want to optimise their mix. Sometimes we found slippage in our concreting because we did not get the right quality of mix, and this disrupts our work progress. So we had to hack back the concrete three times and redo the work. We still have not achieved the concrete strength that we want right now.

In this case, the quality of the concrete they tested had only achieved marginal strength. Subsequently, the section of the building that was already built using the supplier's mixed concrete had cracked, causing substantial rework and disrupting the overall work progress. Hence, the incompetence of other parties in the supply chain can affect the level of quality of the public organisations' operations. The frequent financial crises reported earlier by the respondents could also be a contributory factor to quality issues, as cash-flow problems may result in the contractors or suppliers sacrificing quality to save costs. Abdul-Aziz (2001) and Sambasivan and Soon (2007) also raised concerns about the quality of work provided by unskilled foreign workers. The Malaysian construction industry relies heavily on foreign workers, who come predominantly from neighbouring Indonesia (MALBEX, 2005). However, Sambasivan and Soon (2007) contended that some of them are illegal workers and are not as well trained as the local labourers in carrying out the work on-site. Indeed, Contractor CO4 shared his difficulties in dealing with the foreign workers,

> At one time I worked with more than 300 workers from Indonesia. It is just tiring in terms of answering their queries because they are not as competent as us and do not think ahead yet. If we say A, they will do A only, they do not know where to modify or alter works if problems arise. Like for plastering, they will do just plastering.

Consequently, unskilled foreign workers could hamper the quality and efficiency of the project delivery. The same contractor further justified why he prefers to engage his own foreign workers,

> I hire my own foreign workers from Indonesia and train them because I am brave enough to take that risk. If I want to make my job easier, I will sub the works to other labour under the sub-contractors. But by hiring my own foreign workers, I can get more profit than what was stated in the Bills of Quantities (BQ); instead of RM2 million, I can get profit up to RM3 million. So it all depends on the risk the contractor is willing to take, because it is indeed a high risk to train your own foreign labour.

Ultimately, it can be seen from interviewee PO2's and CO4's experience that there is a degree of inconsistency in the goals set by the public organisations and those of the suppliers or contractors in terms of prioritising profit as opposed to quality, which could affect the public projects' overall performance. This scenario is indeed not ideal to encourage quality in the supply chain operations. Hence, substantial improvements are needed by both parties to achieve and maintain quality standards in public projects.

Loss of productivity

On the other hand, the contractors and consultants reported having faced higher critical effects of disruptions on their internal performance: loss of productivity (16%), decrease in profit (15%) and loss of skilled workers (9%). Based on Figure 4.2, the contractors and consultants rated loss of productivity as one of the top three critical effects of disruptions on their operations. These results are in line with the findings identified in the Business Continuity Institute's (2014) survey of the global construction sector, whereby the loss of productivity was reported to be one of the key consequences of supply chain disruptions, above increased cost of working and loss of revenue. Certainly, researchers in the Malaysian construction industry (Abdul-Kadir et al. 2005, Ibrahim et al., 2010; Durdyev et al., 2016) have acknowledged that it is facing low productivity due to inadequate technology usage, over-dependence on foreign workers, poor performance monitoring and control, unskilled labour, shortage of construction manpower, and material supply. It seems that other developing countries are facing similar issues: constant rework, inadequate equipment and the lack of materials were perceived as major constraints to construction productivity in Nigeria (Olomolaiye et al., 1987). Issues such as the method and technology adopted in the construction projects, planning and supervisory system, as well as weather and site conditions, are major factors affecting sub-contractors' productivity in Iran (Ghoddousi and Hosseini, 2012). In the case of the public sector supply chain, poor productivity can be attributed to inefficient practices within the supply chain operations. These include the previously discussed client's constant design changes mentioned by interviewees PO1, PO6, CS2 and CO3, and inconsistencies in the quality of the workmanship on-site highlighted by interviewees PO3 and CO3. External factors such as fluctuation in material prices addressed by Contractors CO1 and CO3, and the lengthy government regulations pointed out by interviewees PO3, PO1 and CS1, could also affect the level of productivity in delivering public projects. Moreover, Contractor CO3 found that the size of the construction organisation could also affect their level of productivity,

> Large companies have too many layers of authority causing slow decision making. It is not easy to go straight to the board of directors in large companies to make decisions and it is not the directors' priority to manage problems as they have other things to do. For us, a medium-sized company, we do not have a project manager, but we have a project director who reports to me daily. Sometimes I call him hourly. So we are more productive and efficient in terms of handling problems on-site. It is different with the big companies, I do not think the director will call the lower level project director or go all the way to the supervisor to ask what is the problem?

Ultimately, this contractor believes that small and medium-sized construction organisations are more productive and efficient because all of the work is done within the company without too many layers or departments. Contractor CO1 added that increasing productivity is crucial, especially when recovering from disruptive events,

> …we did the recovery day-to-day, by having daily targets to overcome the delay. For recovery we added more machines and manpower to recover from the disruptive events. We want to increase productivity and cut time.

Indeed, looking at the contractor's operations, their main inputs are labour, materials, machinery, services, sub-contractors, suppliers, profits and other costs (Bernold and AbouRizk, 2010). Hence, any disruptions due to the failure of their manpower and resources will affect their level of productivity.

Decrease in profit

The survey results revealed that the contractors also faced higher loss of profit in their operations than the public organisations. Understandably, when construction projects face time overruns, the contractors' performance will be seriously affected, resulting in increased costs in their operations and reduced profit margins (Endut et al., 2009). For instance, Contractor CO1 shared his experience in dealing with the loss of profit due to late land acquisition by the public organisations,

> We had to bear a lot of loss due to the delay in land acquisition. We lost about RM8 million due to this problem. We had to fight with the public organisations to justify the claims for the loss and expense incurred due to late land acquisition.

Disruptions arising from incompetent sub-contractors also affected contractors' profits, as pointed out by Contractor CO4,

> Problems arise when the sub-contractors do not perform. Because the schedule and timeline is under the main contractor, the one who bears the loss is the main contractor. So if when sub-contractors do not perform on time, the contractor's time and money will be affected.

This shows the level of interconnected risks between the supply chain operations, whereby disruptions caused by other parties in the supply chain (i.e. public organisations, sub-contractors) can ultimately affect the contractor's level of profit. Furthermore, Contractor CO3 shared his concern in dealing with very low profit margins when undertaking public projects adopting the Industrialised Building System (IBS),

> If 80% of the contract cost is to be spent on the suppliers for the IBS components, how much does the main contractor need to mark up their price in the tender to get profit? Just imagine, if that project is RM5 million for a school, the IBS component alone is over RM3 million, and the remaining RM2 million is for the main contractor to construct it.

In this case, the contractor had to make large initial payments to the supplier for the IBS components. A large amount of the contract sum was therefore spent on the supplier's operations, resulting in the contractor working with a limited profit margin. Evidently, this shows the high exposure of contractors to losses in construction projects. On the other hand, the public organisations (4%) do not perceive the loss of profit as a critical impact, possibly because they are more concerned about the cost effectiveness of the project and ensuring that the public's money is spent wisely (see Section 2.2.1). Certainly, this is a different case from the private organisations, because as a business entity, maintaining and gaining profit is even more crucial for the long-term survival of these organisations. The lack of ability to bounce back from disruptions in construction, however, could impede the progress of their operation, causing immediate and long-term negative impacts on the growth of their business.

Loss of skilled workers

The survey also highlighted that some of the contractors and consultants were affected by the loss of skilled workers in their operations. Indeed, Ofori (2012) found that the lack of skilled construction workers is prevalent, especially in developing countries, due to the inadequate training of the workforce. Contractor CO2 explained that,

> It is not easy to develop the required skills, especially for foreign workers, due to the language barriers and their existing skills or knowledge. Maybe in their country, they serve as a farmer, and suddenly when they come here they have to use tools such as hammer and material such as concrete. Indeed the beginning is always a problem. What we can do is train them and give them just general work at the beginning.

It is indeed challenging to deal with a construction workforce that does not provide the quality of service that the local professionals are used to (Ofori, 2012). Another contractor (CO3) contended that the Malaysian construction industry still needs to rely on foreign workers because the local people will not do this kind of 'dirty and dangerous' work in construction,

> …some people do not agree with engaging foreign workers, but for the people who are actually involved in the industry like us, without the foreign workers, who wants to do the work? Out of 22 to 25 million people in Malaysia, the skilled workers that we have constitute about 30 percent. So foreign workers are favourable to my industry. But when the government stops foreign work applications and do a lot of raids on-site, despite having a work permit or not, these workers will run away. And we end up facing the loss of workers on-site.

He added that the construction industry will not move forward without the engagement of foreign workers. Similarly, Ibrahim et al. (2010) found that the construction industry's human resources were a key issue with a significant impact on the Malaysian construction industry's performance in meeting demands.Two of the contractors interviewed also addressed their concerns regarding the local consultants' current level of knowledge and skills,

> …even though the consultant engineers do the design, it does not mean that they can construct. Let's say they want to use Y32 steel bars in their design, that is big, with the spacing between the bars, 8 millimetres. They do not even know if there are enough spaces to pour the concrete in between the steel gaps. You see? Engineers, but they do not know up to that level. But people like us, who work on-site, would know. With the spacing they suggested between the bars, we know there is a risk that we will not be able to pour the concrete in that small space.

Hence, in reality, despite being qualified as professional engineers, some of the consultants' or designers' knowledge could not be applied to what is actually on site. This shows the great discrepancies between the consultants who plan, design (including both architectural and engineering), and prepare documentation and the parties who plan, implement and execute the actual construction on-site, such as the contractors (Ibrahim et al., 2010). Contractor CO4 had a similar view,

> The local engineers think they are smarter, but the fact is, sometimes they do not know the actual work on-site. The labourers on-site are sometimes smarter than the local engineers. For instance, we usually have to calculate first, one tonne of Y32 steel bars equals how many numbers of bars? But the workers on-site can straight away tell us that one tonne equals 12 bars, they know more than us. But in the end, the engineer gets the credit.

Subsequently, the inadequate level of skills among the project team members could be problematic, causing the significant loss of productivity previously discussed in the supply chain's operations.

Reputation damage

Unlike the contractors and consultants, the public organisations perceived that disruptions could critically damage their reputation (14%). This is possibly due to the sensitivity of reputation in the eyes of the public higher up the hierarchy. It can be observed through the survey results that the risks in time, cost and quality impacts frequently damaged their reputation. According to one interviewee from the public organisations (PO3),

> …if we do not solve our problems, the client, public and media will not trust us any more. Indeed, when disruptions arise, the public organisations' reputation is at stake, and it is shameful if we do not provide the quality of services that we are expected to give. It also involves the pride of the different state and the country.

Indeed, the public organisations are highly exposed to public scrutiny as they play a significant role in providing major infrastructure to achieve the nation's socio-economic needs and raise the national quality of life and standard of living (Othman et al., 2006). It is evident from the interviews that the public organisations still faced various complaints from the public and their stakeholders on project performance. For instance, the interviewees highlighted various complaints from the public on the newly upgraded highway projects delivered by the public organisations. Consultant CS2 pointed out complaints by local road users in rural areas due to drastic changes in the traffic flow; Consultant CS1 mentioned the significant pressure the project team faced from the media to fix a collapsed road very quickly; while Expert PO5 highlighted that they are not able to entertain all public complaints because it is not feasible to fulfil everyone's requirements. Another expert from the public organisations (PO2) explained that,

> When we work we need to have two sets of skills, the hard skills for the technical work, and soft skills as well. Soft skills are the ones we need in terms of how you want to deal with the complaints from local people who do not have the same understanding as an engineer or manager. It depends on how do you want to deal with them. We have to handle complaints individually and give them justification.

Indeed, dealing with the public that does not have the same technical background as the construction professionals could affect the public's perception of the public organisations' operations. Contractor CO4 shared his experiences in controlling the impact of a design failure in a completed public project,

> The project was in the middle of the city, so when it stopped due to design failure, the public organisations did not want the public or media to know. So we had to demolish the building by excavating it slowly so that people could not see what we actually did on-site. We could not straight away bulldoze it and demolish everything. The people only know that the building there is not completed yet.

This shows how important it is to prevent the impact of disruption from spreading, in order to maintain the public organisations' reputation. An article in the *Malay Mail* entitled, "We must learn from past disasters" (2009) highlighted one of the worst disasters faced by the public organisations, when the roof of the completed Sultan Mizan Zainal Abidin Stadium in Kuala Terengganu, that had cost RM292 million, collapsed. This questioned the professional conduct of the various parties involved in the construction of the stadium, and the public demanded a thorough and transparent investigation at the time of the incident (*Malay Mail*, 2009). Undeniably, cases like this could reduce the public's confidence in the public organisations. It is therefore very important for public projects to be completed on time and to meet the quality standards, as the clients, users, stakeholders and the general public usually look at project success in relation to time, quality and cost (Lim and Mohamed, 2000). On the other hand, the private organisations (7%) do not consider reputational damage as one of the critical impacts of disruptions. As discussed in Section 2.2.1, they have much more flexibility in their operations than do public organisations, as they are not responsible for handling the public's money.

Overall, the discrepancies between the public and private organisations' perceptions in this survey suggest that they have different priorities, with the former's main concern being higher quality and public reputation, and the latter's, as business entities, the long-term profitability of their operations. This degree of dissimilar goals within the same supply chain is problematic considering the interconnected risks they share (see interdependency in Sections 1.1 and 2.3). Finding common ground or mutual objectives is therefore imperative to reduce the impact of disruptions in public projects and build supply chain resilience.

Table 6.1 summarises the key findings on frequent disruptive events and the critical effects of acute disruptions in public projects.

Table 6.1: Summary of the frequent disruptive events and the critical effects in public projects

Frequent disruptive events in public projects	Critical effects of acute disruptions
1. Quality problems due to poor workmanship on-site 2. Failure of key customers including frequent design changes by client 3. Failure of key suppliers (including utility companies) due to delay in supplying materials and inconsistent information shared 4. Financial crisis due to devaluation of currency and late payment by public organisations 5. Regulatory issues such as strict government regulations and layers of approval	1. Delay and cost overruns in operations 2. Defects in quality due to poor workmanship and material supply 3. Loss of productivity due to inefficient practices in operations 4. Decrease in profit faced by private organisations 5. Loss of skilled workers on-site 6. Reputational damage to the public organisations

6.2.3 Level of Frequency and Severity of Disruptions in Public Projects

One of the key findings identified in the survey is the statistically significant differences in the scores on the perceptions of level of disruption frequency among the public organisations, contractors and consultants, as shown in Figure 4.3 and the Kruskal-Wallis test in Table 4.5. Over half of the respondents from the private organisations reported that they often or always face disruptions in dealing with public projects. Further detailed statistical results showed that the contractors from the private organisations overall recorded a higher mean rank, 70.08, than the public organisations (mean rank = 47.68) and consultants (mean rank = 47.63) in rating the level of frequency of disruptions in public projects. This indicates that despite all parties in the supply chain facing disruptions, disruptive events were perceived to have originated in the contractors' operations from the bottom tier of the supply chain (see Figure 2.4) during public project delivery. Considering the interdependence of the design-construction process in a construction project, it might be that inefficiencies earlier in the supply chain are realised at the construction phase, in which the contractors are mainly involved. An expert from the public organisation (PO2) who supervises construction work on-site contended that,

> Usually problems arise at the planning phase and spread to the procurement, design, construction until the handing over phase. Because everything is done based on planning.

Indeed, Hamid et al. (2008) argued that disruptions during construction frequently arise as a result of poor integration and deficiencies in the pre-construction phase, which subsequently leave the parties involved in the following construction phase exposed to potential disruptions and the impact of such inefficiencies. An interviewee from the public organisations (PO4) highlighted a similar case in which frequent disruptions occurred during the construction phase of a public sports hall project, due to poor planning and late awarding of the contractor at the tendering phase. In this case, the time was fixed as the construction had to be completed before the fixed date of a sports event that would be held at the hall,

> None of the deficiencies at the pre-construction phase, such as late decision making on procurement, unclear drawings, and the scope of work not being presented well in the public organisations' negotiation with the contractor, was rectified before construction began. From this point onwards, those issues accumulated over time causing all these disruptions during construction. The construction period was supposed to be eight to ten months, but it was reduced to three months because of the late appointment of the contractor. In the end, it became a rushed job. When the time is short, it affects the contractor's resourcing and capacity, resulting in low flexibility for the contractor to make any design changes.

This example shows how deficiencies in the earlier pre-construction phase could disrupt the subsequent construction phase if not managed properly. Abdul-Karim (2008) also reported that public projects in the Ninth Malaysia Plan (2006 to 2010) had faced problems associated with acquiring the list of projects from ministries, preparing resources and master plans, and inadequate briefing, causing delay to the project delivery on-site. The fact that the public organisations and consultants did not acknowledge this in the survey suggests that the risks might have been transferred to the contractors at the subsequent construction phase, explaining the high frequency of disruptions reported by the contractors.

In terms of the impact of the disruptive events, the majority of respondents from both the public and private organisations dealt with the disruptions in public projects as part of business-as-usual, as depicted in Figure 4.4. As discussed in Sections 1.1 and 1.2, disruptions often occur in the day-to-day operations of the construction industry, perhaps explaining why most respondents dealt with disruptive events as part of the project delivery process. However, a further Kruskal-Wallis test (Table 4.5) revealed that the disruptions overall had a greater impact on contractors than on the consultants and the public organisations. The greater repercussion of disruptions on the contractors compared to other parties in the supply chain is of great concern as it suggests that most of the risk of disruptions is borne by the contractors. This does not necessarily mean that the contractors are more vulnerable to disruptions than the other parties; rather, it may be that the present practice in the industry is that the contractors are expected to bear the impact of many risks, whether they could appropriately manage them or not (Ahmed et al., 1999). Contractors CO4 claimed that,

> When we do not foresee problems during the planning phase, our construction will be really bad, the impact is bad to our construction. The public organisations should be better prepared at the planning and design phase because the moment they fail, we at the construction phase are the ones who will receive the severe consequences and are likely to fail too. The project cost will increase and we have to do so many things to recover on-site.

However, it should be noted that any disruptions affecting the contractors' work will eventually have an impact on the consultants, who will need to extend their consultancy services with no additional fees if delay occurs, and to the public organisations who will end up paying for the increased costs of these disruptions, as highlighted by the project manager from the public organisations (PO5). Hence, in building the resilience of the supply chain to disruptions, this interdependence is an important consideration as the risk of disruptions might have a knock-on effect on the upper tiers of the supply chain if not managed properly.

6.2.4 Current Disruption Management Approach employed by the Organisations

In managing disruptions, the majority of the respondents from the public organisations reported that risk management is adopted by their organisation (see Figure 4.5). This is reasonable, as risk management has been widely practised in the Malaysian construction industry. In this case, the public organisations have developed a standard guideline on risk management to be adopted by the project team and stakeholders in implementing public projects. This includes the general risk management process of identifying and analysing risks through workshops, prioritising risk based on likelihood and impact, developing risk-mitigation plans, and monitoring and reviewing risks during implementation (PWD, 2008). However, Expert PO1 pointed out that,

> Although we have a risk management plan, things usually do not follow according to plan during implementation. We sort of rush things to be done and do not work according to plan. We have the risk workshops and seminars, to beautify the process. But once we receive a project, it is usually not the case.

Hence, although ideally the public organisations should follow the risk management plan throughout the project delivery, the actual response departs from the plan in various ways depending on the circumstances. Expert PO4 justified why it is hard for the organisations to contain the disruption impacts despite having good planning, a project management plan, risk management workshops and scheduling,

> When disruption occurs, it has cascading effects and spreads. Until the reactive and recovery phase, there are still cascading effects that we have to deal with. So it is all firefighting after that. It is not like there was just one disruptive event and the impacts occur straight away, there were a series of preceding events that caused the project to suffer. Because in terms of planning, all the preparation was fine.

Indeed, the impacts of disruption are not always immediate. As discussed in Section 2.3.1, it may take time for the disruption to show its full impact on supply chain performance (Sheffi and Rice, 2005). On the other hand, it might also be that the segregation between the departments in the public organisations (discussed in Section 5.7) in delivering the planning, design, tender and construction phase makes it harder to implement the risk management plan effectively. The SO from the public organisation (PO2) stated that,

> Although the people from Head of Project Team (HOPT) do the risk management at the planning phase, I can only consider risk management during the planning work as a guide, but I can not use it on-site, because they only mention risks during the planning work. HOPT does not deal with contractors, we are the ones who are in charge of the contractor. So when it comes to me, when we want to start the construction, we have to do this risk workshop again, but only dealing with the risks during construction.

All the project team members and stakeholders, including civil and structural engineers, architects, mechanical and electrical engineers and utilities departments, are involved in this three-day risk workshop to discuss any variation orders or any changes and contractual matters in the construction phase. The SO also appoints her own risk manager to assess the risks on a monthly basis during construction in an attempt to reduce the risks with the rest of the project team. However, the SO expressed her concern at the lack of involvement of professionals from the public organsiations' planning team (HOPT) during the risk meeting on-site,

> HOPT do not always attend the site meeting, they only attend if I asked them to come. If I do not call them, they will not be there.

However, the planning team perceives that problems arise because the public organisations' state representatives do not adhere to the initial risk management plan provided by the HOPT. Expert PO4 from the HOPT contended that,

> Within the risk management that we did for the state representatives, we have stated that for instance, if the contractor's appointment is late, a lot of problems will occur. All in the details. And then when the things we said happened, we also have some sort of mitigation plan, because we have done the risk management right. The state representatives however did their own thing as they go along despite knowing from the risk management plan that the disruption impacts will occur.

In this case, Expert PO4 felt that the risk mitigation measures set up by the planning team were not effectively carried out by the public organisations' state representatives. This shows that despite having a comprehensive risk management system, the blame-game is still prevalent between the departments within the public organisations themselves. Consequently, poor coordination among these departments makes them vulnerable in responding efficiently to any potential risk of disruptions.

Apart from the conventional risk management approach, 16% of the public organisations also have disaster management plans in place to deal with disruptive events. Disaster management in Malaysia deals with natural disasters such as flood, which includes activities such as the 'detection' of flood through the collection of meteorological data, 'forecasting' flood through the interpretation of the data collected, and the dissemination of 'warnings' to the public (Billa et al., 2006). This differs considerably in the case of the contractors and consultants. Despite the fact that they have faced frequent serious disruptions due to natural disaster or severe weather conditions in their operations, compared to the public organisations (see Figure 4.1), only a small percentage (6%) of these private organisations employ disaster management in their operation. Instead, emergency management (21%) and crisis management (13%) are adopted by the contractors and consultants to handle disruptions, as highlighted by Consultant CS2,

> …if there is an accident, we have an emergency response team. It depends on the type of incident as well, the type of damage. If it involves small damages, we will respond within two hours, some response is within one day, and there are some cases where the recovery takes months. So that such emergency does not occur, we make plans first before it happens.

In this case, emergency management refers to the handling of incidents on-site such as accidents and the collapse of roadwork. On the other hand, crisis management refers to the handling of a disruption during construction that threatens the project team's high priority goals and demands a time-pressured response (Loosemore, 2000). An additional concern identified in the findings is that the majority of the contractors and consultants (28%) have no specific management in place to handle disruptions. Consultant CS3 found that, as a consultant, a formal risk management approach is not essential to their operations, unlike the contractor's operations that involve more risks,

> In terms of risk management, the contractor needs more risk management. Like for us consultants, we do not really practise risk management 100 percent, we just have it but do not really practise it.

On the other hand, the contractors seem to prefer to handle disruptions as they arise without engaging a specific risk manager, as explained by Contractor CO4,

> If it is a big project, we will engage a risk manager, but most of the time we just handle the risks ourselves. And usually we do not call the risk manager from the start; only when the project is sick do we call them. That is usually the case for contractors in Malaysia based on my observation. Because contractors in Malaysia do not like to pay blindly if their (risk manager) service is not needed. Same goes to safety officer, we only called them when needed.

Here, 'sick projects' are referred to as public projects that face a delay of more than three months, or are abandoned (Sambasivan and Soon, 2007). This ad-hoc approach to engaging the risk manager only when disruptions arise badly exposes the contractors to disruptive events. It was also clear from the interviews that the contractors are reluctant to invest in a risk manager because they want to save costs and maintain their profit. However, the lack of investment in proactive measures may result in costly recovery actions, as discussed in Section 6.2.2. On the other hand, it might also be the case that the contractors and consultants rely heavily on the public organisations' risk management meetings in managing disruptions,

> We do not have a specific risk manager. Usually we depend on the public organisations' project manager to manage the risks. (Contractor CO1)

> Every month we have a site meeting with the public organisations, contractor, supplier and sometimes, authority to discuss all the problems on-site. (Consultant CS3)

This is promising as it encourages collaboration among the public organisations and their supply chain members in handling disruptions collectively. However, during the risk meetings, the contractors do not share with the public organisations all their information on the risks they are currently facing in their operations,

> …as contractors, we are not putting all the risks to public organisations' risk team. We are not going to tell them all the risks, because sometimes it backfires on us. So we just tell them what is related to them only. For example like the poor supply of electricity, that is a risk, but that is the risk on our side. Same goes for labour, currency, finance, those risks are our risks that we have to overcome.(CO3)

> Like for risks, actually we do not encourage ourselves to create the risks that are already there, we will think whether it is worth for us to classify them as risks. Because in construction, everything is risk. So not everything is included in the risk meeting.(CO2)

In other words, the contractors seem to inform the public organisations' risk management team only of the potential risks of disruption if the risks are considered crucial to them. The lack of information shared on potential risks could ultimately hinder the public organisations' ability to detect any hidden problems that lie within their supply chain. Hence, it is not surprising that some of the contractors found that risk meetings were ineffective,

> …but most of the time with public organisations risk management meetings, the risk meeting can be repetitive because the problems were not solved.(CO3)

> …what we identify and list in risk meetings have already occurred, even though we tried to mitigate them, they still occur. And we do modify the plan slightly as there are new risks that we identify during construction that we did not foresee before this.(CO2)

This suggests that in some cases, the contractors adopt a firefighting approach to rectify the impacts of disruption, instead of during project delivery. Similarly, some of the respondents from the public organisations (15%) do not employ a risk management plan in their operations, as clarified by Expert PO4,

> …sometimes our stakeholders or clients do not adhere to the mitigation measures we stated in the risk management plan, and keep on making design changes. In the end, it becomes like ad-hoc actions, as we go along we settle the problem.

This shows that in some cases, the public organisations have to take a more reactive approach in reducing the impacts of disruptions due to the external parties' (stakeholders') failure to consider potential risks.

6.2.5 Respondents' Proposed Suggestions to Manage Disruptions

As shown in Figure 4.6, over half the total respondents find that planning is important in managing disruptions. Contractor CO3 believes that good planning can eliminate a lot of risks,

> …if you manage the risk earlier, which is proactive, then the risk will not be there, so there are no such reactive actions. So we override and think about that risks ahead, that is considered as planning. Better to be proactive.

However, he added that certain risks, like fluctuations in currency, will not work in this case, as they are outside their control. Contractor CO4, on the other hand, found that planning could help contractors to control potential disruptions from lack of finance,

> When talking about finance, it affects your planning. How do you plan your work? You must know your sequence of work, to what extent the finance will return to you, and how long before will you receive payment from the public organisations. You need to plan all that.

Meanwhile, Consultant CS1 acknowledged that planning the work is essential in order to understand each other's responsibilities and tasks and to coordinate the response between the project team in handling disruptions,

> Most importantly when you want to do the planning, you have to know the sequence of work. Who has to deal with who, this is under who's authority. This will result in prompt response.

Hence, all the respondents seem to agree that planning is important in their operations. Indeed, the results in Table 4.17 show that organisations with explicit disruption management strategies have higher capability scores in contingency planning. By having formal plans to cover a range of contingencies in the supply chain operations, they will be better prepared in responding to disruptions. However, it is worth noting that the success of a risk management plan depends on how well the developed contingency plans are implemented during disruptions (Berg et al., 2008). In this regard, the public sector supply chain must also work on how to implement the risk management plan effectively, as there are still mixed perceptions of the current risk management practice, as discussed in Section 6.2.4. Furthermore, Expert PO1 considered that more time should be spent on the planning phase in order to reduce the risks of disruptions,

> Planning should take a lot of time, it should take at least 40% of the overall project duration. In our case, we only allocate 5 to 10% of the project time for planning. Most of the time, 80% of the time we use for construction. For example, 10% planning, 80% construction, and 10% for the post-construction phase. So there is only limited time for planning, which is not right.

Increasing the time spent on planning could also reduce the severe impacts of disruptions felt by contractors in the subsequent construction phase, as reported in Section 6.2.3.

Collaboration with supply chain members was also perceived by the respondents in the survey as a key factor in mitigating disruptions. This was confirmed in the interviews,

> Looking at the World Bank study, our main problem is that we have no integration among parties. There should be no problems in construction if we have integration. From the bottom until the upper tiers of the chain, everyone play a part. It is like a single chain line, and if the chain is strong, we will be strong, our project will be completed on time or even ahead of time. (Expert PO1)

> We are trying to encourage this practice of collaboration, but to implement good practice takes a lot of effort and everyone's cooperation. Convincing people is not easy. (Consultant CS2)

This might be attributed to the *behaviour* pathogen discussed in earlier Section 5.8. Consultant CS2 added that one of the challenges to collaboration is the inconsistent goals between the project team members. This is in line with the results discussed in Section 6.2.2, that discrepancies exist between the public and private organisations' (contractors, suppliers) goals in terms of prioritising quality versus profit respectively. The survey respondents also identified that staff engagement and involvement in responding to disruptions are important in controlling the disruptions. Expert PO2 contended that,

> …when people are not included in the team, they will not feel like it is their problem. So if you make the problems their business, they themselves will not be a problem but become a problem solver instead in the team. More or less, their mentality changes a bit. If not, the people will stay in complacency state.

In other words, the project team members will feel committed when they are part of the problem, and thus are motivated to help to reduce disruptions. On the other hand, compared to the public organisations (14%), having insurance is perceived to be more important to contractors and consultants (19%) to recover from disruptions. However, the contractors interviewed found that insurance could be costly,

> Let's say the project is worth RM20 million, the work insurance alone, minimum is RM40,000 to 45,000.. We also have to pay 0.025% levy for total construction work contracts that exceed RM500,000 to the CIDB (Construction Industry Development Board) first, even before the work begins, it is like paying tax. So these alone have taken up our cash, at least 4 to 5% from the total amount of contract costs.(CO4)

This essentially means that before the contractors start work on-site, they have to spend money on things that are not physical, such as insurance. Hence, it is important for the contractors to manage their finance wisely in order to accommodate any potential losses that might result from disruptive events.

6.3 Critical Supply Chain Vulnerability Factors and Its Related Capabilities

The following discussions are based on the analysis presented in Section 4.4.

6.3.1 Political/Legal Pressures

Exposure to political disruptions

The construction industry, compared with other industries in Malaysia, experiences consistently more disruptions (Yin, 2006) as it is faced with constant changes in the environment that hamper the construction organisations' ability to survive and sustain growth in the industry (Abu-Bakar et al., 2011). Similarly, this survey reveals that challenges from external threats are still prevalent, particularly in the public sector supply chain. The most interesting result here is that what the public organisations perceived as their greatest external threat differs considerably from that perceived by the contractors and consultants as their greatest challenge arising from the volatile external environment. The detailed comparative analysis conducted using the Mann-Whitney U test (see Table 4.14) shows that while political/legal pressures were perceived as the greatest threat to the public organisations, this was not the case for the private organisations, where market pressures were identified as a greater problem affecting the contractors' and consultants' operations.

Understandably, the government bodies have an obligation to spend public money wisely, following a set of rules and regulations (Jaafar and Nuruddin. 2012), hence making them even more vulnerable to any political disruptions or changes in government rules. The public organisations are ultimately bound by the government's policy, treasury circulars, technical instructions and specifications (Ibrahim et al., 2010) in executing public projects. This is not to say that the contractors and consultants do not have to adhere to government policy; however, the case is different for the private organisations as they have much more autonomy when proceeding with a project award (Jaafar and Nuruddin, 2012; Gould, 1997). Unlike the private organisations, the public organisations are highly accountable and can be constantly questioned in terms of how they manage public assets and use taxpayers' money. Indeed, based on the results presented in Table 4.14, there is a significant difference between the public and private organisations' scores for the vulnerability sub-factor exposure to political disruptions, the former being significantly more vulnerable.

In this regard, the Malaysian public sector has frequently faced political interference especially during project award stages (Jaafar and Radzi, 2013), which contributes to the higher significance of this score within public sector projects. Expert PO1 addressed his concern on this matter,

> We should be transparent, everything should be open tender, but it did not happen. Ideally, we should tender it. Then only it is fair and square. Even after tendering, inside those parties there is this person and your person. So it is like politics. We as a technical body should have ethics, but cannot even manage this. It is hard.

In this case, the public organisations generally use the cut-off system in their open tender, whereby the contractor is selected according to the organisations' tender limit. However, Contractor CO4 observed that the public organisations do not always have the final say in selecting the contractor. He explained that,

> …because the public organisations does not supply the money. The ones who provide the finance, like the client, can give instructions, "I want this person, full stop". But the contractor's tender price must be reasonable too.

This shows that politics as well as monetary terms could disrupt the tender selection process. Subsequently, such political involvement could cause tensions among the project team members. The appointed contractor's competence is also questionable in this case, as pointed out by Expert PO2,

> Sometimes we do not know the contractor because during evaluation there could be political interference. There are cases where the contractor won the project but was not able to execute the job. He managed to sustain it for just a short time, for one year, then we have to terminate the contract because we know he cannot deliver the job.

Furthermore, Jaafar and Radzi (2013) argued that, regardless of the procurement system adopted, the strong tendency to political involvement in awarding public projects contributes to the increase in the number of contracting firms that are only interested in winning the contracts. This has consequently led to the contracting firms sub-letting the total project to other contractors or sub-contractors, which then raises the issue of payment due to the multi-layered sub-contracting. Political involvement may also affect the price of materials. Contractor CO4 pointed out that some material supply has been heavily politicised and monopolised,

> …it is political, steel is a monopolised item. Once there is political interference, we cannot do anything because they are the ones who control the price. For instance, we bought the steel at the factory based on the index price of RM3,800, but when making claims, the government used a lower RM2,800 index price as recommended by the National Trade Agency. But when we bought it, it was a different price. And then sometimes we have to pay in cash. This is the same problem that other contractors face, not just me.

The contractor may not be able to progress with their work due to the inconsistencies in the price of steel. Indeed, steel is a controlled item in Malaysia, and the National Trade Agency publishes the price index. However, it is evident in this case that there are differences between the published and the actual price paid by the contractor, as a result of political involvement. Political pressure can also disrupt the consultant's design work, as pointed out by Consultant CS2,

> Sometimes the public organisations want to review our designs at short notice, because they have been chased by higher authorities and politicians who kept asking about the project. So

> their boss got stressed and kept asking us how long will it take to finish? They want to review designs a lot of times, and up until the last minute, we are still reviewing drawings.

Frequent design changes cause delay in finalising the design drawings. Consultant CS1 observed that sometimes the impact of political interference is indirect,

> Political involvement, it can affect the project so that we cannot even see the connection, that's how powerful politics is. For instance, changes in political power when the project is ongoing. They (political party) can simply say, "stop this project, there is no need to construct the project here". Because of what? In another two weeks' time, he wants to make a speech there before the election.

This shows that political influences are sometimes not obvious but could have a catastrophic impact when they occur, such as halting public project operations. Hence, although the private organisations are not as badly exposed to political disruptions as the public organisations, the impact of political disruptions can spread across the supply chain, affecting the consultants, multiple contractors and sub-contractors and resulting in time and cost overruns.

Considering that such political influences have always been a problem in public projects, the public organisations are able to anticipate such disruptions in their operations. As previously discussed in Section 5.5, one interviewee from the public organisation (PO1) highlighted that political risk is the top risk listed in the list of risk priorities in public projects. This is consistent with the survey results on the public organisations' capabilities (see Section 4.4). The public organisations were reported to have good business intelligence (a top five capability sub-factor, Table 4.11) to anticipate the behaviour of their key players, including potential political interference. Nevertheless, despite this strength, their lack of transparency in communicating information not only with their stakeholders, but also with the contractors and consultants (rated as a moderate capability, 21 of 44 in Table 4.11) makes it hard to control the spread of political impacts on their supply chain operations. An interviewee from the public organisation (PO3) acknowledged that one of the things that the public organisations suffer from is poor communication with supply chain members. Clear communication, however, is important to facilitate collaborative decision making and counteract the critical political interference.

Table 6.2: Summary of the critical vulnerability of exposure to political disruptions

Critical Vulnerability Factor	Pathogens	Linked Capability Factors
Exposure to political disruptions	• *Practice* of lack of transparency in tender selection • *Circumstance* of unfavorable project team selection • *Practice* of acceleration in delivering plans due to added pressure by top authorities • *Circumstance* of monopolisation of material • *Practice* of frequent design changes due to added pressure by top authorities • *Circumstance* of changes in political power	C5. Anticipation of potential political disruptions C4.1 Business intelligence gathering C9.1 Communication with supply chain members C4.3 Collaborative information exchange

Changes in government regulations

On the other hand, there were no significant differences in score between the public and private organisations in the other sub-factors of changes in government regulations (see Table 4.14). This suggests that although the contractors' and consultants' operations are not as highly exposed to political disruptions as the public organisations, they are still to some degree affected by changes in government regulations. Certainly, regulatory frameworks involving multiple authorities at the federal, state and local levels that govern the construction industry in Malaysia can be very complex and difficult to navigate (CIDB, 2015). This is evident from the case highlighted by Expert PO1 in managing highway projects,

> The planning of roadworks involves two cities in making the public transport effective. Two cities that have different regulations or codes of practice, which makes it hard to get approval from both sides of authorities.

This makes the private organisations extremely vulnerable to differences in regulations which may vary from one state to another. It has also been reported that certain states place restrictions on architects and engineers gaining planning permission during the design phase of a project (CIDB, 2015). The regulations imposed affect not just public projects, but also private ones carried out by the contractors and consultants in a particular state. Consultant CS2 pointed out that the regulations set by the local authorities are unclear,

> Our planning permission is constantly rejected because of the unclear regulations, we had to make further amendments and resubmit. And when we have enquiries on the unclear terms, it is so hard to reach them by phone, we have to go to the office just to ask for clarification on the regulations. It's a waste of time.

This consultant added that they have to get planning permission from several departments in the local authorities, which have different regulations. For instance, the building design is approved by one department, and approval for the land use is from another department. Plus, not all the departments will approve the plans at the same time, causing delay in the planning approval process. Additionally, according to Consultant CS1, it takes two to three months just to get the official approval letter from the local authorities. He shared his frustration with the local authorities' delay in providing the official letter,

> I had to go to the local authority office to ask for the letter and collect the letter myself. And the letter was actually issued at an earlier date, they just didn't send it to us. So although it was approved, in black and white, we couldn't use the approval letter because of the issuance date, it was invalid.

Hence, inconsistency in regulations between different departments in the local authority could result in confusion and misinterpretation of the terms by different stakeholders. This reduces the ease of the private organisations in doing business, and could also create disputes between the public and private organisations that can be costly in terms of time, money and effort. Abdul-Aziz and Ali (2004) argued that quite often, the lack of knowledge of government regulations and procedures of the consultants engaged by the public organisations resulted in confusion over the terms in the regulations. This might be due the public organisations' layers of administrative procedures identified in the *organisation* pathogen, as discussed in Section 5.7. Smith and Gavin (1998) believe that this risk should be best managed by the owner (i.e. the public organisations), by including in the contract clear statements on the responsibilities of all parties under the regulations, and updating the private organisations on any new policies imposed. Interaction between private organisations and the government is also imperative and needs to be pragmatic as well as participatory in managing policy changes (Wu and Ramesh, 2013; Tan, 2010).

Table 6.3: Summary of the critical vulnerability of changes in government regulations

Critical Vulnerability Factor	Pathogens	Linked Capability Factors
Changes in government regulations	• *Convention* of complex regulations that are hard to navigate • *Convention* of inconsistent regulations imposed by different authorities • *Convention* of high bureaucracy in decision making process • *Organisation* structure with multiple departments	C1. Flexibility in approval process C8.1 Distributed decision-making C6. Anticipation of potential regulation changes C9. Collaboration with supply chain members

6.3.2 Market Pressures

Severe price fluctuation

Less than the public organisations, the survey highlighted that the contractors and consultants are seriously vulnerable to market pressures (see Table 4.14). The volatility of the external environment is felt most by the private sector, as expected. This essentially means that the contractors and consultants are highly susceptible to severe price fluctuation and strong price competition (both ranked in the top ten vulnerability sub-factors in Table 4.9) caused by the construction market and economy. The result, however, is surprising in that the contractors and consultants claimed to have good financial strength (a top three main capability in Table 4.12) to cover threats such as price fluctuations. This shows that financial strength alone is not sufficient to overcome the unforeseen bad economic conditions. Poor economic conditions, especially in developing countries, can affect a construction project in many ways, such as escalation of material prices (Toor and Ogunlana, 2008; Sweis et al., 2007; Frimpong et al., 2003), increase in the cost of financing due to higher interest rates (Toor and Ogunlana, 2008) and lower returns on investment once the project is completed (Hoe, 2013). Indeed, despite government attempts to boost the economy through infrastructure spending, it can be observed that the broader national economic troubles are taking their toll (Freitas, 2016). For instance, the knock-on effect of the falling Ringgit Malaysia resulted in increasing the cost of overseas materials and equipment, and consequently in local suppliers raising the price of scarce material. This led to the contractors facing severe price fluctuations, as in the case highlighted by Contractor CO3,

> …for example, the hospital project that we are doing right now, a lot of the medical equipment is actually imported. So with the currency that's now changing, the price increase drastically. That is the exposure to losses for the contractor on the financial part.

This shows how the contractors' vulnerability to price fluctuations can reduce their profit, as indicatedin the survey (see Section 6.2.2). In this case, even though the contractors can claim Variation of Price (VOP) from the public organisations for changes in material price, according to the majority of interviewees it takes a long time for the contractors to get approval and receive payment from the public organisations. This subsequently affects their cash flow, as illustrated by Contractor CO4,

> …because we use our money to buy the material. Contractors usually say they have the money, but at certain times, when it reaches a certain level, we do not have sufficient money. We have to bear these risks. Depends on the project, if the project is big, then the model will be higher.

On the other hand, contractual arrangements such as the design and build and turnkey contracts have a fixed price, so the contractors are unable to claim VOP, as the maximum contract sum has alrready been agreed. The contractor has to bear the financial risks of fluctuations in material prices in such cases. Contractor CO3 found that the risk of fluctuations is hard to manage, because disruption such as currency devaluation is outside the contractors' control. Indeed, price fluctuation is generally difficult to predict and is principally the result of the high inflationary trend, especially in developing countries (Le-Hoai et al., 2008). However, Contractor CO2 argued that contactors can reduce the impact of such disruption by being proactive and ordering the material much earlier, when the currency is stable, in order to lock the price,

> When the currency falls, like this parliament project, for the cable, lift, and computers that we imported, all the prices become higher. Because in the contract we don't have VOP, we have to lock the price of certain things much earlier by making the order in advance to be safe, even though we don't need the material right now. But there are materials that we ordered at the last minute, so for that we have to bear the costs.

This shows how important it is for the contractors to build their resilience by reserving imported materials ahead (a low capability sub-factor, ranked 38 of 44 in Table 4.13), in case the local currency falls. Meanwhile, Contractor CO1 opted for a more reactive approach, by modifying the method of construction and mode of transportation of materials when faced with the significant rise in the oil price. He also reduced the number of sub-contractors engaged to reduce the losses,

> What I did was, we reduced the sub-contractors, we did most of the work ourselves. If you reach sub-contractors, they will take at least 8 to 10% of the profit, so there was saving there. Before this we outsourced everything, we just managed the works on-site. But in this case, when this happened, with having to cut down the losses, we did it ourselves. So I only outsourced machinery.

This shows that adding flexibility to the contractors' operations (a bottom two capability factor in Table 4.12) and utilising their current resources (ranked 31 of 44 capability sub-factors in Table 4.13) could help in reducing the impact of disruption. These capabilities allow contractors to modify their operations (ranked 41 of 44 capability sub-factors in Table 4.13) and mobilise their resources quickly (ranked 33 of 44) in recovering from disruptions such as fluctuations in the price of materials. Nonetheless, the threat of price fluctuation would best be shared between both the public and private organisations by including contract clauses that define the required parameters and conditions for sharing (Smith and Gavin, 1998). This is because a rise in material price will also subsequently affect the public organisations, causing a substantial increase in the overall cost of the public projects. This could be problematic considering that cost overruns were reported to be one of the critical effects faced by the public organisations (Section 6.2.2). However, risk sharing between the public organisations and contractors is still rare (a bottom three capability sub-factor in Tables 4.11 and 4.13), suggesting the lack of agreement between the parties. Both parties should therefore find a middle ground where they can agree on the contract conditions to counteract price fluctuations.

Table 6.4: Summary of the critical vulnerability of severe price fluctuation

Critical Vulnerability Factor	Pathogens	Linked Capability Factors
Severe price fluctuation	• *Circumstance* of unpredictable economic conditions • *Circumstance* of contractual arrangements • *Convention* of late payment by public organisations • C*ircumstance* of monopolised materials • C*ircumstance* of limited material supply when in high demand	C2.1 Reserve capacity C1. Flexibility in operations C3.2 Resource utilisation C1.5 Fast re-routing of requirements C9.3 Risk sharing with contractual parties C12. Financial strength

Price pressures

Further detailed analysis in Table 4.14 also identified that the private organisations are significantly more vulnerable to price pressures than the public organisations. Understandably, unlike the public organisations, profitability of projects is their main priority in surviving in the competitive market of the construction industry, making them even more vulnerable to price pressures. It can be observed from the survey that the highly competitive construction market causes significant downward pressure on the private organisations' profits and market share, based on the low ranking of this capability (43 of 44 capability sub-factors in Table 4.13) by the contractors and consultants. The tender price of government projects is extremely competitive, especially in an open-tender system. Although this system is the best way to ensure completion of any project or contract at the lowest price, it is the most difficult obstacle any contractor has to face in the real competitive world (Yin, 2006). The contractors are burdened with the responsibility to produce good quality work at the cheapest price. In order to submit a tender at a competitive price, the contractors must make effective strategic decisions to obtain the cheapest rate from their suppliers, difficult in the current unpredictable economic conditions. Moreover, the majority of the contractors interviewed commented that the public organisations' goals for higher quality and low cost resulted in the under-pricing of tenders by contractors, eventually affecting their profit margin. Consequently, this under-pricing could severely increase the contractors' vulnerability to the fluctuations in material price, as evidenced in the survey result (ranked in the top 10 vulnerability sub-factors in Table 4.9). Contractor CO3 explained that although it may seem that large contractors have a better chance of winning public project tenders, given their strong financial background, this does not necessarily means that big companies can deliver a better quality job than the small contractors,

> Like me, we are a small company, but we deliver a job like our hospital right now that costs billions of RM. But who are we? We're small, we only have 20 people employed for the direct work. And my salary, is not like the CEO of the big companies. And I go to the site, I'm making decisions daily because in terms of the money, it is directly mine. Compared to other people in the big companies, you are the CEO and you have too many things to do, what is a couple of million RM job to you? You have to get another director to look after that project, a project manager, a contractor manager, etc. (CO3)

In other words, this contractor believes that small companies have a better competitive price than large companies as a result of their lower project overheads. However, Expert PO5 had an opposing view, arguing that in some cases large construction companies can offer more favourable pricing, because as long as they have other projects in hand that can sustain them, they can lower their profit margin in their tender price. He added that,

> Usually the small contractors' dilemma is that if they accept a low profit margin, they worry that they can not continue after the project is completed with no further project in hand. But if they put in a higher tender price, there is a high risk that they will not get the job.

Hence, the contractors' strategic decision plays a significant role in overcoming strong price competition. In this case, Chan and Pasquire (2002) and Solomon (1993) suggested that contractors can gain a competitive advantage by adjusting their project overheads. They tend to overlook the importance of project overhead estimates as they contribute to a relatively small percentage (15-30%) of the contract sum, but the main variations in the contractors' bids are the estimates for these indirect costs (Assaf et al., 1999, Chan and Pasquire, 2002). Reasonable pricing of project overheads will not only help to increase the chance of the contractor winning the bid, but also serve as a way for the contractor to gain profit. As confirmed by Contractor CO3,

> The big companies' overheads are very high, for the layers of departments and for the people who are not doing the actual job, but they are still overheads. But to us, every single man in the company, as long as they are getting their salary, they have a function there, otherwise they are out.

This shows how important it is for contractors to utilise their resources (a low capability, ranked 31 of 44 capability sub-factors) to maintain efficiency and gain competitive advantage.

Similarly, competition among consultants is high as the public projects contribute to their annual turnover. Obtaining repeat projects from the public organisations is essential in developing their portfolios for commercial reasons. However, unlike the contractor, the consultant's fees are fixed, as they are paid on the scale of fees determined by the Board of Engineering Malaysia. Consultant CS3 added that,

> Yes, definitely, there's a high market competition in public projects. But for consultants, whatever it is you can't give discounts like contractors, because we will be paid based on the scale of fees. So how do we lobby our service? We can only polish or showcase our technical know-how. And you can build the relationship with the client by maintaining social, good reputation, etc. It will take some time, but once people remember you, it gets easier.

Thus the competititive edge for the consultants in this case is their technical background and the quality of the service they have to offer. Both contractors and consultants also face market pressure from foreign players; several international parties have gained an increasing market share across various types of project in Malaysia over the last few years (CIDB, 2015). This threatens the private organisations' current market position, as reflected in the survey results (bottom two capability sub-factors in Table 4.13). Hence, in order to remain competitive and be on a par with the foreign competition, local private organisations have to be able to foresee the future market conditions during the contract period, increasing their chance of bidding at a competitive price and being awarded the contract (Yin, 2006). The private organisations could also utilise their current strength in gathering business information on possible market changes and the trends of their competitors (a top five capability sub-factor in Table 4.13) to design a more efficient process to reduce the cost of operation, thus maintaining a competitive advantage.

As already mentioned, good financial strength alone does not protect contractors and consultants from severe market pressure. Thus, while it is important to maintain their current financial strengths, the private organisations must also work on their weaknesses, such as developing their ability to anticipate and recover from potential market disruptions to survive in the long run; these are still weak, based on the low ranking of both capabilities (bottom five capability factors in Table 4.13). Learning from previous public tendering experience is also important, as suggested by Fu et al. (2003) who explained that frequent bidding opportunities for similar work contracts present contractors with ample learning opportunities which are then reflected in their competitiveness in bidding for contracts of similar types. Maintaining long-term relationships with their bottom-tier supply chain (i.e. sub-contractors, suppliers) is also important for the contractors to obtain the best prices for material from their domestic or foreign suppliers. However, Contractor CO4 founds that getting reasonable prices from specialists is hard because they control the payment from the start,

> Specialists are troublesome to us, they control the material and payment. You must pay 30% first, just to book them, but we only need the supply in two years' time, so our money has been buried there. So the ones who are making business is them. They hold 30% of our money, that's not fair. They have no competition. After that to ask them to go on-site, pay another 20%, then only they deliver the materials. And then when they start to do work on-site, we have to pay another 30% and so on.

In this case, the contractors are required to take the specialists proposed by the public organisation for certain items, and so have no choice but to adhere to the specialists' terms. It is therefore not surprising that the survey results show that the contractors' collaboration with their sub-contractors and suppliers is still poor, based on the lowest ranking of this main capability factor (see Table 4.12). Collaboration and partnership between the private organisations and the upper tier of supply chain members (i.e. public organisations) can also be improved to mitigate the negative effects arising from severe price competition. For consultants, maintaining a good reputation with the public organisations could promote partnerships in future projects, as highlighted by Consultant CS3,

> Whatever the client wants, we'll try to do it the best possible. So that they can remember, "ok, this consultant can really perform". When we perform, they know we can attend meetings on time, and the design is produced on time, tender is on time. So reputation is number one. And quality is important to the client. So we have to groom our capability in that area.

Matthews et al. (1996) suggested a semi-project partnering approach, meaning that the tendering process involves limited competition, so that price negotiations between the contractors and public organisations would be encouraged.

Table 6.5: Summary of the critical vulnerability of exposure to price pressures

Critical Vulnerability Factor	Pathogens	Linked Capability Factors
Price pressures	• C*ircumstance* of competitive open tender • *Circumstance* of unpredictable economic conditions • *Convention* of public organisations' goals for higher quality and low cost • *Practice* of underpricing by contractors • *Circumstance* of market pressures from foreign players • *Convention* of supplier controlling price • *Convention* of specialists selection by public organisations	C10.1 Market share C3. Efficiency of operations C3.2 Resource utilisation to lower overheads C6. Anticipation of potential market condition C4.1 Business intelligence gathering on future market trends C7. Recovery from disruptions C5.4 Learning from tendering experience C9. Collaboration with supply chain members

6.3.3 Management Vulnerability

Timing of business decisions

Management vulnerability is ranked as the second factor that both the public and private organisations experience, as presented in Tables 4.6 and 4.8 respectively. In this case, timing of business decisions (a sub-factor of management vulnerability) was identified as the greatest vulnerability facing both the public and private organisations (rated 1 of 39 vulnerability sub-factors in Tables 4.7 and 4.9). This result is similar to that reported in the Malaysian Construction Industry Master Plan (2006-2015) whereby duplication of work, lengthy approvals and work time were identified to be problematic in local construction projects (CIMP, 2007). Delay is indeed a significant issue generally in the construction industry worldwide (Koushki et. al., 2005; Choudhury and Rajan, 2003; Ng et. al., 2001) and specifically in Malaysia, where it is one of the main factors hampering the performance of local construction projects (Mehdi-Riazi et al., 2013; Endut et al., 2009; Sambasivan and Soon, 2007; Othman et al., 2006; Chan, 2001). Further detailed analysis shows that the organisations' strategic operations might have contributed to delay in the decision-making process. Decision making takes time in the case of the public organisations possibly, because of the lack of distribution of their key resources (rated as moderate capabilities, 18 of 44 in Table 4.11) in a highly distributed market (a top five capability sub-factor in Table 4.11). Chan (2001) agrees that resources such as skilled labour are less plentiful in the less developed areas compared to the capital city in Malaysia, suggesting that the non-uniform distribution of resources could cause late information flow and slow decision making in public sector projects located across different geographic regions. The private organisations' market, on the other hand, is not as geographically dispersed as the public organisations' (30 of 44 capability sub-factors in Table 4.13), but dealing with a large number of supply chain members (a top 10 vulnerability sub-factor) with services or production operations that are very complex (ranked 18 of 39 vulnerability sub-factors) might contribute to the late decision making on the private organisations' part. Hence, instead of the common blame-game often played out among supply chain members when projects face delay (see Section 5.8), it is important to have a good understanding of how parties in both the upper tier (i.e. public organisations) and lower tier (i.e. private organisations) operate to reduce delays in decision making collectively in the supply chain.

Based on the survey results, it seems that decision-making power is still concentrated at the top management level for both the public and private organisations (29 of 44 capability sub-factors in Tables 4.11 and 4.13). Expert PO1 acknowledged that for federal government projects, approval headquarters (HQ) is required,

> The public state representatives can only make certain decisions but with approval from the higher authority, either from HQ or client departments. In financial terms as well you can't comment much, all the approvals in terms of the cost of work come from another unit. If there are changes in design, the management will coordinate with the design office at a different level.

These layers of approval could result in poor communication and slow decision making among employees, especially during disruptions. The time-consuming communication channels could also cause distortion and discontinuity of ideas (Gold et al., 2001), discouraging imaginative solutions (Deal and Kennedy, 1982) to deal with disruptive events. This is evident in the case observed by Expert PO4,

> The state representatives decided to do pad footing for the foundation, but due to the approval procedure, the people on-site had to refer to the designer in HQ, and that alone took one month. That's why the public works department become slow.

Hence, regardless of whether the representatives onsite have the technical expertise, they are unable to make the final decisions without referring to the designers in HQ (as previously discussed in Section 5.6). Expert PO4 added that this disrupts the progress of work as it is time consuming to have to rely on other people and wait for their decision every time disruption occurs. Indeed, distributing the decision making was perceived by Expert PO5 as a reactive response to disruptions. In this case, the project manager faced disruptions on-site due to discrepancies in the design drawings. He then took a reactive response to make his own decision on-site to mitigate the disruption impact quickly,

> I was reactive, I have to respond quickly, no need to refer to any other authority, just me and the contractor discuss how to modify the design, extra piling things like that. So I directly deal with my engineer, because of one beam that has no detail, I asked him to design, then I'll check. I told him I'll take responsibility if things don't work. So a month after that, then only the official instruction arrive from the designer in HQ, and it was the same decision as what we already did. If I hadn't reacted and made that decision earlier, there would have been a one-month delay.

In this case the project manager decided to take responsibility for the decisions he made, believing that the people on-site wers sufficiently expert in rectifying problems and saving time. This distributed decision making would also help to improve the public organisations' ability to seize advantage from disruptions occurring on-site (rated as a low capability, 34 of 44 in Table 4.11) and also reducing the organisations' vulnerability to inadequate management control over supply chain members (a top 10 vulnerability sub-factor in Table 4.7). Similarly, large contractors also face late decision making in their organisations, as observed by Consultant CS3. In this case, the construction site was in Kuala Lumpur, but the contractor's headquarters were in another state, resulting in miscommunication in terms of the decision making. Consultant CS3 explained that,

> For instance, the work is starting tomorrow, the site staff want to buy concrete, cement, etc, but they have to get approval from their HQ, but the HQ was quite slow, so due to the distance they had miscommunication. Even though there's Internet and all, the things on-site are equally important, because they have to liaise with their HQ. The site staff is just for supervision, monitoring, delivering. Usually for big mega-projects only they have their on-site team. Because this project is quite small, maybe they took it for granted.

As a result of the contractor's poor communication and mismanagement within their own team, the project faced a year's delay. Hence, it can be observed in the former case of the public organsation and the latter case of the contractor, empowering experts on-site to make key decisions, regardless of their level of authority, is important in overcoming late decision making. Understandably, it is unrealistic for the management to allow thousands of employees to have decision-making authority without some limits (Argyris, 1998). However, employees should be given a degree of freedom and autonomy in the decision-making process, especially for decisions directly related to their own work (Johari and Yahya, 2009), to encourage prompt communication through any part of the supply chain when disrupted.

Table 6.6: Summary of the critical vulnerability of timing of business decisions

Critical Vulnerability Factor	Pathogens	Linked Capability Factors
Timing of business decisions	• Blame-game *behaviour* among project team • *Convention* of centralised decision-making • *Organisation* structure with multiple departments • *Practice* of poor assumptions in decision-making • P*ractice* of prioritisation of project by public organisations based on its importance	C8.3 Decentralisation of key resources C8.4 Geographic dispersion of markets C8.1 Distributed decision making C9.1 Communication C5.2 Seizing advantage from disruptions C1. Flexibility in approval process C4. Visibility of supply chain operations

Reliance upon information flow

The survey also revealed that both the public and private organisations rely heavily on a continuous information flow in their operations (a top three vulnerability sub-factor in Table 4.7 and 4.9). Understandably, this is crucial to operations which are outsourced operations to many different parties in the supply chain (4 and 7 of 39 vulnerability sub-factors in Tables 4.7 and 4.9). Considering a consistent information flow between parties is critical to the organisations' operation, enhancing collaboration, but the weakest capability for both parties (see Tables 4.10 and 4.12). Increased transparency in communication (a low capability sub-factor in Tables 4.11 and 4.13) is imperative for both parties to overcome this vulnerability collectively. Indeed, information flow between project team members is important in managing the supply chain, and sharing information is the key feature of collaboration (Nawi et al., 2013; Cohen and Russel, 2005). However, transparency in sharing information might be hard to achieve without an adequate level of trust between the public organisations and the supply chain. As discussed in Section 6.2.4**,** the lack of information revealed by Contractor CO3 on the actual risks on-site during the risk management meeting could mean that certain risks of disruption within the supply chain might be overlooked by project team members. In this case, the contractor was discreet about sharing certain information with the public organisations to avoid being blamed should any risks occur. It is therefore not surprising that risk sharing among the supply chain members is still poor, as reported in the survey results in Tables 4.11 and 4.13 (a bottom three capability for both parties). Similarly, Briscoe and Dainty (2005) identified that lack of confidence in the working relationship between client and contractor could result in poor information exchange among the supply chain members. For instance, the lack of direct information exchange between the client and the bottom tiers of the supply chain depended on the willingness of the main contractor to facilitate it (Briscoe and Dainty, 2005). The centralised decision making of both public and private organisations could also make the respondents even more vulnerable to timely continuous information flow. Hence, in addition to improving communication, enhancing collaborative data sharing between the public organisations and the supply chain (a moderate capability, 22 of 44 in Table 4.11) is essential to manage a continuous flow of information. In this case, Information Technology (IT) tools such as Building Information Modelling (BIM) could be useful in improving information flow and encouraging collaboration in the supply chain (Kamar and Hamid, 2011). Visibility of the public organisations' supply chain's operations can also be enhanced by having real-time data on the location and status of key resources (a low capability, 25 of 44 in Table 4.11).

Table 6.7: Summary of the critical vulnerability of reliance upon information flow

Critical Vulnerability Factor	Pathogens	Linked Capability Factors
Reliance upon information flow	• *Practice* of lack of transparency in sharing information • *Behaviour* of "us versus them" in project team • *Convention* of outsourcing work to external parties	C9. Collaboration with supply chain members C9.1 Communication C4.3 Collaborative information exchange C9.3 Risk sharing with partners C4. Visibility of supply chain operation C4.2 Products, assets, and people visibility

6.3.4 Liquidity/Credit Vulnerability

Lack of financial resources

Financial vulnerability is also a top threat to the public organisations, based on the reported high susceptibility to liquidity/credit vulnerability (a top three vulnerability) in Table 4.6. This includes the vulnerability to any changes in financial and economic policies and the lack of financial resources to cover all potential needs (ranked 9 and 12 respectively of 39 vulnerability sub-factors). This result is consistent with Goh and Abdul-Rahman's (2013) study in which financial risk was identified as one of the major risks in the Malaysian construction industry. This could be problematic considering that financial crisis was reported earlier to be one of the top three most frequent disruptive events in public projects (see Section 6.2.1), and higher cost of operation as one of the critical effects of disruptions on public projects (see Section 6.2.2). The public organisations also had a significantly lower score in financial strength (mean rank = 45.07), as per Table 4.15, compared to the private organisations (mean rank = 61.39). This result is surprising considering that as a government body it is expected that it should have sufficient funds to deliver public sector projects effectively in the interest of the stakeholders, particularly the public. Hence, it might be that insufficient funds were available to public sector clients (i.e. the local ministries) ultimately in charge of providing funds to the public organisations to carry out the respective projects.

In the Malaysian public projects case, the client department (e.g. Ministry of Higher Education, Ministry of Health) is ultimately responsible for providing the funds to public organisations for the implementation of public projects, based on the budget allocated by the Economic Planning Unit (EPU) of the Prime Minister's Department (Ibrahim, 2011). The budget allocation for intended public projects is planned well in advance, and clients are required to bid for their annual budget from EPU during March for implementation of their respective projects in following year (Economic Planning Unit, 2009). Ahmad et al. (2012), however, pointed out that more often, the scope of works for the proposed public projects is reduced and lower budgets are approved by EPU because of the department's focus on cost reduction. The lack of financial resources for the public organisations compared to the private organisations might therefore stem from the rigidity of this financial policy that requires the cost of the project to be estimated a year ahead for budgetary purposes, and consequently might not be sufficient to accommodate any changes during project delivery. This limited budget could also have an impact on the quality of the project as the public organisations have to adjust the project scope accordingly. As previously discussed in Section 5.5, Expert PO1 explained that the public organisations can only optimise their design according to their available budget,

> For our engineering design, we mostly optimise what we have, we cannot maximise the design. Sometimes the client requests for the design to be implemented in two phases, so that the subsequent phase can be implemented when they receive the necessary funding. But what if the money does not arrive in the subsequent phase of the project? That's quite risky. So it is better to plan ahead and reduce the standard of design according to the budget they currently have.

Limited budgets have also resulted in limited resources spent on the overall planning phase. Expert PO2 explained that,

> We try to identify as much risks at the planning phase but with restraints such as cost. We cannot put our costs for planning so much. For the planning phase, there is only a limited budget for us to prepare documents, a little bit of drawings, like for roadwork, we need utility mapping, survey, things like that. We can't cost for it that much.

On the other hand, as discussed in Section 6.2.5, Expert PO1 stated that only limited time is spent on the planning phase, possibly because of the limited budget provided by the client. This could result in disruptions in the subsequent construction phase of the project, due to deficiencies that were not realised much earlier at the planning phase (as discussed in section 6.2.3).

Table 6.8: Summary of the critical vulnerability of lack of financial resources

Critical Vulnerability Factor	Pathogens	Linked Capability Factors
Lack of financial resources	• *Circumstance* of limited budget by client • *Convention* of financial allocation to be estimated a year ahead • *Practice* of cost savings by government • *Circumstance* of reduced scope of works due to lesser budget approved	C12. Financial strength C12.3 Financial reserves and liquidity

Finance policies and procedures

The survey result on the public organisations' financial vulnerability is a great concern as it could have a knock-on effect on the operation of the private organisations. A majority of the professionals interviewed stressed the issue of late payments to the contractors from the public organisations. Contractor CO4 explained that, previously, part of the contractual terms for progress payment by the public organisations had amounted to a payment of 75% of the material price that have arrived on-site. More recently, to help alleviate the contractors' financial problems, the public organisations increased this payment to 100%. However, Contractor 4 stated that,

> Even if you send 100% of the material price, they won't pay you 100%, the most I can get based on my experience is 75%. But based on the current terms, they are supposed to make 100% payment. So we should receive full payment. But their people do not dare to take the risk, they play safe a lot. We receive 100% payment only when we have completed the work on-site.

In reality, therefore, the public organisations still follow the previous terms of paying 75% of the material price, even though the contractors need prompt payment to execute the construction work on site and to make the necessary payments to their suppliers and sub-contractors. This explains why the private organisations are equally highly vulnerable to any changes made in financial policies and procedures (ranked 2 of 39 vulnerability sub-factors in Table 4.9). Expert PO3 acknowledged that, in some cases, the public organisations' representatives on-site are very strict in terms of the valuation,

> But on our side, like our payment was not really up to mark. Our team on-site were very strict on payment. They were checking here and there, checking so thorough. They didn't make the payment every two weeks like they're supposed to.

He added that this should not be the case as the public organisations can always recover the expense through the next interim payment if the contractor actually did not deliver the work on-site. Expert PO2 observed that some of the smaller contractors depend heavily on the public organisations' interim payments to carry out the work on-site,

> If the contractor depends on our payment entirely, when he fails, how to recover and pay the rest of the team on-site? The worst-case scenario that could happen is that the project faces severe delay for more than 60 days, or is even abandoned'.

On the other hand, Expert PO5 stated that some of the contractual payment arrangements between the main contractors and their suppliers could also result in the suppliers not receiving adequate payment (as discussed in Section 5.5). Certainly, Abdul-Kadir et al. (2005) revealed the detrimental effects of late payment which resulted in suppliers not getting paid on time by the contractors, causing frequent stoppages of material delivery and loss of trust in the contractors, hindering overall progress. Thus, the private organisations' good financial strength does not guarantee that they can overcome the effect of under-payment or late payment by the public organisations. Late payment to the consultants by the public organisations was also reported. As the consultants have fixed fees, they are paid in stages from the preliminary design to the final design. Expert PO5 justified this,

> …sometimes when the consultant overdesigns stage 1 or needs a variation order, they will claim some money from the stage 2 percentage of payment, and when that happens, it becomes a headache. The more variation orders and redesign, the more it overlaps here and there on the payments. That's why our financial team haven't paid them because they have to estimate the fees properly.

In this case, although the consultants' payment is not as high as that of the people that involved in the construction phase, the consultants still need timely payments to pay for their staff. Timely payment also ensures timely progression of the design work by the consultants. Payment issues in construction projects are also prevalent in other developing countries such as Vietnam (Le-Hoai et al., 2008), Kuwait (Koushki et al., 2005), Ghana (Frimpong et al., 2003) and Nigeria (Aibinu and Odeyinka, 2006), making it even more imperative for the construction supply chain to manage the difficulties arising from this financial threat. The contractors also tend to mobilise financial resources among their public and private sector projects to maintain the progress of work, so any delayed payment from the public sector projects will subsequently affect the resources available to carry out other private sector projects. This shows how the impact of financial vulnerability could also spread and cascade from one project to another in the supply chain.

Understandably, the external threat of changes to financial policies is difficult to overcome as it is beyond the control of the public organisations and the supply chain. It is to the responsibility of the policymaker to reduce the detrimental effects of this problem and provide a more efficient solution through reasonable financial procedures. What both public and private organisations can do, however, is to improve their capacity to reduce the impact of this financial threat on their operation. The public organisations' significantly low efficiency level in Table 4.15 (mean rank = 45.21) compared to the private organisations (mean rank = 61.25) is not reassuring to reduce this threat. It includes significant lower efficiency scores in areas such as labour productivity (mean rank = 47.66), asset utilisation (mean rank = 46.33) and product variability reduction (45.68), indicating inconsistency in the quality of the public organisations' operation. This is of concern as the government bodies are tightly in charge of the crucial briefing, tendering and design process in the pre-construction phase that will determine the outcome of the whole project. It is therefore not surprising that inefficient traditional approaches which have dominated the Malaysian industry have constantly been blamed for the industry's project failures (Munns & Bjeirmi, 1996). On the other hand, the survey revealed that the private organisations have balanced their vulnerability to changes in financial policies with top three capability factors of having good financial strength, high visibility of their supply chain operations and high adaptability in responding to these changes (see Table 4.15). Nonetheless, their anticipation of and recovery capabilities (bottom five main capability factors in Table 4.12) from expected payment delay and return to normal operation, once disrupted by such threat, can be further improved to counteract this problem. Indeed, Contractor CO3 suggested that contractors should anticipate the extent of the finance that will return to them, and manage the construction works accordingly,

> You must programme your work at the site accordingly. Don't overwork day and night when the government's financial provision for that year is only this much. That means you're ahead twice from the government's price allocation for that year. Who shall pay you later? And that's why it is very important for us to always ask the public departments, is there sufficient financial provision? And to what extent? We have to ask them that. So we have to do the job based on the financial provisions they have.

Ye and Rahman's (2010) studies also identified that understanding and researching the owner's ability to pay was perceived by contractors as the most effective solution in mitigating the risk of late payment. Overall, it can be seen here that resilience to financial threats would be difficult to achieve in isolation, considering that the weakness of the public organisations' operations could ultimately hamper the private organisations' ability to deliver the project efficiently. Hence, both parties need to work cooperatively to deliver the project within the available budget and ensure that the terms of payment in the procurement contract are clear and reasonable between the client and the project team; in practice, they still have trouble achieving this, based on the lowest ranking of the collaboration factor in Tables 4.10 and 4.12.

Table 6.9: Summary of the critical vulnerability of finance policies and procedures

Critical Vulnerability Factor	Pathogens	Linked Capability Factors
Finance policies and procedures	• *Practice* of late payment by contracting parties • *Behaviour* of lack of trust among parties • *Circumstance* of contractual payment arrangements between contractors and their team • *Convention* of government payment arrangements • *Circumstance* of complexity in estimating design fees when variation occurs	C12. Financial strength C3. Efficiency of operations C4. Visibility of supply chain operation C5. Adaptability in responding to changes C6. Anticipation to forecast potential payment delay C7. Recovery from late payment C9. Collaboration with supply chain members

6.3.5 Strategic Vulnerability

Degree of outsourcing

In the Malaysian public sector, it is common for the pre-construction tasks (i.e. design, brief preparation, tender evaluation) to be outsourced to external consultants (Abdul-Aziz & Ali, 2004) such as independent quantity surveyors and architects. Indeed, the survey result shows that the public organisations have a high degree of outsourcing, a top five vulnerability sub-factor in Table 4.7. Although this strategic initiative of outsourcing provides an opportunity for the private organisations to engage in public projects, the survey shows that the public organisations failed to evaluate the associated risks. Unlike the private organisations, the public organisations seem to have lost control over the visibility of their supply chain (a low capability sub-factor, ranked 25 of 44 in Table 4.11), hindering the collection of information and collaborative data sharing among project team members (a moderate capability, 22 of 44). The loss of control and visibility reflect the public organisations' uncertainty about the state of the public sector supply chain, making it harder for the public organisations to detect any disruptions arising from the supply chain or obtain a complete picture of the current situation affecting project delivery. Plus, unlike the private organisations, any deficiencies in the public organisations' operations are highly visible to stakeholders (a top 5 vulnerability sub-factor in Table 4.11), making it even more imperative for the public organisations to detect any abnormalities in the outsourced operations before they escalate to other parts of the supply chain.

In this case, the public organisations' high degree of outsourcing in their design work could be attributed to incompetence in their internal team. For instance, Expert PO2 pointed out that the public organisations' design teams do not have the capacity to design steel structures. This has been an issue especially in conventional procurement where the in-house design team is required to provide the design. He explained that,

> The design team had asked the contractor to do the steel design in this conventional contract. And then the planning team questioned, "we already asked you to design, why did you ask the contractor to design it?". So it ends up that a portion of work becomes design and build.

He added that the design team's current software used standardised sizes of steel members which could not accommodate the complexity of the structural steel design of the building. The internal design team was not confident of producing the design, resulting in the contractor designing the steel structure. Experts PO3 and PO5 attributed this incompetence to the fact that the public organisations' training centre had been closed for 20 years. Expert PO3 explained this,

> Our competence level left out a lot because our training centre has been closed. For such a big organisation like a public organisations, if you don't have a training centre, it's not good. That's why I hope my young engineers aged 41, 44, 48 can survive. I try to groom them back and train them, because we lost this training centre nearly 20 years ago. We have to train our young engineers to become experts.

He concluded that only with the relevant knowledge and experience could the professionals in the public organisations improve their competence. Indeed, Expert PO4 pointed out that this lack of competence in the team resulted in poor administration of non-conventional contracts, such as design and build. He explained the confusion of the internal team,

> Some of them think, for design and build, they assume they don't need to distribute the work, don't need to be concerned with the work at all. They just leave all the works to the external party. But some said, they get too involved in design and build because they're used to the conventional way. So the concept is still, not really that it cannot be delivered, but there are still many areas to be improved.

This lack of relevant competence in the public organisations' internal team resulted in the high degree of outsourcing in their design and procurement work. The poor administering of non-conventional contract might also be due to the *convention* pathogen of poor documented lessons learnt (discussed in earlier Section 5.6). The public organisations' vulnerability to poor administration of the contract could also result in the contractors' opportunistic *behaviour* (pathogen discussed in Section 5.8) in using the contract conditions to secure additional finance when faced with costly disruptions.

Sheffi (2005) pointed out that managing additional suppliers and having deep relationships with multiple suppliers are often too costly to maintain, which explains why the public organisations have inadequate management control over their supply chain members (a top 10 vulnerability sub-factor in Table 4.7). Plus, when disruptions occur, the private organisations who serve only as an alternative source to the public organisations may not be inclined to take the risk of investing ahead of time to help the public organisations who chose not to do business with them in the first place (Sheffi, 2005). This can be seen in the reported low risk sharing of the public organisations with their suppliers (a bottom three capability sub-factor in Table 4.11). Hence, for their procurement strategy to be successful the public organisations should consider either deepening their relationships with their key suppliers, especially those providing specialty sources, or developing shallow connections with multiple suppliers (Sheffi, 2005).

Table 6.10: Summary of the critical vulnerability of high degree of outsourcing

Critical Vulnerability Factor	Pathogens	Linked Capability Factors
High degree of outsourcing	• *Circumstance* of high visibility of disruptions to stakeholders • *Circumstance* of poor competency of design and procurement team • *Organisation* with poor training centre • *Convention* of poor documented lessons learnt • Opportunistic *behaviour* by contractors	C4. Visibility of supply chain operations C4.3 Collaborative information exchange C9.3 Risk sharing with partners

Reliance upon specialty sources

Similarly, the private organisations also outsource their operations to many different suppliers (ranked 7 of 39 vulnerability sub-factors in Table 4.9). This might be due to the fact that they rely heavily on specialty sources in delivering the construction projects (a top five vulnerability sub-factor in Table 4.9). However, despite the high level of outsourcing, the private organisations seem to have better control of their supply chain and are well aware of the location and status of their current resources, compared to the public organisations, based on the high scoring of their visibility capability in Table 4.12 (a top three capability factor). Further detailed analysis through the Mann-Whitney U test (Table 4.15) reveals that the private organisations have a statistically significant higher capability score in visibility compared to the public organisations. However, one of the problems highlighted by the private organisations in the interviews is the difficulties in reserving materials from outsourced suppliers. This is common, especially for specialist items such as steel. For instance, Contractor CO4 pointed out that,

> The maximum material I can reserve, like for steel, we can buy them in cash money maximum 80 tonnes only. For instance, my current project is being disrupted due to the increase in steel price. Because the maximum you can buy is only 80 tonnes of steel. Yes, the supplier is careful not to give more than that, because they know that the price of steel will keep on increasing. So this means, you can only buy maximum 80 tonnes of steel and you have to make payment at that time.

This can be attributed to the uncertainty in economic conditions highlighted in Sections 6.2.1 and 6.3.2. This interviewee added that there are few suppliers of steel, and therefore no option but to order the limited amount the contractors are allowed. Similarly, Consultant CS3 stated that the public organisations cannot reserve capacity such as electrical services should disruptions occur on site. She explained that,

> For electricity, if we request this much energy from the utility provider, and we do not fully utilise it, they can penalise you. All utilities have their own requirements.

Contractor CO2 commented that in order to mitigate the low reserved capacity, a lot of time must be devoted to the procurement of the material,

> Let's say in the normal situation, the material will be delivered in one month, but maybe we can order it one and a half or two months before the date of delivery, so we have a buffer time there. Because in projects, the quantity is usually fixed, you can't buy extra, if you buy extra maybe you can buy just about 5% extra, to cover any material damage or disruptions.

It is therefore not surprising that reserved capacity was rated as one of the lowest capability factors of both public and private organisations (ranked in the bottom 10 capability sub-factors in Tables 4.11 and 4.13 respectively). Furthermore, the circumstance of lack of skilled workers has also resulted in the contractors' dependence on engaging foreign workers (see Section 5.5). This strategic measure, however, has resulted in the public organisations being exposed to defects in quality due to poor workmanship on-site, as discussed in Section 6.2.2.

Table 6.11: Summary of the critical vulnerability of reliance upon specialty sources

Critical Vulnerability Factor	Pathogens	Linked Capability Factors
Reliance upon specialty sources	• *Convention* of outsourcing operations for specialists work • *Circumstance* of lack of skilled workers • *Convention* of high dependency on foreign workers	C4. Visibility of supply chain operations C2.1 Reserve capacity C2. Capacity of resources C6.4 Contingency planning in procuring specialists materials

6.3.6 Supplier or Customer Disruptions

In addition to these top five critical vulnerability factors, it is important to note the relatively low ranking of the vulnerability of the public organisations to supplier and/or customer disruptions, as shown in Table 4.6. Despite reporting earlier that they faced disruption from to the failure of their key suppliers during public project delivery (see Figure 4.1), the public organisations claimed that their suppliers and clients do not suffer from frequent disruptions (bottom 10 vulnerability sub-factors in Table 4.7) and that their suppliers have enough capacity to deal with unplanned changes in demand (ranked 27 of 39 vulnerability sub-factors). This raises the question of whether the public organisations face more supplier or customer disruptions than reported, and whether they are fully aware of the condition of their supply chain members. Based on the survey, contrary to the public organisations' perception, the private organisations reported the capacity of their supply chain members capacity as one of their weakest capabilities (Table 4.12). Factors such as multiple redundant resources (i.e. access to alternative facilities and equipment for back-up) and reserved capacity of materials, equipment and labour are areas of concern for the private organisations (ranked 35 and 38 of 44 capability sub-factors in Table 4.13). As discussed in Section 6.3.5, the public organisations do not have full visibility of their supply chain members (ranked 25 of 44 capability sub-factors in Table 4.11) and therefore are not fully aware of the current condition of the private organisations. The public organisations' assumption that the private organisations engaged can deal adequately with demand changes could be problematic, as it will put an unnecessary burden on the private organisations to meet unexpected demand changes within their limited resource capacity. It is therefore not surprising that the private organisations reported being highly vulnerable to unpredictability of demand (ranked 13 of 39 vulnerability sub-factors in Table 4.9), as indicated by the survey result. Hence, despite the public organisations having many alternative supply chain members in case of disruptions (a top 10 capability sub-factor in Table 4.11), they will not be able to obtain the full advantage of this capability if poor visibility of their supply chain members (ranked 25 of 44 capability sub-factors) and insufficient management control over them (a top 10 vulnerability sub-factor in Table 4.7) persist.

Table 6.12: Summary of the critical vulnerability of supplier or customer disruptions

Critical Vulnerability Factor	Pathogens	Linked Capability Factors
Supplier or customer disruptions	• *Circumstance* of unpredictability in demand • *Practice* of poor assumption of supply chain's capacity to deal with changes • *Practice* of frequent design changes	C2. Capacity of resources C2.2 Redundancy (assets, labour) C2.1 Reserve capacity C4. Visibility of supply chain operations C1.2 Multiple sources C4.2 Products, assets, people visibility

The public and private organisations' capability factors are discussed in the following section.

6.4 Supply Chain Capability Factors

6.4.1 Public Organisations' Capabilities

Based on the scatterplot in Figure 4.12, the public organisations scored adaptability as their strongest capability factor; lies within the high capability and high importance quadrant of the scatterplot. Nevertheless, despite these strengths, the public organisations' ability to take advantage of disruptions is still weak, based on the reported low ranking of this sub-factor in the adaptability category (ranked 34 of 44 overall sub-factors in Table 4.11). Considering that the public organisations are still highly vulnerable to political/legal pressures, management vulnerability and liquidity/credit vulnerability, one could argue whether their adaptability, as a capability factor might rather act against these vulnerabilities, and whether it could obstruct or strengthen their ability to manage disruptions effectively.

According to Limnios and Mazzarol (2011), adaptive organisations tend to fall into the rigidity trap by continuously reinforcing past successful strategies and failing to identify changing market conditions. This organisational state is also known as routine rigidity, from the inability to change the patterns and logic that underlie organisational investments (Gilbert, 2005). In other words, although the public organisations are very adaptable, in the case of disruptions in public projects, they either actually learn from the past or eventually fall back into normal routines or traditions (as discussed in the *convention* pathogen in Section 5.6). March (1991) argued that the process of organisational adaptation and learning can either involve the adoption of exploitation (i.e. utilising or improving existing skills and resources) or the process of exploration (i.e. looking for new opportunities). Highly adaptable organisations, such as the public organisations in this study, are said to characteristically improve exploitation more rapidly than exploration, resulting in cycles of exploitation reinforcement that tend to discourage exploration (March, 1991). This can be seen through the survey results where, despite the public organisations' strong capacity to learn from experience, their ability to seize advantage from disruptions is still very poor. In this case, their over-reliance on exploitation for organisational learning might work against them. They must therefore consider how to balance their exploration and exploitation strategies to be able to continuously scan their environment and identify the need and opportunity for change when it presents itself, while maintaining and evolving the key organisational capabilities (O'Reilly and Tushman, 2004).

The public organisations' attributes of high levels of adaptability but low levels of planning (high susceptibility to management vulnerability and strategic vulnerability) also suggest that these organisations are highly agile but unsystematic in their approach. Previous researchers have referred to these attributes as adaptive resilience (Pal et al., 2012). Although the inherent adaptability of such organisations may contribute to their resilience, allowing them to perform well and survive disruptions, their tendency towards a more adaptive rather than a planned approach can undermine their ability to find strategic opportunity from disruptions (Vargo and Seville, 2011). This might further explain the weaknesses identified in their current risk management approach (Section 6.2.4), where despite their pre-planned measures, a more ad-hoc approach is adopted when disruptions occur. Hence, it is important for the public organisations to overcome their management and strategic vulnerabilities and to balance the two complementary behaviours of planning and adaptation, which can improve their overall ability to grow in the face of disruptions in public projects.

6.4.2 Private Organisations' Capabilities

Like the public organisations, the contractors and consultants reported adaptability as their strongest capability factor, as presented in the scatterplot in Figure 4.12. This is possibly why the majority of the private organisations reported that they dealt with disruptions as part of business-as-usual (Figure 4.4). On the other hand, unlike the public organisations, the private organisations excel at taking advantage from disruptions in public projects, as reflected in the Mann-Whitney U test results in Table 4.15. This is surprising considering that, unlike the public organisations, most of the contractors and consultants have no specific disruption management approach (Section 6.2.4). The private organisations' strong ability to adapt and seize advantage from disruptions might therefore be due to the fact that they are more experienced in dealing with a high frequency of disruptions in their operations (see Section 6.2.3) than are the public organisations, and have developed the necessary skills to take advantage of such disruptions. It could also mean that the private organisations' opportunistic *behaviour* materialised due to the public organisations' vulnerabilities in areas such as poor procurement and poor visibility of their supply chain (see Section 6.3.5), thus enabling the private organisations to take advantage of disruptive events. However, as most of the private organisations also claimed to have no detailed contingency plans to deal with disruptions (ranked 32 of 44 capability sub-factors in Table 4.13), they might have adopted more of a firefighting approach in handling them, whereby short-term solutions are used to fix problems as they occur during project delivery; hence, the reason they also claimed to be willing to take immediate action to mitigate the effects of disruptions despite the short-term costs (a top ten capability sub-factor). The firefighting approach might work as a temporary solution, but its hidden effects in the long run can be problematic and might have a cascading effect on contractors' and consultants' operations. Considering that the private organisations are still vulnerable to the volatility of the construction market and their own poor management (both in the top three vulnerability factors in Table 4.8), they should perhaps consider a more planned approach in dealing with disruptions to maintain their position in the market and survive in the long term.

6.5 Recommendations on Resilience Response Strategies by Respondents

Table 6.13 below presents a summary of the respondents' recommendations on the appropriate resilience response strategies to mitigate the identified critical vulnerabilities and pathogenic influences discussed throughout Section 6.3 of the thesis. Overall, along with the supply chain capabilities assessed in the survey (Section 4.4), these recommendations were used as a guide in developing the capabilities in the final resilience response framework presented in the following Section 6.6 of the thesis.

Table 6.13: Summary of the recommendations on resilience response strategies from interviews

Pathogens	Recommendations on resilience response strategies
Exposure to political disruptions	
Practice of lack of transparency in tender selection	• Public organisations must have a systematic and well documented tender evaluation based on actual facts and data. • Selection of tender board committee should be persons of high integrity. • Public organisations' top management should communicate well with regular briefings with politicians on the integrity and outcome of the evaluation. • Malaysian anti-corruption commission should be invited as observer in tender board meetings. • Sign off "integrity pack" between contractor and public organisations, with terms not to involve in any lobbying or bribery practices where the consequences is that they can be disqualified or contract can be terminated (if awarded).
Circumstance of monopolisation of material	• Government should liberalise market for key construction materials suppliers e.g. more permits for importer permits or manufacturing licence. • Private organisations should report to government any suppliers that impose any infavourable condition that contravene with the government approved permit.
Practice of frequent design changes	• Head of Project Team must be competent in handling design team to avoid any unnecessary changes to design. Must control the time element in design schedule. • Consultants should produce design complying to all specific standards, regulations, government policy on green and environment to avoid many changes.
Circumstance of changes in political power	• Public organisations to communicate with the new government on the outcome/implication/consequence of the project being halt including possibility of being sued by the contractor. • Private organisations to take action according to what is entitle to in the contract.
Changes in government regulations	
Convention of complex regulations that are hard to navigate	• Public organisations should engage the relevant professional bodies to be part of any changes. • Private organisations should be more proactive in preparing, accepting, and keeping abreast to government regulation changes e.g. IBS, BIM and green policy. • Public organisations to include in the contract clear statements on the responsibilities of all parties on the regulations, and updating the private organisations on the new policies imposed.
Convention of inconsistent regulations imposed by different authorities	• Government should set several committees of relevant government agencies such as professional bodies to address the inconsistencies. • Local authority should embark on local government transformation program to increase the efficiency and standardisation of local government practices and regulations.

Severe price fluctuation	
Circumstance of unpredictable economic conditions	• Include contract clauses between public and private organisations that define the required parameters and conditions for sharing risk of price fluctuations • Contractors must be proactive and reserve imported materials much ahead when currency is stable.
Circumstance of contractual arrangements	• Public organisations should have base value of ringgit in contract at tendering for high cost equipment that are supply at a later stage of the projects.
Circumstance of monopolised materials	• Public organisations to incorporate Variation of Price calculations especially for imported equipment.
Circumstance of limited material supply	• Add flexibility in construction operations to accommodate changes. • Utilise current resources and modify operations accordingly. • Ability to mobilise available resources quickly.
Price pressures	
C*ircumstance* of competitive open tender	• Contractors should make reasonable pricing of project overheads to increase chance of winning bid. • Learning from previous public tendering experience to improve bidding.
Circumstance of unpredictable economic conditions	• Contractors to utilise current resources available when oil price increase. • Increase efficiency in construction operations to reduce the loss of profit.
Convention of public organisations' goals for higher quality and low cost	• Statistical cut-off price in tender evaluation should be modified whereby the cut-off price from the tender selected cannot be much lower than 10% of government estimates.
Circumstance of market pressure from foreign players	• Private organisations must be able to anticipate and recover from potential market disruptions to survive in the long run.
Convention of supplier controlling price	• Maintaining long-term relationship with bottom tier supply chain to obtain the best reasonable prices.
Convention of the engagement of specialists by public organisations	• Collaboration and partnership with suppliers. • Maintain good reputation with public organisations.
Timing of business decisions	
Convention of excessive bureaucracy in decision-making process	• Some government process have to relook using "lean project management" to reduce unnecessary bureaucracy and too many hierarchy of authority. • Simplify layers of approval process.
Convention of centralised decision-making	• Empower workers on site to make decision to be able to seize advantage from disruptions. • Distribute final decision making to professionals carrying out the work.
Practice of poor assumptions in decision making	• More training and certification programme for government project team to increase competency in decision making. • Must have better planning and as much information as possible at planning phase to reduce further rework at later stage.

Reliance upon information flow	
Practice of lack of transparency in sharing information	• Public organisations should come up with good communication plan at every level of project phase, covering all the important stakeholders. Tools like stakeholders analysis and communication matrix can be used. • Information Technology (IT) tools such as Building Information Modeling (BIM) could be useful to improve information flow and encourage collaborative supply chain.
Convention of outsourcing work to external parties	• Public organisations should engage competent scheduler to assist project manager in better control of site progress. • Good scheduler can assists project manager to make decision or procure in time all the necessary resources needed. • Supervising consultant should be able to monitor and control project well and address all possible risk that can impact progress.
Lack of financial resources	
Circumstance of limited budget by client	• Public organisations should include value management at planning stage to optimise scope. • For clients who wants project scope that includes future needs but have limited finance, when design, do a master plan to include future needs but implement in phases, phases based on financial provisions available at that time. • Focus on immediate needs first, then can expand the project scope when finance is obtained.
Convention of financial allocation to be estimated a year ahead	• Public organisations should have realistic and achievable schedule so can better estimate budget needed for following year.
Practice of cost savings by government	• Efficiency in managing yearly budget requirements from client is essentials. • Programme manager should be competent in preparing yearly budget. • Public organisations should increase efficiency, labor productivity and resource utilisation.
Circumstance of lower budget approved	• Consultant to have competency in coming up with more functional design eliminating wastage. Design to cost or budget. • Increase collaboration with project team to work cooperatively to deliver the project within the available budget.
Financial policies and procedures	
Practice of late payment by contracting parties	• Government to intervene during operation if late payment arise. • Contractor should make immediate payment as and when materials arrive on-site. • Anticipate the extent of finance that will return to the contractor, and managing the construction works accordingly.
Circumstance of contractual payment arrangements between contractors and their team	• Contractors should collaborate with suppliers who can give better credit facilities.

Convention of government payment arrangements	• Include timely payment in Key Performance Indicator (KPI) for project manager. Report monthly payment performance to top management, record those projects with payment within 7 days. • Public organisations should make payment immediately or weekly, instead of monthly, especially when problems arise.
High degree of outsourcing	
Circumstance of high visibility of disruptions to stakeholders	• Improve visibility of supply chain members by monitoring closely operations and managing the contract with supply chain members efficiently. • Increase risk sharing with supply chain members. • Deepen relationships with key suppliers, especially those providing specialty sources.
Circumstance of poor competency of design and procurement team	• Public organisations should select competent consultant that are used to government requirements. • Include new agreement that can penalise consultant if they delay completion of design. Can be reported to the professional board and suspension of license for professional misconduct.
Reliance upon specialty sources	
Convention of outsourcing operations for specialists work	• Control supply chain through contract management and quality management system. • Contractor should build trust with supplier that they have done business with in the past. • Contractor to build trust with banker that issue the letter of credit to finance for imported items.
Convention of high dependency on foreign workers	• Contractor should invest more on skilled workers. • Government should ease the permit process for skilled foreign labours.

6.6 Synthesis and Development of Final Framework

The research findings indicated that the top five critical vulnerability factors of the public and private organisations are political or regulatory changes, market pressures, management, liquidity or credit and strategic vulnerability. Additionally, supplier or customer disruptions were included as critical vulnerabilities, as the failure of key customer or supplier was reported as one of the most frequent disruptions in public projects (see Section 6.2.1). It can be observed throughout the survey results that vulnerability arising from any part of the chain could impact another supply chain. These impacts are presented through the layered cascading impact (CI) channels in Figure 6.1. For instance, the increase in the price of materials imposed by the suppliers and manufacturers (CI 1) due to the market pressures identified in supply chains B and C causes the contractors and sub-contractors to face price fluctuation in their operation. This results in the escalation of the overall cost of both public and private projects in which the supply chain partners are involved. It shows how poor performance in one supply chain can result in a set of organisations entering a vicious cycle of poor performance based on the organisations' vulnerability levels. The survey also revealed how vulnerabilities arising from one organisation could ultimately affect the capabilities of other parties in the supply chain. The result shows that despite the private organisations' high capabilities in financial strength, the public organisations' financial vulnerability destabilises the entire supply chain (as discussed in Section 6.3.4). Late payment to the contractors by the public organisations in (CI 2) causes delayed payment to the suppliers by the contractors, resulting in frequent stoppages of material deliveries, and hindering overall progress. Furthermore, misinterpretation of the terms in the government regulations by the consultants (CI 3) causes inadequate valuation of the interim payments, resulting in insufficient payment by the public organisations to the contractors, who then need adequate finance to make timely payment to their subcontractors. This subsequently creates disputes among contracting parties that can be costly in terms of money, time and effort.

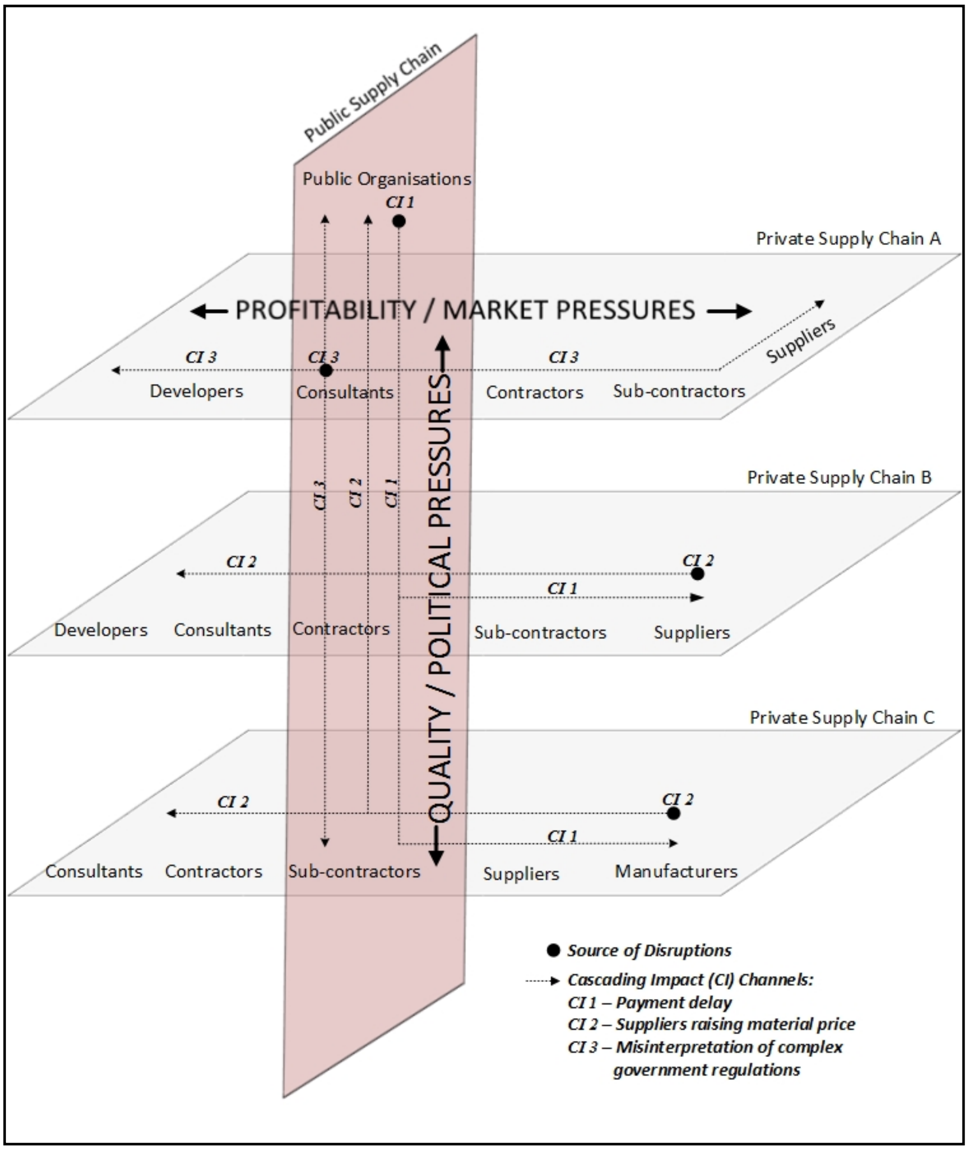

Figure 6.1: Cascading impacts on supply chains represented through a layered framework

On the other hand, considering the public organisations' high level of outsourcing (see Section 6.3.5), they should take into account other parties engaged in their supply chain network in making timely decisions, as this can affect the related parties' operations. Furthermore, the public organisations' low efficiency level in project delivery also deters the private organisations from delivering public sector projects on time (Section 6.3.4). Limited time and cost spent by the public organisations in the planning phase could also result in deficiencies in the following design and construction phase in which the private organisations are involved. Indeed, the survey showed that the public organisations should not think in isolation, as some of their actions will have an impact on a different supply chain with only private sector players. The degree of incongruent goals identified among the supply chain members (i.e. quality by the public organisations and profitability by the private organisations) is also of great concern as collaboration between the public and private organisations is important in overcoming these critical vulnerabilities that will affect not only the organisations individually but also the network of supply chains.

It was also identified from the survey that some of the capabilities, such as high dispersion of resources, work against the organisations' operations; instead, they make them vulnerable to other factors as a result of their own strategic decisions. For instance, the public organisations' capability of having a highly dispersed market and the private organisations' strategic decision to engage a large number of supply chain members increased their vulnerability to late information and slow decision making (see Section 6.3.3). The public organisations also failed to evaluate the risks associated with outsourcing and seem to have lost control over the visibility of their supply chain as a result of this strategic initiative. Hence, despite having many alternative supply chain members in case disruptions occurs, the public organisations will not be able to obtain the full advantage of this capability if poor visibility and insufficient management control over their supply chain members persist. The contractors were also identified as facing a higher repercussion from disruptions to public projects as compared to other parties in the supply chain (see Section 6.2.3), suggesting that the impact of inefficiencies is not always immediate but may be realised later in the project. It is also of concern that the majority of the contractors do not employ any specific disruption management strategies, as they have adopted short-term solutions to fix problems as they occur during project delivery (see Section 6.2.4).

It was found that the critical vulnerabilities are attributed to the pathogenic influence of *circumstance* (i.e. political environment, economic conditions, lack of skilled workers) in which the supply chain operates, which influences individual *practice* (i.e. poor assumptions in decision making) and *behaviour* in response to this project environment. Existing *organisational* structures and established *conventions* in government procedures also influence management in operational and strategic decision making. Overall, these critical vulnerabilities and pathogens are presented in Table 6.14, along with the resilience capabilities proposed to reduce the vulnerabilities. The capabilities in Table 6.14 were identified from the discussions throughout this chapter. Recommendations by respondents in Section 6.5 was also considered in addressing the resilience capabilities. This table was used as a guide in developing the final resilience response framework, described in the following section.

Table 6.14: The proposed resilience capabilities to reduce critical vulnerabilities in public sector supply chain

Critical Vulnerability Factors	Pathogens	Resilience Capabilities
Exposure to political disruptions	• *Circumstance* of political interference in tender selection • *Practice* of acceleration in delivering plans • *Circumstance* of monopolisation of material • *Practice* of client's frequent design changes • *Circumstance* of changes in political power	C5. Anticipation of potential political disruptions C4.1 Business intelligence gathering of future trends and behaviour in the industry C9.1 Improve transparency in communicating information with supply chain members C4.3 Collaborative information exchange with project team members
Changes in government regulations	• *Convention* of complex regulations that are hard to navigate • *Convention* of inconsistent regulations imposed by different authorities • *Convention* of excessive bureaucracy in decision-making process • *Organisation* structure with multiple departments	C1. Flexibility in approval process C8.1 Distributed decision making among project team members C6. Anticipation of potential regulation changes C9. Collaboration with supply chain members in responding to changes in regulations
Severe price fluctuation	• *Circumstance* of unpredictable economic conditions • *Circumstance* of contractual arrangements • *Convention* of late payment by public organisations • *Circumstance* of monopolised materials • *Circumstance* of limited material supply when in high demand	C2.1 Reserve imported materials when currency is stable C1. Add flexibility in construction operations to accommodate changes. C3.2 Utilise current resources and modify operations accordingly C1.5 Fast re-routing of resources to reduce losses C9.3 Risk sharing with contractual parties in making claims C12. Financial strength; reserve finance to cover potential needs

Critical Vulnerability Factors	Pathogens	Resilience Capabilities
Price pressures	• *Circumstance* of competitive open tender • *Circumstance* of unpredictable economic conditions • *Convention* of public organisations' goals for higher quality and low cost • *Practice* of underpricing by contractors • *Circumstance* of market pressure from foreign players • *Convention* of supplier controlling price • *Convention* of specialists selected by public organisations	C10.1 Market share C3. Efficiency of operations C3.2 Resource utilisation to reduce overheads C6. Anticipation of potential market conditions C4.1 Business intelligence gathering on future market trends C7. Recovery from disruptions C5.4 Learning from tendering experience C9. Collaboration with supply chain members
Timing of business decisions	• Blame-game *behaviour* among project team • *Convention* of excessive bureaucracy in decision-making process • *Convention* of centralised decision-making • *Organisation* structure with multiple departments • *Practice* of poor assumptions in decision making • *Practice* of prioritisation of projects by public organisations based on its importance • *Convention* of prioritising response based on level of authority • *Practice* of frequent design changes by client • *Behaviour* of poor sense of urgency by parties	C8.1 Distribute decision making and empower workers on site to make decision C9.1 Improve communication lines with project team members C5.2 Seize advantage from disruptions by making prompt decisions C1. Flexibility in approval process to reduce time of waiting for approval C4. Improve visibility of supply chain operations to ensure timely decision-making
Reliance upon information flow	• *Practice* of lack of transparency in sharing information • *Behaviour* of "us versus them" in project team • *Convention* of outsourcing work to external parties • *Organisation* structure with multiple departments	C9. Collaboration with supply chain members C9.1 Transparency in communication with project team members C4.3 Collaborative information exchange among project team members C9.3 Risk sharing with partners C4. Improve visibility of supply chain operation to ensure consistent information flow C4.2 Improve visibility on current materials, resources and people through information technology tools

Critical Vulnerability Factors	Pathogens	Resilience Capabilities
Lack of financial resources	• *Circumstance* of limited budget by client • *Convention* of financial allocation to be estimated a year ahead • *Practice* of cost savings by government • *Circumstance* of reduced scope of works due to lower budget approved	C12. Financial strength; ensure financial allocation is sufficient to cover project scope C3. Improve efficiency of operations through value management C3.1 Increase labour productivity C3.2 Utilise current resource C3.3 Consistent quality in operations to avoid rework C4. Improve visibility of supply chain operations to ensure operations meet the current budget
Financial policies and procedures	• *Practice* of late payment by contracting parties • *Behaviour* of lack of trust among parties • *Circumstance* of contractual payment arrangements between contractors and their team • *Convention* of government payment arrangements • *Circumstance* of complexity in estimating design fees when variation occurs	C12. Financial strength to cover potential late payment C3. Efficiency of operations C4. Visibility of supply chain operations to know the current progress for payment C5. Adaptability in responding to changes in financial policies C6. Anticipation of potential payment delay C7. Recovery from late payment C9. Collaboration with supply chain members
High degree of outsourcing	• *Circumstance* of high exposure of disruptions to supply chain members • *Circumstance* of poor competency of design and procurement team • *Organisation* with poor training centre • *Convention* of poor documented lessons learnt • Opportunistic *behaviour* by contractors	C4. Visibility of supply chain operations to have adequate control over outsourced works C4.3 Collaborative information exchange with supply chain partners C9.3 Risk sharing with partners

Critical Vulnerability Factors	Pathogens	Resilience Capabilities
Reliance upon specialty sources	• *Convention* of outsourcing operations for specialists work • *Circumstance* of lack of skilled workers • *Convention* of engaging foreign workers	C4. Visibility of supply chain operations by closely monitoring outsourced works C2. Adequate capacity of resources C6.4 Contingency planning in procuring specialists' materials C9. Collaboration; deepen relationships with key suppliers providing specialty sources
Supplier or customer disruptions	• *Circumstance* of unpredictability of demand • *Practice* of poor assumption of supply chain's capacity to deal with changes • *Practice* of frequent design changes	C2. Sufficient capacity of resources to respond to unpredictability of demand C2.1 Reserve capacity to quickly boost output if needed C4. Visibility of supply chain operations to understand their current capacity C1.2 Multiple sources; alternative sources to deal with changes in demand C4.2 Products, assets, people visibility

6.6.1 Presentation and Validation of Final Resilience Response Framework

The study was based on the conceptual framework developed in Section 2.8 of the literature review. The conceptual framework enabled the researcher to identify the key areas in the literature that could help fulfil the aim of the study, developing a resilience response framework to improve supply chain performance in mitigating against disruptions in public projects. Subsequently, the study had identified the critical areas of vulnerability, pathogenic influences, and resilience capabilities of the public sector supply chain, and developed the final resilience response framework accordingly, as depicted in Figure 6.2 below. The resilience response framework in Figure 6.2, together with Table 6.14 and Figure 6.1, was validated by five experts in the field (two professionals from the public organisations, two professionals representing the private organisations, one researcher). The experts were asked to give their comments in terms of the clarity and their understanding of the research results. The experts found that the layered supply chain network in Figure 6.1 was clear and helpful in understanding how the supply chain vulnerabilities can send cascading impacts to layers of supply chain network. The experts from the private organisations added that apart from the identified private supply chains in Figure 6.1, other stakeholders such as utility companies and foreign suppliers can also have their own supply chain network that overlap with the public sector supply chain. Nevertheless, the experts agreed that the supply chain network and vulnerabilities identified in Figure 6.1 were sufficient in reflecting the main respondents and focus of the study.

Furthermore, the experts also found that the critical vulnerabilities, pathogens and its related capabilities listed in Table 6.14 were clear and useful as a guide in developing the necessary capabilities required to build their resilience in responding to disruptions in public projects. However, some wording in the table was changed in response to their recommendations, to suit the public and private organisations' understanding of the terms. Finally, in validating the proposed resilience response framework in Figure 6.2, all experts agreed that the matrix of the vulnerabilities and its proposed capabilities was very clear and easy to understand. Additionally, the experts recommended that the current strengths of the public and private organisations' should also be highlighted in the framework, to obtain a holistic view of the results of the study. In light of their recommendations, the following Figure 6.3 was developed based on the analysis in Section 4.5 to show the current level of the public sector supply chain capabilities. Figure 6.3 was then included as a reference in the final resilience response framework, as shown in Figure 6.2.

Proposed Public Sector Supply Chain Resilience Response Framework

Vulnerability Factors (refer Figure 6.1 & Table 6.14) / Capability Factors (refer Figure 6.3 & Table 6.14)	Political/Legal Pressures		Market Pressures		Management Vulnerability		Liquidity/Credit Vulnerability		Strategic Vulnerability		Supplier or customer disruptions
	Exposure to political disruptions	Changes in government regulations	Severe price fluctuation	Price pressures	Timing of business decisions	Reliance upon information flow	Lack of financial resources	Finance policies and procedures	High degree of outsourcing	Reliance upon specialty sources	
C1. Flexibility in operations		x	x		x						x
C2. Capacity of resources			x							x	x
C3. Efficiency of operation			x	x			x	x	x		
C4. Visibility of supply chain operations	x			x	x	x	x	x	x	x	x
C5. Adaptability in responding to challenge	x			x	x		x	x		x	
C6. Anticipation of potential disruptions		x		x			x	x		x	x
C7. Recovery from disruptions				x			x	x			
C8. Dispersion of resources		x			x						
C9. Collaboration with supply chain	x	x	x	x	x	x		x	x	x	x
C10. Market Position				x							
C11. Security against threats											
C12. Financial Strength			x				x	x			
Pathogens (refer Table 6.14)	(P), (CI)	(CO), (O)	(CI), (CO)	(CI), (CO),(P)	(B), (CO), (O), (P)	(P), (B), (CO), (O)	(CI), (CO), (P)	(P), (B), (CI), (CO)	(CI), (O), (CO), (B)	(CO), (CI)	(CI), (P)

Frequent disruptive events:

1. Quality problems
2. Failure of key customers
3. Failure of key suppliers
4. Financial crisis
5. Regulatory issues

Critical effects:

1. Delay and cost overruns
2. Defects in quality
3. Loss of productivity
4. Decrease in profit
5. Loss of skilled workers
6. Reputational damage

Pathogens:

(P) People's deliberate practice
(CI) Circumstance of project environment
(CO) Conventions, standards and routines
(O) Organisation system or structure
(B) Behaviour of contracting parties

Figure 6.2: Final resilience response framework

Figure 6.3 below highlights the critical capability factors of the public and private organisations. It shows that although the public organisations are highly adaptable and have strong security measures, they still need to improve their strengths in areas such as finance, efficiency and collaboration with supply chain members. On the other hand, the private organisations should prioritise spending on improving in areas such as their flexibility in operations, capacity of resources and collaboration.

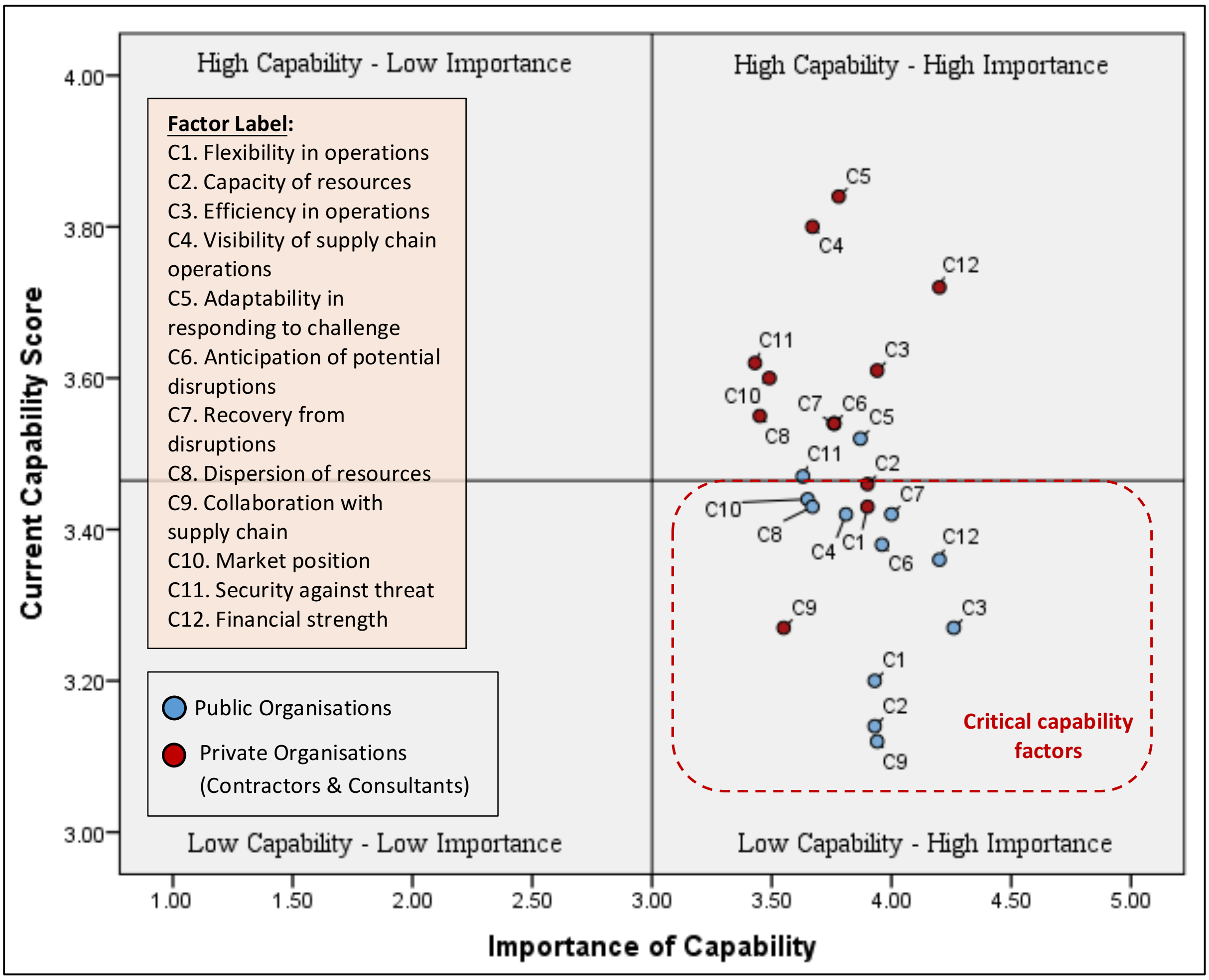

Figure 6.3: Current level of supply chain capabilities

Overall, by including Figure 6.3 in the final resilience response framework, the public and private organisations will be able to prioritise spending their resources on the capabilities that they want their organisations or supply chain members to improve in reducing the critical vulnerabilities identified in the final framework. This in turn, will enable the supply chain to achieve better preparedness and resilience in responding to disruptions in public projects and improve their supply chain performance.

6.7 Summary

Overall, the findings of this study have conveyed a full picture for construction professionals on how the impact of interdependencies could set in motion a chain reaction to manifest and destabilise the entire supply chain if not managed properly (Figure 6.1). Indeed, resilience to supply chain disruptions would be difficult to achieve in isolation due to the interdependencies of the supply chain vulnerabilities identified in this survey. This chapter has also provided managers with the relevant insight into the public organisations' and their supply chain partners' critical vulnerabilities and their current capabilities, which might not have been obvious before. As the vulnerability of any parties in the supply chains can dramatically degrade the overall resilience of the supply chain, the output from this study (Figure 6.2) that considers all parties will be useful in guiding the organisations and their supply chain to build resilience to disruptions in the delivery of construction projects. Overall, the presentation and validation of the final resilience response framework at the end of this chapter had fulfilled Objective 5 of the study (in Section 1.4).

CHAPTER 7

CONCLUSION AND RECOMMENDATIONS

7.1 Introduction

This thesis consists of seven chapters. Chapter 1 introduced the research background and topic, highlighting the research problem, research gap and aim and objectives of the study. The critical literature review was presented in Chapter 2, and the conceptual framework introduced; the research process and methodology were highlighted in Chapter 3. Chapter 4 presented the results of the questionnaire survey and Chapter 5 those gathered from the subsequent interviews. The main findings from these analyses were triangulated in Chapter 6, and the final framework developed and discussed. Finally, this chapter provides a summary of the study by revisiting the research aim and objectives and presenting the key findings. It underlines the theoretical and practical contributions, along with the limitations of the study, and makes suggestions for potential future research areas.

7.2 Summary of Research

The Malaysian construction industry has faced several supply chain disruptions (see Section 1.2.3) that hinder the government's goal of becoming a developed country by the year 2020. Understandably, managing these risks and the parties from different tiers of the supply chain is indeed challenging, especially with disruptions that cause large swings in capacity and resources in project delivery. These disruptive events prevent the public organisations from getting the best value from their expenditure, consequently damaging their reputation in the public eyes. Many initiatives have been put forward by the Malaysian government and previous researchers in light of this supply chain issue, such as partnering and outsourcing (Nawi et al., 2013), but there is still a lack of understanding on the current resilience of the public organisations and its supply chain and how they currently respond to and recover from actual disruptions. Furthermore, the supply chain as a concept, and especially how risks transcend organisational boundaries, is not well-understood in Malaysia and there is much discontinuity in supply chain partnerships in the local construction industry (Mehdi-Riazi et al., 2011). As the emerging risk of disruptions reaches the level of networks, this calls for studies beyond organisational boundaries to develop resilience within organisations and supply chains.

The purpose of the study is to improve the supply chain resilience in public projects so that they become more efficient in delivering public projects. In assessing the public sector supply chain's resilience level, Pettit et al.'s (2010) study a foundation for this research, identifying organisations' vulnerabilities and a set of capabilities to mitigate the critical areas of vulnerability. In addition, pathogenic influences were identified to help explain why supply chain members might be highly vulnerable in some areas rather than other, and to identify hidden effects. Overall, the research aims to develop a resilience response framework to improve preparedness and build resilience of the supply chain against disruptions in the effort to improve the Malaysian public sector project delivery. The study has achieved its aim by meeting the following objectives:

Objective 1: To examine the phases of supply chain disruptions faced by Malaysian public sector projects.

The study has investigated the characteristics of the Malaysian construction industry and the current challenges faced by the public sector supply chain (Section 2.2). Deficiencies in construction supply chain performance, identified from the literature (see Section 2.2.1), have resulted in the government not achieving the best value for money in its projects. The industry has also faced disruptions due to global economic shocks, such as the severe fall in the prices of major export commodities and devaluation of the Ringgit Malaysia against major currencies (EPU, 2015), that affected the overall cost of public sector projects. Calls for improvements in public project performance have been made throughout the series of national plans to improve public service productivity and efficiency. As a result, the researcher was intrigued to develop the best resilience strategy to address the supply chain disruptions faced in public projects, in order to improve the supply chain's efficiency in delivering construction projects.

Workable definitions of supply chain disruptions were examined in Section 2.3 through the comprehensive literature search. Supply chain disruptions are defined in this study as any foreseeable or unforeseeable event which affects the usual operation and stability of an organisation or a supply chain (Barroso et al., 2008). It is an event that takes place at one point in the chain and can adversely affect the performance of one or more parties in other parts of the supply chain, disrupting the normal flow of goods and materials in their operations (Craighead et al., 2007). A typical supply chain network in the context of the Malaysian construction industry is represented in Figure 2.4. The pre-, during, and post-disruption phases were examined in greater detail in Section 2.3.1, to understand how supply chains prepare, respond to and recover from disruptive events. The pre-disruption phase includes the proactive approach of the risk management process before construction begins on-site, which is common in the Malaysian construction industry. During the disruption, the effective reactive response depends on how well the risk management programmes set by the construction organisations in the supply chain are followed and implemented. However, in some cases, alternative responses outside the traditional work routines are required to prevent the spread of the disruption. Finally, the post-disruption phase involves the recovery and learning process of the organisations to reduce the likelihood of future disruptions. The integrated proactive and reactive responses are presented in the summary of disruption phases depicted in Figure 2.7, enabling the researcher to establish a workable definition of supply chain disruptions and understand the issues arising from them.

Objective 2: To examine the concept of resilience and its applicability in managing supply chain disruptions.

In order to manage supply chain disruptions, the concept of resilience was examined in Section 2.4 through an extensive literature review. The study presents a workable definition of supply chain resilience as the supply chain's ability to react to the negative effects of disruptions that occur at a given moment, in order to maintain the supply chain's objectives or recover to a better state (Barroso et al., 2008). The study highlights that in assessing supply chain resilience, it is important to identify the disruption areas, vulnerabilities, and how the disruptions can be mitigated through the development of capabilities (Pettit et al., 2010). The researcher then reviewed the extensive literature on supply chain resilience and compiled a classified list of vulnerability (see Section 2.5) and capability (see Section 2.6) factors, that was used as the basis of the questionnaire design. The concept of pathogens in construction projects and the integration of pathogens in resilience studies were also critically discussed to fill the gap identified in the supply chain literature (see Section 2.7). Ultimately, pathogens were identified as the key factors that contribute to the supply chain's vulnerability to disruptions in construction projects. The main categories of pathogens were also presented and are used as a guide in analysing the interview data. Lastly, the conceptual framework was introduced in

Section 2.8, integrating the three major knowledge domains: supply chain disruptions, supply chain resilience, and pathogens. The conceptual framework became a useful guide for the researcher in developing the final resilience response framework in this study.

Objective 3: To analyse the emergent vulnerability and capability factors of the public sector supply chain in coping with supply chain disruptions.

The questionnaire survey developed from the literature review was used to determine the emergent vulnerability and capability factors of the public sector supply chain. The respondents consisted of two main groups: construction professionals from the public organisations (51%), and the professionals (i.e. consultants and contractors) from the private organisations (49%) appointed by the public organisations to deliver the public projects. An analysis of the supply chain vulnerability and capability fron the survey results was presented in Section 4.4. It was identified from the survey that the public organisations are statistically significantly more vulnerable to political pressures than were the private organisations. In particular, the public organisations were identified as being significantly more vulnerable to exposure to political disruptions than were the private organisations. However, no significant differences in score between the public and private organisations were identified for the vulnerability of changes in government regulations, suggesting that the private organisations are also to some degree affected by changes in government regulations. Meanwhile, the private organisations were identified as being significantly highly vulnerable to market pressures compared to the private organisations, especially in terms of significant price pressures in the market.

In terms of capabilities, the public organisations have statistically significantly lower capability scores in the visibility of their supply chain operation than the private organisations, which makes it harder for the former to detect any disruptions arising from their supply chain members. The private organisations, on the other hand, were identified as having higher financial strength than the public organisations, which was surprising considering that the latter as a public entity should have the required financial reserves to deliver public projects. Overall, the top five critical vulnerabilities of the public sector supply chain were identified from the scatterplot in Section 4.5, as political or legal pressures, market pressures, management vulnerability, liquidity or credit vulnerability and strategic vulnerability. These critical vulnerabilities from the survey were also used as a guide for the researcher in the subsequent interviews to identify the inherent pathogenic influences that make the supply chain highly vulnerable in these critical areas. The critical vulnerabilities and capabilities are further discussed in Section 7.3 below on the main findings of the study.

Objective 4: To identify the causes and the cascading effects of supply chain disruptions to the Malaysian public sector project performance.

The causes and cascading effects of supply chain disruptions in public projects were identified from the interviews with 12 construction professionals in the field. The identification of the pathogenic influences in the interviews enabled the researcher to systematically assess why the public and private organisations are more vulnerable in some areas than other, as part of the intermediate process in developing appropriate resilience strategies to mitigate the vulnerabilities. Five critical pathogens emerged from the interviews as causing disruptions: *practice, circumstance, convention, organisation* and *behaviour,* as discussed in Chapter 5. The interview findings show that these pathogens are interrelated. In this regard, the individual *practice* (i.e. poor assumptions in decision making) and *behaviour* (i.e. opportunistic behaviour, blame-game) of the public sector supply chain were attributed to the *circumstance* in which the projects operate, such as the political environment and current economic conditions. It was also identified that the established *convention* in government procedures and existing *organisational* structure of hierarchical departments of the public organisations, clients and external stakeholders result in late approvals and decision making in the supply chain operations. The relationship between these pathogens and how they influence the top five critical vulnerabilities identified are further discussed in Section 7.3.

The study also discussed how disruptions can cascade from one point to another through the layers of supply chain network, as presented in Figure 6.1. For instance, late payment of contractors by the public organisations causes delayed payment by the contractors to their suppliers, resulting in delay in the material supply that in turn affects the contractors' operations. This shows that poor performance by any parties in the chain could impact another supply chain network at a different level, resulting in a set of organisations entering a vicious cycle of poor performance based on their vulnerability levels. Critical effects were also identified from the questionnaire results and interview data, including delay and cost overruns in operations, defects in quality due to poor workmanship and material supply, loss of productivity due to inefficient practices in operations, decrease in profits faced by private organisations, loss of skilled workers on-site, and reputational damage to the public organisations (see Section 6.3.2).

Objective 5: To establish and validate the resilience response framework to improve supply chain performance in meeting its resilience goals to mitigate against disruptive events in Malaysian public sector projects.

The final resilience response framework in this study was developed from the triangulation of the findings of the questionnaire survey, interviews and literature on the critical vulnerabilities, pathogenic influences, and resilience capabilities of the public sector supply chain (see Table 6.14). The final framework presented in Figure 6.2 is a matrix of the critical vulnerability factors and linked capability factors. The sets of capabilities identified to mitigate these vulnerabilities were based on the interview data presented throughout Chapters 5 and 6, and on the literature. The inherent pathogens are also presented in the framework to highlight the underlying causes that make the public sector supply chain highly vulnerable in these critical areas. The proposed resilience response framework was validated by five experts in the field, on its clarity and their understanding of the framework. The interview data also served as a qualitative validation of the questionnaire findings on the supply chain vulnerabilities and capabilities, as discussed throughout Section 6.4. Overall, the final framework allowed the experts from the public sector supply chain to understand the areas of critical vulnerability of their organisation and their supply chain members. The set of capabilities identified in the framework also serve as a guide for the public sector supply chain to reduce the disruptive impacts arising from these critical vulnerabilities, in the effort to build better preparedness and resilience against disruptions in public sector project delivery.

7.3 Research Main Findings

Frequent disruptions and critical effects of disruptions

- The study revealed a possible issue of trust between the public and private organisations considering that the public organisations blamed quality problems on contractors' deficiencies, and that the private organisations blamed the failure on their customers (i.e. the public organisations) for the most frequent disruptions in public projects. The failure of key suppliers was prevalent in the contractors' operations as most of the specialist materials such as steel were imported from foreign suppliers. This resulted in late supply of material on-site and inconsistencies in terms of the quality of the materials imported by their suppliers. The volatility of the economic situation in Malaysia also affected the construction industry's operations, as both the public and private organisations reported having faced frequent financial crises due to the drop in value of the Ringgit Malaysia. The public sector supply chain also faced regulatory issues such as strict government regulations and layers in the approval process, suggesting that government's unfavourable legislation and inefficient bureaucratic practices could hinder the project team members' operations in reacting to and recovering from disruptive events.

- The study highlights the effect of transcending supply chain relationships with private clients (see layered supply chain network in Figure 6.1) where the same key suppliers or customers might pose a threat of disruption resulting in interdependent impacts on other supply chains in the layered framework. In this regard, the shortage of material such as steel was prevalent due to high demand from both public and private projects, especially when projects were being delivered concurrently with mega-infrastructure work such as the Mass Rapid Transit (MRT). This resulted in the substantial increase in steel prices. The study found that as the contractors and consultants could be working on one public project and several private projects involving international suppliers for private sector clients, the failure of any one supplier or customer arising from eith public or private sector-initiated supply chains could disrupt their operations in the projects, including the public projects.
- The study identified that the private organisations faced higher critical effects of disruptions on their internal performance, such as the loss of productivity, decrease in profit, and loss of skilled workers. The loss of profit and poor productivity were attributed to the inefficient practices within the supply chain operations, such as unpredictable changes in demand by clients, and incompetent sub-contractors. The lack of skilled workers was due to inadequate training of the construction workforce and the lack of interest of local people in construction work on-site, causing the Malaysian construction industry to rely heavily on foreign workers. The inadequate level of skills among the project team members could be problematic as it could cause a significant loss of productivity and efficiency in the supply chain operations.
- The critical effects of disruptions such as quality problems could critically damage the public organisations' reputation, as they are widely exposed to public scrutiny and

media pressure. In fact, the public organisations' main concern for higher quality and public reputation, and the private organisations' main concern for profitability, suggests that they have different priorities. This degree of dissimilar goals within the same supply chain is problematic considering the interconnected risks they share due to the interdependence of their operations. Finding common ground or mutual objectives is therefore imperative here, to reduce the impact of disruptions to public projects and to build supply chain resilience.

- The study found that while all parties in the supply chain face disruptions in public projects, the frequency and severity of disruption were felt most in the contractors' operations during public project delivery. Considering the interdependence of the design-construction process, the deficiencies arising in the pre-construction phase are only realised in the subsequent construction phase, causing cascading impacts on the contractors' operations. The repercussion of disruptions on the contractors is higher than that on other parties in the supply chain, a serious problem as it suggests that most of the risks of disruption are borne by the contractors rather than the consultants and public organisations. However, any disruptions affecting the contractors' work eventually have an impact on the consultants, who are required to extend their consultancy services with no additional fees if delay occurs, and to the public organisations who end up paying for the costs stemming from these disruptions.

Current disruption management approach by public sector supply chain

- The public organisations' current risk management practice appears not to be effectively carried out due to the fragmentation of the various departments' interdependent tasks. Despite having a comprehensive risk management system, the blame-game is still prevalent between the departments within the public organisations, making it hard to coordinate the risk management plan from the planning to the construction phase. Consequently, poor coordination among the public organisations' departments makes them vulnerable in responding efficiently to any potential risk of disruptions. The lack of transparency among project team members in sharing information during risk management meetings was also identified as making it harder to detect any potential disruptive events. The private organisations also seem to depend heavily on the public organisations' risk management plans as they can not justify the expense of a risk manager of their own. Most disruptions were tackled as they arose by their own employees in a firefighting approach. This ad-hoc approach, however, makes the contractors highly exposed to unexpected disruptive events.

Critical vulnerabilities and capabilities of public sector supply chain

Political/Legal Pressures

- The study found that the public sector supply chain is highly vulnerable to political interference especially during project award stages, causing unfavourable project team selection and the questionable competence of contractors. The strong tendency to political involvement in awarding public projects identified in the literature contributes to the increase in the number of contracting firms that are only interested in winning the contracts. This had led to these firms sub-letting the total project to other contractors or sub-contractors, resulting in complex payment through multi-layered sub-contracting. The cost of materials such as steel is determined by political power, causing the inconsistencies.
- The study found that although the private organisations are not as badly exposed to political disruptions as the public organisations, the impact of political disruptions could spread across the supply chain affecting the consultants, multiple contractors and sub-contractors and resulting in time and cost overruns. The public organisations are in a better position to anticipate potential political interference, but despite this strength, their lack of transparency in communicating the information with their stakeholders and private organisations makes it hard to control the spread of political impacts through their supply chain operations.
- The private organisations were extremely vulnerable to any changes in government regulations, especially as they vary from one state to another. The regulatory frameworks involving multiple authorities at the federal, state and local levels that govern the construction industry in Malaysia are complex and difficult to navigate. The confusion and misinterpretation of government regulations by different stakeholders cause further difficulties for the private organisations. as well as creating disputes between the public and private organisations that can be costly in terms of time, money and effort. This risk should be best managed by the public organisations, by including in the contract clear statements of the responsibilities of all parties according to the regulations, and updating or providing training for the private organisations on the new

policies imposed. The interaction between the private organisations and the government is also imperative and needs to be participatory in managing policy changes.

Market Pressures

- Despite the private organisations' great financial strength, they are highly susceptible to severe price fluctuations and strong price competition caused by market and economic circumstances. Severe price fluctuations were attributed to the falling of the local currency, resulting in local suppliers raising the price on scarce materials. The process of claiming for Variation of Price (VOP) from the public organisations was found to be time consuming for the contractors in obtaining approval and receiving payment. Certain contractual arrangements limit the ability of the contractors to claim VOP, where the maximum contract sum has been agreed upon in advance by both the public and private organisations. The contactors can reduce the impact of such disruption by being proactive and ordering materials much earlier when the currency is more stable, in order to lock in the price. They could also consider modifying their method of construction and mode of transportation of materials when faced with significant rises in the price of materials.
- The highly competitive nature of the construction market puts significant downward pressure on the private organisations' profits and market share. The private organisations also face market pressure from foreign players; international parties have increasingly gained a market share across various types of project in Malaysia in recent years. The tender price of government projects is also found to be extremely competitive, especially in an open tender system. The public organisations' goals of higher quality and low cost have resulted in the under-pricing of bids by contractors, resulting in the contractors working on a low profit margin. In this case, they can gain competitive advantage by adjusting their project overheads to increase their chance in winning the bid. Learning from past tendering experience can also increase the contractors' competitiveness in bidding for contracts of similar types. Additionally, maintaining long-term relationships with key sub-contractors and suppliers is important to obtain the most reasonable prices of materials from domestic or foreign suppliers.

Management Vulnerability

- The public sector supply chain is identified as being highly vulnerable to late decision making. This is attributed to the public organisations' concentration of decision-making power in their highly dispersed market. The *organisation* structure pathogen of layers of approval in the various departments of public organisations results in poor communication and slow decision making among the project team members, especially during disruptions. Empowering experts on-site to make key decisions regardless of their level of authority could help the public organisations to overcome late decision making. It would also help to improve their ability to seize advantage from disruptions and reduce their vulnerability to inadequate management control over supply chain members.
- Both the public and private organisations rely heavily on a continuous flow of information in their operations, due to the extent of their supply chain network. However, the study found that transparency in information sharing was hard to achieve due to the inadequate level of trust between the public and private organsiations. This can be attributed to the behaviour pathogen of "us versus them" in project teams. The centralised decision making of the public sector supply chain also makes them highly vulnerable regarding timely information flow. Information Technology (IT) tools such as Building Information Modelling (BIM) should be used to improve information flow and encourage collaboration in the supply chain. This will, in turn, increase the visibility of the status and resources of the public organisations' supply chain.

Liquidity/Credit Vulnerability

- The public organisations were identified as having a lack of financial resources and significantly less financial strength than the private organisations. This result is surprising as the public organisations would be expected to have sufficient funds to deliver the public sector projects effectively. The study found that insufficient funding rises from their clients' (i.e ministries') limited budgets. The *convention* pathogen in the financial policy that requires the cost of public projects to be estimated a year ahead for budgetary purposes also limits their spending in response to unpredictable changes in demand. The financial constraints limit the design scope of projects and the resources available in the planning phase. The public organisations should therefore improve their efficiency level in areas such as labour productivity and utilisation of resources to overcome financial limitations.

- The public organisations' financial vulnerability has led to late payment of contactors, which subsequently causes late payment by the contractors to their suppliers and sub-contractors. Contractual terms of payment of materials on-site are not adhered to by the public organisations, due to the lack of trust in the contractors' operations. This makes the contractors highly vulnerable to any changes in financial policies and procedures. The impact of financial vulnerability could also spread and cascade from one project to another in the supply chain, as any delayed payment in the public sector projects could affect the resources available to contractors for private sector projects. The study found that even the private organisations' greater financial strength could not overcome the impact of under-payment or late payment by the public organisations. The private organisations have to increase their ability to anticipate the extent of the finance that will return to them, so that they can plan their work accordingly.

Strategic Vulnerability

- The public organisations' strategic decision to outsource many of their operations has resulted in poor visibility of their supply chain members' operations. This makes it difficult to detect potential disruptions arising from the supply chain, or to obtain a complete picture of the current situation affecting project delivery. The study found that this high degree of outsourcing was attributed to the incompetence of their internal team. Lack of expertise in administering non-conventional contracts such as design and build also resulted in the contractors' opportunistic *behaviour* in taking advantage in making claims. The public organisations' training centre was closed down over 20 years ago, resulting in the *convention* of poor documentation of lessons learnt , exposing them to repeat the same mistakes in subsequent public projects. The public organisations should either strengthen their relationship with their key suppliers, especially those providing specialty sources, or develop less formal connections with multiple suppliers for their procurement strategy to be effective.
- The private organisations rely heavily upon specialty sources in their operations. Despite the high degree of outsourcing, they seem to have better control of their supply chain and are fully aware of the status of their current resources, unlike the public organisations. However, reserving materials from outsourced suppliers proves difficult

for the contractors in uncertain economic conditions. The contractors can order only a limited amount of specialist materials such as steel, and are therefore unable to reserve extra capacity in case of disruption. The contractors should make contingency plans for procuring specialist materials to ensure they arrive on-site within the stipulated time.

Supplier or Customer Disruptions

- The public organisations' reported assumption that the private organisations have sufficient capacity to deal with unplanned changes in demand raises the question of whether the public organisations are fully aware of the condition of their supply chain members. The private organisations in fact rated capacity as one of their weakest capabilities, especially concerning multiple redundant resources and reserved capacity of materials. This further supports the study's findings that the public organisations have poor visibility of their supply chain operations and resources. Their assumption that the private organisations can deal with changes in demand puts an unnecessary burden on the private organisations to meet unexpected demand changes within their limited resource capacity. In order to obtain the full advantage of their strategic outsourcing, the public organisations need to have full visibility of their supply chain members' operations in order to adequately manage and control the delivery of public projects.

7.4 Research Contributions to Theory

This study adds an important angle to the existing literature by considering a holistic view of managing supply chain disruptions in construction. To date, researchers in the Malaysian construction industry have largely focused on the risk management aspects at the pre-disruption stage by analysing the probability and impact of the risk of potential disruptions in construction projects. The lack of research on the supply chain's response following actual disruptions has resulted in its not being able to take the opportunity to learn from existing disruptions or utilise current capabilities to mitigate such problems. While it is important to be ready to mitigate the potential risk of disruptions, managing disruptions as they materialise through reactive strategies such as increasing flexibility and adaptability are equally important in handling disruptions efficiently. Hence, by utilising an integrated approach of both pre-disruption and post-disruption phases and considering both proactive and reactive strategies, this study brings a holistic view of managing disruptions to the existing construction literature.

Another theoretical contribution is the addition to the literature on supply chain resilience of pathogenic studies. Although the concept of pathogens has been presented in previous construction studies, there is still no research integrating pathogens in the resilience literature. Inherent pathogens that reside in the system or supply chain could hinder the effort to build resilience in the construction supply chain. Without addressing the pathogenic influences of the problem, organisations will continue to repeat the same mistakes, making them more vulnerable to disruptive events. Previous resilience studies also tended to overlook these latent conditions or pathogens that made an organisation vulnerable to disruptive events in the first place. By introducing pathogenic influences to the supply chain's vulnerability and capability factors, the level of supply chain resilience can be assessed through a different approach, offering a significant new perspective on both the construction and resilience studies.

Furthermore, the existing theory documents several commercial pressures on the construction industry and its firms, hence many of its players tend to operate with very low margins. Some of the new procurement systems tend to anticipate cost savings year-on-year to keep supply chain relationships intact. In such a context, this research provides some theoretical insights to assess an organisation's vulnerability not just in terms of its explicit dimensions but also the hidden dimensions. This builds up new theoretical pragmatic risk management approaches in a field where the current theories only allow general contingency measures.

The final theoretical contribution to knowledge is the assessment of supply chain resilience in the context of the Malaysian construction industry, inadequately studied to date. Although pathogenic effects such as quality problems, delays and cost overruns are common in Malaysia, there has been no formal study on the pathogens affecting the resilience of the construction supply chain. This research therefore bridges this gap by identifying the significant pathogens that affect the construction supply chain's vulnerability and that undermine their capability to recover and thrive from disruptions, which have not been considered by previous researchers.

7.5 Research Contributions to Practice

Contributions to Practitioners

In terms of the study's practical contributions, this research can offer the managers of the public organisations relevant insights into their organisations' and supply chains' critical areas of vulnerability and capabilities. The significant linkages between the pathogenic influences, vulnerabilities and capabilities presented in this study will allow the public sector supply chain to make full use of their current capabilities and prioritise their spending on other areas that need further improvement. The research outcome that considers both the upper tiers and bottom tiers of the supply chain network (i.e. the public organisations and private organisations) is also valuable in informing and guiding the public sector supply chain to build their preparedness and resilience to disruptions in order to improve public project delivery. While it is impossible to eliminate all the risks of disruption in construction projects, by improving the supply chain's resilience in public projects, it can become more efficient in delivering the projects. It is worth noting here that the idea of the study is not to prevent risk-taking by the project managers and clients in the construction industry, but rather to give them guidance on being mindful of the pathogenic effects, vulnerabilities and capabilities (Table 6.14) and to identify them more effectively. The study also gives them a pathway to recognise how disruptive the full brunt of a pathogenic impact can be, as depicted in the cascading effect illustrated in Figure 6.1. Such new knowledge will give a better opportunity for project managers, clients and other stakeholders to take a firm grip on construction projects. Although this study concentrated on public projects in Malaysia, it may offer advantages in similar contexts in terms of understanding the dynamics of the supply chain's vulnerabilities and capabilities in a layered supply chain network, as presented in Figure 6.1. Future research can also take this study forward by considering the dynamics and interdependence in assessing bottlenecks across several layers of supply chains, not just in construction but also in other industries.

Contributions to Construction Industry

Considering that the Malaysian construction industry's output is smaller than other sectors' such as services (GDP 55.2%) and manufacturing (GDP 24.5%) (Department of Statistics Malaysia, 2014), a higher level of efficiency developed through supply chain resilience strategies in one project could result in a significant increase in the growth of the construction industry. The improvement in supply chain performance might also have multiplier effects on other interdependent industries, moving the economy towards the Malaysian Vision 2020 goals. There is indeed a concept of dynamism in risk management, in which risks do not disappear fully; it is a case of transferring risk from one party to another rather than removing it. For instance, the private organisations used some of the disruptive events and the public organisations' vulnerabilities as opportunities through the opportunity to submit claims for losses and expenses, which is a way of increasing profitability to the detriment of another party.

From the point of view of a public project client, it will be in their best interests to find ways of reducing or removing the impacts by a resilience response strategy. This is practically the case in the construction industry. This study therefore helps to understand the hidden vulnerabilities by analysing performance in terms of vulnerability and capability factors, which are the two sides of the coin in terms of resilience against disruptive events in supply chain operations, and can be extremely useful to organisations and supply chains. Ultimately, the ability to reduce the impact of disruptions such as a cost overrun, or to identify a potential future cost overrun, could add value to both practice and theory.

Contributions to Policy-makers

In terms of the policy-making point of view, the research can offer policy makers an input into the current level of competencies of the construction supply chain and their critical vulnerability areas that need to be improved. Policy-makers can take forward the results of the study and consider improving the resilience of the supply chain by encouraging partnering in public projects, setting up policies on the training of foreign workers, and ensuring consistent quality and costs of material from qualified foreign suppliers. Policy-makers could also gradually introduce the use of innovative solutions such as the use of Building Information Modelling (BIM) to improve transparency in information flow and encourage collaborative decision-making. This will, in turn, increase the visibility of the status and resources of the construction supply chain and improve their productivity in the construction operations. Ultimately, the research outcome shows that there should be a coherent strategy in the policies where all organisations within the supply chain all pull together in the same direction with better goal congruence to improve project performance.

Contributions to Professional Bodies

The research also allows professional bodies such as the Malaysian Construction Industry Development Board (CIDB), Malaysian Institute of Architects, the Malaysian Institute of Engineers, and the Malaysian Institution of Surveyors to understand the dynamics of the public and private organisations' vulnerabilities and capabilities in improving resilience within the construction supply chain. In building the competencies of the construction professionals, the professional bodies can use the results from the resilience response framework (Figure 6.2) as a guide to prioritise their investments on the capability areas that need further improvements in reducing the critical vulnerabilities. The professionals bodies could also work closely with the Government in building these competencies, such as promoting high level of integrity in the professionals' operations especially in the tendering process of government projects to reduce misconduct in their practices (i.e. political interferences), and encouraging alternative partnering procurement approach to improve supply chain integration. The research also suggests that there are still confusion among the professionals in understanding the government rules and regulations, as identified through the convention pathogens in this study. In this case, the professional bodies should ensure that the private organisations are well informed of any new practices and regulations imposed by the Government through their respective bodies. This will allow the professionals to be proactive in preparing for any changes in the policies and regulations.

7.6 Research Limitations

The limited time available to conduct the study posed constraints in terms of the number of semi-structured interviews that could be conducted with the professionals in Malaysia. Only 12 construction professionals were interviewed to triangulate the findings identified in the questionnaire survey. Furthermore, given the large size of the population, the sample group of contractors in the questionnaire survey was limited to Class G7 contractors involved in projects greater than RM10 million in the state of Selangor and the Federal Territory of Kuala Lumpur. These states were selected as the economic and administrative centre of Malaysia; it was assumed that the characteristics of this area qualify the sample to represent the Malaysian construction industry as a whole. The questionnaire survey was also limited to professionals working with Malaysian public organisations, consultants and contractors. External stakeholders such as the client, utility companies, and suppliers were not included in the study sample due to the limited costs and time available.

Furthermore, in the interview analysis, while identification of some of the pathogens in the interview data was generally straightforward, other pathogens overlap (i.e. the same pathogens could be classified in two different categories). As in Love et al.'s (2009) study, separation of a specific pathogen proved difficult, especially in terms of *convention* and *circumstance*. The pathogens were also based on the respondents' interpretations of the root cause of the problems they faced, and so may vary from case to case. The classification of pathogens also relied on the researcher's own interpretations, based on examples from previous studies (Busby and Hughes, 2004; Busby and Zhang, 2008; Love et al., 2008).

7.7 Recommendations for Future Research and Final Remarks

Future research might include the assessment of pathogenic influences and supply chain resilience in related industries in the manufacturing and services sectors. It would be interesting for future researchers to assess the dynamics and interdependencies between supply chains from different industries, in terms of how bottlenecks across the several layers of the supply chain network have cascading effects on other interdependent industries: for instance, how the supply chains in the steel industry could affect the operations of supply chains in the construction industry. Future research could also consider the scale of disruptions; in terms of its frequency and severity in applying the resilience response framework. This will help to determine the relevant capabilities required to respond to the different level of magnitude of disruptions. Quantitative studies of the pathogens could also be useful in terms of classifying the factors and conducting inferential analysis of the pathogenic effects.

Further recommendations from the research in building the public sector supply chain's resilience to disruptions in construction projects are as follows:

- The public organisations should consider simplifying their approval process by distributing the decision making to the professionals that are directly involved in the project. This would ease the process of decision making, especially when fast response are needed in handling disruptions that disrupt the current work progress. The public organisations should also ensure that the scope of the project is within the allocated financial provision and the design is finalised before proceeding to the subsequent phase of the project to reduce deficiencies in their supply chain's operations and mitigate cost overruns.
- The public organisations could also provide professional training to their in-house team to ensure that their knowledge can be shared across the different departments, especially in terms of the lessons learnt from previous public projects. Training should also be adequately available for the private organisations engaged in delivering public projects, so that they have a better understanding of the government's system, process and procedure. This in turn, will reduce disputes and encourage collaboration among the public sector supply chain. Public organisations could also consider the use of project team communication matrix and stakeholder analysis to improve visibility of their supply chain operations and manage their stakeholders' expectations.
- In terms of the policy-making point of view, any new policies imposed by the government should be implemented gradually to allow time for the construction

professionals to adapt to the new requirements and gain adequate information on the new practice that they are not used to. Policy maker should be involved in building the competencies of the construction professionals and ensuring high level of integrity among the professionals to reduce misconduct in their operations.

- The private organisations should ensure that they are up to date and well informed in current government policies and regulations to ensure they are well prepared when new policies are implement. Consultants should know well in advance the government's terms and regulations especially in dealing with the contractors' claims so that they could manage the contract and payments sufficiently.
- The contractors should improve their transparency in sharing information on the current risks in their operations to the public organisations so that the project team can collectively identify the best response to such risks. They should also consider building their relationship with key suppliers especially those providing specialty sources to ensure timely procurement and delivery of material. Credible suppliers that have been qualified by the government should be engaged to ensure consistent quality in their operations.
- The private organisations should plan their resources and work well based on the expected return on finance (i.e. the expected timing of payment by the public organisations) to ensure they have sufficient resources and finance throughout their operations. The private organisations should also prepare contingency plans in their operations to reduce the impacts of supply chain disruptions.

Overall, the thesis has discussed the relevant research problem, the vulnerability of the construction supply chain to disruption. Malaysia, a developing country, is facing disruptions in local public construction projects that cause time and cost overruns, resulting in loss of revenue and poor reputation of the public entities. This presents an ideal scenario for the study to investigate the level of resilience of the public sector supply chain in dealing with disruptions and subsequently to develop a resilience response framework to strengthen their preparedness and resilience to disruptive events. By assessing the vulnerability and capability factors through the questionnaire survey and identifying the pathogenic influences through the interviews, this study offers public and private organisations a better understanding of their supply chain disruptions, enabling them to develop the actions required to utilise their supply chain capabilities and mitigate their vulnerabilities, in the effort to improve public project performance.

REFERENCES

Abdul-Aziz, A. and Ali, N. (2004). Outsourcing and quality performance: Malaysia's Public Works Department. Structural Survey, Vol.22, No.1, 53-60.

Abdul-Aziz, A. R. (2001). Foreign workers and labour segmentation in Malaysia's construction industry. Construction Management & Economics, 19(8), 789-798.

Abdul Kadir, M.R. et al. (2005). Factors affecting construction labour productivity for Malaysian residential projects. Structural Survey, 23(1), 42-54.

Abdul-Karim, J. (2008). Strategies of effective project delivery system. Paper presented at School of Professional and Continuing Education, University Technology Malaysia.

Abdul-Karim, S.A.Q. (2013). The significance of owner participation for a successful detached housing development in Malaysia. PhD Thesis, Queensland University of Technology.

Abdul-Rahim, H. (2010). Effective project delivery – strategies for success implementation of projects under 10th Malaysia Plan. Submitted to Faculty of Civil Engineering, University Teknologi Malaysia.

Abdul-Rahman, H. and Alidrisyi, M.N. (1994). A perspective of material management practices in a fast developing economy: the case of Malaysia. *Journal of Construction Management and Economics,* Vol. 12, pp. 413-22.

Abdul-Rahman, H. et al. (2005). Beyond basic: the potential role and involvement the QS in public projects–an observation. In QS National Convention: Sustaining the Profession–Towards Diversification (pp. 10-18). Kuala Lumpur, Malaysia.

Abdul-Rahman, H. et al. (2006). Delay mitigation in the Malaysian construction industry. *Journal of Construction Engineering and Management*, *132*(2), 125-133.

Abdul-Rahman, H. et al. (2007). A study on quality management during pre-construction stage of design-and-build projects. Proceedings of the CME 25 Conference, Reading, UK 16-19 July

Abd. Shukor, et al. (2010). Issues and barriers of construction supply chain in the Malaysian construction industry". 2nd International Conference on Construction in Developing Countries (ICCIDC II) Advancing and Integrating Construction Education, Research & Practice, 3-5 August, Cairo,Egypt.

Abowitz, D. A. and Toole, T. M. (2010). Mixed method research: fundamental issues of design, validity, and reliability in construction research. *Journal of Construction Engineering and Management,* 136(1), 108-116.

Abranovic, W.A. (1997). *Statistical Thinking and Data Analysis for Managers*. Reading, MA: Addison-Wesley.

Abu-Bakar, A.H. et al. (2011). Survival strategies of construction companies in Malaysia during two periods of recession. *International Journal of Academic Research,* 3(4).

Ahmad, S.A. et al. (2009). A study on the practise of delay analysis techniques in the Malaysian construction industry. 13th Pacific Association of Quantity Surveyors Congress (PAQS), 2009, pp. 24-31.

Ahmed, S. M. et al. (1999). Risk management trends in the Hong Kong construction industry: a comparison of contractors and owners perceptions. Engineering construction and Architectural management, 6(3), 225-234.

Aibinu, A.A. and Odeyinka, A. (2006). Construction delays and their causative factors in Nigeria. *J. Constr. Eng. Management*, ASCE, Vol. 132, No. 7, pp. 667-677.

Akintoye, A., McIntosh, G. and Fitzgerald, E. (2000) A survey of supply chain col- laboration and management in the UK construction industry. *European Journal of Purchasing and Supply Management*, 6(1), 159–168.

Alaghbari, W. E., Kadir, M. R. A., and Salim, A. (2007). The significant factors causing delay of building construction projects in Malaysia. Engineering, Construction and Architectural Management, 14(2), 192-206.

Al-Tmeemy, S.M.H., Abdul-Rahman, H. and Harun, Z. (2012). Contractors' perception of the use of costs of quality system in Malaysian building construction projects. *International Journal of Project Management,* 30 (2012), 827–838.
Alwin, D. (1973). Approaches to the interpretation of relationships in the Multitrait Multimethod Matrix. Sociological Methodology, pp. 79-105.
Alzan, S. A. et al. (2011). Contractors' perception of factors contributing to project delay: case studies of commercial projects in Klang Valley, Malaysia. E-journal, Klang Valley, Malaysia
Ameer-Ali, N.A.N. (2006). A "construction industry payment and adjudication act": Reducing payment-default and increasing dispute resolution efficiency in construction. *Master Builders J.*, 3rd Quarter 2006.
Argyris, C. (1998). Empowerment: the emperor's new clothes. Harv Bus Rev, May-Jun 76 (3): 98-105.
Asbjørnslett, B. E., and Rausand, M. (1997). "Assess the vulnerability of your production system" (No. 97018): Norwegian University of Science and Technology.
Assaf S.A. and Al Hejji S. (2006). Causes of delay in large construction projects. *International Journal of Project Management*, 24, 349-357.
Assaf, S.A. et al. (1999). Project Overhead Costs in Saudi Arabia. Cost Engineering, 41(4), 33–38
Barroso, A., Machado V. and Cruz Machado V. (2008). A supply chain disturbances classification, Proceedings of the International Conference on Industrial Engineering and Engineering Management, (8-11), IEEM, Singapore
BDP International (2013). Two thirds of businesses hit by value chain disruption. Retrieved March 12th, 2015, from www.bdpinternational.com
Becker, P., Abrahamsson, M., and Tehler, H. (2011). An emergent means to assurgent ends: community resilience for societal safety and sustainability. In Proceedings of the fourth resilience engineering symposium. Presses des MINES, Paris, France (pp. 29-33).
Behdani, B. (2013). Handling disruptions in supply chains: an integrated framework and an agent-based model. PhD Thesis, Sharif University of Technology, Iran
Bell, S. (1996). *Learning with information systems: Learning cycles in information systems development.* New York: Routledge
Benton Jr, W.C. and McHenry, L.F. (2010), *Construction purchasing and supply chain management*. McGraw Hill, New York.
Berg, E., Knudsen, D. and Norrman, A. (2008). Assessing performance of supply chain risk management programmes: a tentative approach. *International Journal of Risk Assessment and Management* **9**(3): 288 - 310.
Billa, L. et al. (2006). Comprehensive planning and the role of SDSS in flood disaster management in Malaysia. Disaster Prevention and Management, Vol. 15 No. 2, p. 233.
Blackhurst, J. et al. (2005). An empirically derived agenda of critical research issues for managing supply-chain disruptions. *International Journal of Production Research*, Vol. 43 No. 19, pp. 4067-81.
Blaikie, N. (2000). *Designing Social Research.* Cambridge: Polity Press.
Blos, M. F. et al. (2009). Supply chain risk management (SCRM): A case study on the automotive and electronic industries in Brazil, *Supply Chain Management: An International Journal* 14(4): 247-252.
Bolarinwa, O.A. (2015). Principles and methods of validity and reliability testing of questionnaires used in social and health science researches. *Nigerian Postgraduate Medical Journal*, 22(4), 195.
Boone, H.N. and Boone, D.A. (2012). Analyzing likert data. *Journal of Extension, vol. 50, no. 2*. Retrieved Oct 12th, 2014, from www.joe.org
Boone, C. et al. (2013). Implementation of a System Approach for Enhanced Supply Chain Continuity and Resiliency: A Longitudinal Study. *Journal of Business Logistics* 34 (3): 222–235.

Boyer, K. K. and M. L. Swink (2008). Empirical Elephants—Why Multiple Methods are Essential to Quality Research in Operations and Supply Chain Management. *Journal of Operations Management*, 26 (3), 337-348.

Briggs, S. R. and Cheek, J. M. (1986). The role of factor analysis in the development and evaluation of personality scales. *J. of Personality*, 54(1), 106-148.

Briscoe, G. and Dainty, A. (2005). Construction supply chain integration: an elusive goal?. *Supply chain management: an international journal*, 10(4), 319-326.

Brooks, N. (2003). Vulnerability, Risk and Adaptation: A Conceptual Framework. Working Paper 38, Tyndall Centre for Climate Change Research, University of East Anglia, Norwich.

Buang, N.A. (2012). Entrepreneurs' Resilience Measurement. Entrepreneurship - Born, Made and Educated, Prof. Thierry Birger-Helmchen (ed.). Retrieved June 15th, 2014, from http://www.intechopen.com/books/entrepreneurship-born-made-and-educated/entrepreneurs-resilience- measurement

Burnard and Bhamra (2011). Organisational resilience: development of a conceptual framework for organisational responses. International Journal of Production Research, 49 (18), pp. 5581 - 5599.

Burton, L.J. and Mazerolle, S.M. (2011). Survey instrument validity part I: Principles of survey instrument development and validation in athletic training education research. Athl Train Educ J., 6(1):27-35.

Busby, J. S., and Hughes, E. J. (2004). Projects, pathogens and incubation periods. *International Journal of Project Management, 22*, 425–434

Busby, J.S. and Zhang, H. (2008). The pathogen construct in risk analysis. Project Management Journal, Vol. 39, No. 3, 86–96 Project Management Institute, Wiley InterScience

Business Continuity Institute (2014). Supply chain resilience 2014: An international survey to consider the origin, causes & consequences of supply chain disruption. Zurich Insurance Group.

Camerer, C.F. and Kunreuther, H. (1989). Decision processes for low probability events: Policy implications. *Journal of Policy Analysis and Management,* vol. 8, no. 4, pp. 565- 592.

Campbell, D. T., and Fiske, D. W. (1959). Convergent and discriminant validation by the multitrait-multimethod matrix. Psychological bulletin, 56(2), 81.

Carmines, E.G. and Zeller, R.A. (1979), *Reliability and Validity Assessment.* Beverley Hills: Sage.

Cavan, R. Y., Delahaye, B. L., and Sekaran, U. (2001). *Applied business research: Qualitative and quantitative methods.* Queensland: John Wiley and Sons

Chan, A.P. (2001). Time–cost relationship of public sector projects in Malaysia. *International journal of project management,* 19(4), 223-229.

Chan, C.T.W. and Pasquire, C. (2002). Estimation of project overheads: a contractor's perspective. In 18th Annual ARCOM Conference (pp. 2-4).

Chopra, S. and Sodhi, M.S. (2004). Managing Risk to Avoid Supply-Chain Breakdown, *Sloan Management Review* 46(1): 53-61.

Choudhury, I. and Rajan, S.S. (2003). Time-cost relationship for residential construction in Texas. Retrieved September 2015 <http://itc.scix.net/ paper w78-2003-73>

Chowdhury, M.M.H. et al (2012). Supply chain resilience to mitigate disruptions: A QFD approach. ACIS 2012 Proceedings. Paper 66.

Christopher M and Peck H. (2004). Building the Resilient Supply Chain. *International Journal of Logistics Management,* 15(2), 1-14.

Churchill, G. (1979). A Paradigm for Developing Better Measures of Marketing Constructs. *Journal of Marketing Research*, 16 (1), 64-73.

CIDB (2006). A Report of a Questionnaire Survey on Late and Non-Payment Issues in the Malaysian Construction Industry. Kuala Lumpur, March 2006.

CIDB (2008). Malaysia report – Country report and theme paper. Paper presented at The 14th Asia Construct Conference, Tokyo, Japan.

CIDB (2012). Malaysia country report. Paper presented at The 18th AsiaConstruct Conference, Marina Bay Sands, Singapore.
CIDB (2014). Construction Statistics Quarterly Bulletin. Construction Industry Development Board Malaysia. Retrieved September 8, 2014, from http://www.cidb.gov.my
CIDB (2015). Construction Industry Transformation Programme 2016-2020. Project Management Office, Construction Industry Development Board Malaysia.
CIMP (2007). Construction Industry Master Plan Malaysia 2006-2015. Construction Industry Development Board Malaysia (CIDB). Kuala Lumpur, Malaysia.
Cockram, D. and Van Den Heuvel, C. (2012). Organisational Resilience. Business Continuity Institute, UK.
Cohen, S. and Russel, J. (2005). *Strategic supply chain management: The five disciplines for top performance*. New York, NY: McGraw-Hill.
Collis, J. and Hussey, R., (2003). *Business Research: A practical guide for undergraduate and postgraduate students, 2nd ed.* New York: Palgrave Macmillan.
Comrey, A. L. and Lee, H. B. (1992). *A first course in factor analysis.* Hillsdale, NJ: Erlbaum.
Converse, J. and Presser, S. (1986). *Survey Questions: Handcrafting the Standardized Questionnaire.* Newbury Park, CA: Sage.
Corbetta, P. (2003). *Social Research: Theory, Methods and Techniques*. Thousand Oaks: Sage Publications.
Craighead, C.W. et al. (2007). The severity of supply chain disruptions: Design characteristics and mitigation capabilities. Decision Sciences, 38(1), 131–156.
Creswell, J.W. (2003). *Research design: Qualitative, quantitative, mixed methods approaches, 2nd Edition.* London: SAGE Publications.
Creswell, J.W., and Plano Clark, V.L. (2007). *Designing and Conducting Mixed Methods Research.* Thousand Oaks, CA: SAGE Publications.
Cronbach, L. J. (1970). *Essentials of psychological testing* (3rd ed). New York, NY: Harper & Row.
Cronbach, L. J. (1971). Test validation. In R. L. Thorndike (ed). *Educational measurement* (2nd ed). Washington, DC: American Council on Education.
Cutter, S.L. et al. (2008) A place-based model for understanding community resilience to natural disasters. Global Environmental Change, 18(4), 598-606.
Dainty, A. (2008) Methodological pluralism in construction management research. In: A. Knight and L. Ruddock (eds.), Advanced Research Methods in the Built Environment, Wiley-Blackwell, New York.
Davis, L.L. (1992). Instrument review: Getting the most from your panel of experts. Applied Nursing Research, 5, 194–197.
Day, J.M. (2014). Fostering emergent resilience: the complex adaptive supply network of disaster relief. *International Journal of Production Research,* 52 (7): 1970–1988.
Deal, T.E. and Kennedy, A.A. (1982). *Corporate cultures*. Reading, Mass.: Addison-Wesley.
Department of Statistics Malaysia (2014). Malaysia Economic Indicators. Retrieved 15th July 2014, from, www.statistics.gov.my
De Vaus, D. A. (2001). *Research design in social research*. London: Sage.
Durdyev, S. et al. (2016). On-site construction productivity in Malaysian infrastructure projects. Structural Survey, 34(4/5), 446-462.
Easterby-Smith, M. et al (2008). *Management Research.* London: SAGE Publication
Economic Planning Unit (2015). Eleventh Malaysia Plan 2016-2020. Prime Minister Department, The Economic Planning Unit (EPU).
Egan Report (1997). Rethinking Construction. HMSO, London.
Einarsson, S., and Rausand, M. (1998). An approach to vulnerability analysis of complex industrial systems. Risk analysis, 18(5) 535-546.
El-Sayegh, S.M. (2008). Risk assessment and allocation in the UAE construction industry. *International Journal of Project Management*, vol. 26, pp. 431-438, 2008.

Endut, I. R., Akintoye, A. and Kelly, J. (2009). Cost and time overruns of projects in Malaysia. Retrieved on May 2015, from http://www.irbnet.de/daten/iconda/CIB10633.pdf, pp. 243-252.

Ezell, B.C. (2007). Infrastructure Vulnerability Assessment Model (I-VAM). Risk Analysis, **27**(3) 571-583.

Federation of Small Businesses (2014). Business continuity. Retrieved Oct 10th, 2014, from http://www.fsb.org.uk/thamesvalley/info/community

Fellows, R. and Liu, A. (2008*). Research Methods for Construction* (3rd ed.). United Kingdom: Blackwell Publishing.

Field, A.P. (2009). *Discovering statistics using SPSS: and sex and drugs and rock 'n' roll* (3rd edition). London: Sage publications.

Fiksel, J. (2006). Sustainability and resilience: toward a systems approach. Sustainability: Science, Practice & Policy, Vol. 2, No. 2, (1-8), ISSN 1548-7733

Fraenkel, J. R. and Wallen, N. E. (2007). *How to Design and Evaluate and Research in Education. 6th ed.* Boston: McGraw Hill.

Frimpong, Y., Oluwoye, J., and Crawford, L. (2003). Causes of delay and cost overruns in construction of groundwater projects in a developing countries; Ghana as a case study. *Int. J. Project Management*, Vol. 21, pp. 321-326.

Fu, W.K., Drew, D.S. and Lo, H.P. (2003). Competitiveness of experienced and experienced contractors in bidding. *Journal of Construction Engineering and Management*, Vol. 129 No. 4, pp. 388-95.

Gallopín, G.C. (2006). Linkages between vulnerability, resilience, and adaptive capacity. Global Environmental Change 16 (2006) 293–303

Ghoddousi, P. and Hosseini, M.R. (2012). A survey of the factors affecting the productivity of construction projects in Iran. Technological and Economic Development of Economy, Vol. 18 No. 1, pp. 99-116.

Gilbert, C.G. (2005). Unbundling the structure of inertia: Resources versus routine rigidity. *Academy of Management Journal*, 48(5): 741-763.

Goh, C.S. and Abdul-Rahman, H. (2013). The Identification and Management of Major Risks in the Malaysian Construction Industry. *Journal of Construction in Developing Countries, 18(1), 19–32.* University Science Malaysia

Goh, M., Lim, J. & Meng, F. (2007). A stochastic model for risk management in global supply chain networks. European Journal of Operational Research, Vol. 182, (164-173)

Gold, A.H., Malhotra, A. and Segars, A.H. (2001). Knowledge management: An organizational capabilities perspective. *Journal of Management Information Systems*, 18(1), 185–214.

Gould, F.E. (1997). Managing the construction process: Estimating, scheduling and project control. Upper Saddle River, New Jersey, USA: Simon & Schuster/A Viacom Company.

Grix, J. (2001) Demystifying postgraduate research: From MA to PhD. University of Birmingham Press, Birmingham.

Hair, J.F. et al. (1998). *Multivariate Data Analysis with Readings*, 5th Edition. Englewood Cliffs, NJ: Prentice Hall.

Hair, J.F. et al. (2010). *Multivariate Data Analysis: A Global Perspective*. London: Pearson.

Haynes, S. N., Richard, D. C. S. and E. S. Kubany (1995). Content validity in psychological assessment: A functional approach to concepts and methods. *Psychological Assessment, 7*(3), 238-247.

Hendricks, K., Singhal, V. & Zhang, R. (2008). The effect of operational slack diversification and vertical relatedness on the stock market reaction to supply chain disruptions. Journal of Operations Management, Vol. 27, No. 3 (233-246).

Hinkin, T. R. (1998). A brief tutorial on the development of measures for use in survey questionnaires. Organizational research methods, 1(1), 104-121.

Hope, R. (2012). A vision for the future of construction: supply chain management and integration. JCT Student Essay Competition. Retrieved March 13, 2014, from http://www.jctltd.co.uk/docs/JCTEssayCompetition2012OverallWinnerRichardHope.pdf

Hoyle, R.H. et al. (2002). Reliability and validity of a brief measure of sensation seeking. Pers. Indiv. Differences, 32, 401–414.
Ibrahim, A.R. et al. (2010). An investigation of the status of the Malaysian construction industry. *Benchmarking: An International Journal. 17*(2), 294-308.
Ishak, R. (2004). Special report: Disaster planning and management. NCD Malaysia 2004, volume 3, No.2
Israel, G.D. (1992). Determining Sample Size. University of Florida.
Jaafar, M. and Aziz, A.A. (2009). Procurement reform in public sector governance: A timely necessity. The Malaysian Surveyor, 44(2), 25-29.
Jaafar, M. and King, A.K.C. (2011). Construction briefing process in Malaysia: Procedures and problems in the public sector. *International Journal of Information Technology Project Management, 2*(2), 53-63.
Jaafar, M., and Nuruddin, A.R. (2012). The development of public and private construction procurement systems in the Malaysian construction industry. *Journal of Design and Built environment,* 11(1), 1-11.
Jaafar, M., and Radzi, N.M. (2013). Level of satisfaction and issues with procurement systems used in the Malaysian public sector. *Australasian Journal of Construction Economics and Building,* 13(1), 50.
Jaques, T. (2010). Reshaping crisis management: the challenge for organizational design. Organizational Development Journal 28(1), pp 9-17.
Johari, J. and Yahya, K.K. (2009). Linking organisational structure, job characteristics, and job performance constructs: a proposed framework. *International Journal of Business and Management*, 4 (3), 145-152.
Johnson, R.B., Onwuegbuzie, A.J., and Turner, L.A. (2007). Toward a Definition of Mixed Method Research. *Journal of Mixed Methods Research*, 1, 112 – 133.
Johnson, R.B., and Onwuegbuzie, A.J. (2004). Mixed Methods Research: A Research Paradigm Whose Time Has Come. Educational Researcher, 33(7), 14-26.
Joshi, M. (2009). 80 per cent of Malaysian Government projects delayed, minister says. Retrieved May 1, 2014, from http://www.topnews.in/80-cent-malaysian-Government-projects-delayed-minister-says-2173299
Judd, C.M., Smith, E.R. and Kidder, L.H. (1991). *Research methods in social relations* (6th edition). Fort Worth, TX: Holt, Rinehart, and Winston, Inc.
Judi, S.S. and Abdul-Rashid, R. (2010). Contractor's right of action for late or non-payment by the employer. *Journal of Surveying, Construction & Property* 1: 65-95.
Jüttner, U. and Maklan, S. (2011). Supply chain resilience in the global financial crisis: an empirical study. *Supply Chain Manage.: An Int. J.*, 16 (4), 246–259.
Juttner, U., Peck, H. and Christopher, M. (2002). Supply chain risk management: outlining an agenda for future research, in Griffiths, J., Hewitt, F. and Ireland, P. (Eds), Proceedings of the Logistics Research Network 7th Annual Conference, Birmingham, pp. 443-50.
Kamal, E.M. and Flanagan, R. (2012). Understanding Absorptive Capacity in Malaysian Small and Medium Sized (SME) Construction Companies. *Journal of Engineering, Design and Technology*, Vol. 10(2), pp. 180-198.
Kamar, K.A.M. and Hamid, Z.A. (2011). Supply Chain Strategy for Contractor in Adopting Industrialised Building System (IBS). *Australian Journal of Basic and Applied Sciences*, 5(12): 2552-2557.
Kendall, L. (2008). The conduct of qualitative interview: Research questions, methodological issues, and researching online. In J. Coiro, M. Knobel, C. Lankshear & D. Leu (Eds.), *Handbook of research on new literacies* (pp. 133-149). New York: Lawrence Erlbaum Associates.
Khazaee-Pool, M. et al. (2016). Development and psychometric testing of a new instrument to measure factors influencing women's breast cancer prevention behaviors (ASSISTS). BMC women's health, 16(1), 40.

Kiessling, T. and Harvey, M. (2005). Strategic global human resource management research in the twenty-first century: an endorsement of the mixed-method research methodology. *International Journal of Human Resource Management,* 16(1), 22–45.

Kimberlin, C.L. and Winterstein A.G. (2008). Validity and reliability of measurement instruments used in research. *Am J Health Syst Pharm*, *65*(23), 2276-84.

Kinman, B. (2012). Building a risk-resilient organisation. In *Resilience: Winning with risk*, Vol.1, No.1, June 2012 Issue, PWC. Retrieved November 15, 2014, from https://www.pwc.pl/pl/publikacje/pwc_resilience_winning_with_risk.pdf

Kleindorfer, P. and Saad, G. H. (2005). Managing disruption risks in supply chains, *Production and Operations Management* 14(1): 53-68

Kline, P. (1993). *The Handbook of Psychological Testing*. London: Routledge.

Kosansky, A. and Taus, M. (2014). Managing for Catastrophes: Building a Resilient Supply Chain. Supply Chain Management Review. Retrieved June 15, 2014, from http://www.scmr.com/article/managing_for_catastrophes_building_a_resilient_supply_chain

Koushki, P.A., Al-Rashid, K., and Kartam, N. (2005). Delays and cost increases in the construction of private residential projects in Kuwait. Construction Management and Economics, Vol. 23, No. 3, pp. 285-294.

Kraemer, K. L. (1991). *Introduction.* Paper presented at The Information Systems Research Challenge: Survey Research Methods.

Latham Report (1994). Constructing the Team. HMSO, London.

Lawshe, C.H. (1975). A quantitative approach to content validity. Pers. Psychol. 28, 563–575.

Lee, H., Padmanabhan, V. and Whang, S. (1997). The paralyzing effect of the bullwhip effect in a supply chain. Sloan Manage. Rev., 38(3), 93–102.

Le-Hoai, L., Dai Lee, Y. and Lee, J.Y. (2008). Delay and cost overruns in Vietnam large construction projects: A comparison with other selected countries. *KSCE J. of Civil Eng*., 12(6), 367-377.

Lewis-Back, M., Bryman, A.E., and Liao, T.F. (2003). *The Sage encyclopedia of social science research methods.* Sage Publications.

Lim, C.S. and Mohamed, M.Z. (2000). An exploratory study into recurring construction problems. International Journal of Project Management, 18(3), 267–73.

Limnios, E.M. and Mazzarol, T. (2011). Resilient organizations: Offense versus defense. Future of Work and Organisations, 25th Annual ANZAM Conference, 7-9 December 2011, Wellington, New Zealand.

Litwin, M.S. (1995). *How to measure survey reliability and validity* (Vol. 7). Sage Publications.

Lo, T.Y., Fung, I.W.H., and Tung, K.C.F. (2006). Construction delays in Hong Kong civil engineering projects. *J. Constr. Eng. Management*, ASCE, Vol. 132, No. 6, pp. 636-649.

Loehlin, J.C. (1998). Latent variable models: An introduction to factor, path, and structural analysis. Lawrence Erlbaum Associates, Mahwah, NJ.

Loosemore, M. (2000). *Crisis management in construction projects.* United States: ASCE Press

Love, P.E.D. and Smith, J. (2016). Error management: implications for construction. *Construction Innovation*, 16(4), 418-424.

Love, P. E. D. et al. (2008). Causal modelling of construction disputes. In Proceedings of the 24th Association of Researchers in Construction Management ARCOM Conference (pp. 869-878). Cardiff, UK.

Love, P.E.D. et al. (2011). Causal discovery and inference of project disputes. Engineering Management, IEEE Transactions on, 58(3) 400-411.

Macmillan, S., et al. (2001). Development and verification of a generic framework for conceptual design. Design Studies. 22 (2), pp. 169 – 191.

Madihie, A. (2009). Identification of resilience protective and risk factors among overseas students in Malaysia. Proceedings of the National Counseling 2009, Malaysia

Malay Mail (2009). We must learn from past disasters. Malay Mail 2009, June 11.

Malaysian Country Report (2010). Presented at *the International Conference 2010 Housing and Real Estate Market Development.*

Malaysia Report (2014). Construction market update. Rider Livett Bucknall. Retrieved April 20, 2015, from http://rlb.com/wp-content/uploads/2015/01/malaysia-report-december-14.pdf

MALBEX (2005). Market watch – construction industry. Kuala Lumpur Exhibition Center Report. p. 1–8.

March, J.G. (1991). Exploration and Exploitation in organizational learning. Organization Science, 2(1):71-87.

Mason-Jones, R. and Towill, D. (1998). Shrinking the supply chain uncertainty circle. Institute of Operations Management Control Journal, Vol. 24, No. 7, (17-23)

Mason, J. (2002). Qualitative Researching (2nd ed.). London: SAGE Publications Ltd.

Matthews, J.D. (1996). A project partnering approach to the main contractor-sub contractor relationship. Doctoral thesis dissertation. Loughborough University.

Maxwell, J.A. (2006). *Qualitative Research Design: An Interactive Approach*. (2nd Ed).Thousand Islands: Sage.

McManus, S.T. (2008). Organizational Resilience in New Zealand. PhD Thesis, University of Canterbury.

Mehdi-Riazi, S.R., Skitmore, M. and Cheung, Y.K.F. (2011). The use of supply chain management to reduce delays : Malaysian public sector construction projects. *Proc., 6th Nordic Conf. on Constr. Econ. and Org. in Society*, Vol. 2, 403-414.

Merriam, S.B. (1998). *Qualitative research and case study applications in education.* San Francisco: Jossey-Bass.

Messick, S. (1994). The interplay of evidence and consequences in the validation of performance assessments. Education Researcher, 32(2), 13-23.

Miles, M.B. and Huberman, A.M. (1994). *Qualitative Data Analysis: An Expanded Sourcebook.* California, SAGE Publications

Miller, D., and Friesen, P. H. (1980). Momentum and revolution in organizational adaptation. *Academy of Management Journal*, 23(4): 591-614.

Miller, R. and Lessard, D. (2000). The strategic management of large engineering projects, shaping institutions, risks and governance. USA: Massachusetts Institute of Technology.

Min, S. and Mentzer, J.T. (2004). Developing and measuring supply chain management concepts. *Journal of Business Logistics*, 25: 63-99.

Mitroff, I.I. et al (1987). Effective crisis management. The Academy of Management Executive (1987-1989), Vol. 1, No. 4, pp. 283- 292

Monks, R.A.G., and Minow, N. (2011). Case Studies: Corporations in Crisis, in Corporate Governance (5th ed.) John Wiley & Sons

Mood, A.M., Graybill, F.A., & Boes, D.C. (1974). *Introduction to the theory of statistics.* New York: McGraw-Hill.

Moore, G.C. and Benbasat, I. (1991). Development of an instrument to measure the perceptions of adopting an information technology innovation. Information Systems Research, (2) 3 (September), pp. 192-222.

Morse, J.M. (2003). Principles of Mixed Methods and Multi-method Research Design. In A. Tashakkori and C. Teddlie (Eds.), Handbook of Mixed Methods in Social and Behavioural Research (pp. 189-208). London: Sage Publications.

Munns, A. K., and Bjeirmi, B. F. (1996). The role of project management in achieving project success. *International Journal of Project Management, 14*(2), 81-87.

National Audit Department (2014). Auditor General Report Year 2013: Activities of the Federal Ministries/Departments and Management of the Government Companies. National Audit Department Malaysia

Naoum, S.G. (2007). *Dissertation Research & Writing for Construction Students.* Oxford, Butterworth-Heinemann.

Nawi, H S.A., Rahman A.A. and Ibrahim, O. (2012). Government ICT project failure factors: Project Stakeholders' views. *Journal of Information Systems Research and Innovation*, 2, 69-77.

Netemeyer, R.G., Bearden, W.O. and Sharma, S. (2003). *Scaling procedures: Issues and applications.* London: Sage.

Newman, I., Lim, J., and Pineda, F. (2013). Content validity using a mixed methods approach its application and development through the use of a Table of Specifications methodology. *Journal of Mixed Methods Research*, *7*(3), 243-260.

Newman, I., et al. (2003). A typology of research purposes and its relationship to mixed methods. In A. Tashakkori & C. Teddlie (Eds.), Handbook of Mixed Methods in Social and Behavioural Research (pp. 167-188). Thousand Oaks, CA: Sage Publications.

Ng, S.T. et al. (2001). The predictive ability of Bromilow's time-cost model. *Journal of Construction Management and Economics,* pp. 165-173.

Ngah, A.B. (2011). Redefining Roles and Responsibilities of Project Team Member in JKR Matrix Organization. Submitted to Faculty of Civil Engineering, University Teknologi Malaysia.

Nunnally, J.C. and Bernstein, I.H. (1994). *Psychometric Theory*, 3rd edition. New York: McGrawHill.

Oates, B.J. (2005). *Researching information systems and computing*. London: Sage.

Ocal, E. et al (2006). Crisis management in Turkish construction industry. Building and Environment 41, 1498–1503

Ofori, G. (2007). Construction in Developing Countries. Construction Management and Economics, 25 (1), 1-6

Ofori, G. (2012). *New Perspectives on Construction on Developing Countries.* London: Routledge.

Oke, A. and Gopalakrishnan, M. (2009). Managing disruptions in supply chains: a case study of a retail supply chain. *International Journal of Production Economics*, Vol. 118 No. 1, pp. 168-74.

Olomolaiye, P.O., Wahab, K.A. and Price, A.D.F. (1987). Problems influencing craftmen's productivity in Nigeria. Building and Environment, Vol. 22 No. 4, pp. 317-23.

Olsson, N.O.E. (2006). Management of flexibility in projects. *International Journal of Project Management 24 (2006) 66–74*

O'Reilly, C.A. and Tushman, M.L. (2004).The Ambidextrous Organization. Harvard Business Review 82(4): 74-81.

Othman, A.A., Torrance, J.V. and Hamid, M.A. (2006). Factors influencing the construction time of civil engineering projects in Malaysia. Engineering, construction and Architectural management, 13(5), 481-501.

Pal, R., Andersson, R. and Torstensson, H. (2012). Organizational resilience through crisis strategic planning. Report, Swedish School of Textiles, Borås

Pallant, J. (2013). *SPSS survival manual: A step by step guide to data analysis using IBM SPSS* (5th edition). Berkshire, England: McGraw-Hill Education.

Pathirage, C. et al. (2012). Managing disaster knowledge: identification of knowledge factors and challenges. *International Journal of Disaster Resilience in the Built Environment*, **3**(3) 237-252

Peck H. (2005) Drivers of supply chain vulnerability: an integrated framework. *International Journal of Physical Distribution & Logistics Management*, 35(4), 210- 232.

Pettit, T.J. (2008). Supply chain resilience: Development of a conceptual framework, an assessment tool and an implementation process. PhD Thesis, The Ohio State University.

Pettit, T.J., Fiksel, J., and Croxton, K.L. (2010). "Ensuring Supply Chain Resilience: Development of a Conceptual Framework". *Journal of Business Logistics*, Vol. 31 No. 1, pp. 1- 21.

Pettit, T.J., Croxton, K.L. and Fiksel, J. (2013). Ensuring supply chain resilience: development and implementation of an assessment tool. *Journal of Business Logistics*, Vol. 34 No. 1, pp. 46–76.

Polit, D. F., Beck, C. T., and Owen, S. V. (2007). Is the CVI an acceptable indicator of content validity? Appraisal and recommendations. Research in nursing & health, 30(4), 459-467.

Polit, D.F. and Hungler, B.P. (1999). *Essentials of nursing research* (6th Edition). Philadelphia: J. B. Lippincott.

Ponomarov, S. Y., and Holcomb, M. C. (2009). "Understanding the Concept of Supply Chain Resilience". *International Journal of Logistics Management*, Vol. 20 No. 1, pp. 124-143.

Ponomarov, S. (2012). Antecedents and Consequences of Supply Chain Resilience: A Dynamic Capabilities Perspective. PhD thesis. University of Tennessee, USA.

Pratt, R. (2000). Project management in Malaysia, some ideas on the way ahead. In *Asia Pacific Diligence Sdn Bhd seminar, Project management: strategies, techniques, operations and control*, Kuala Lumpur, Malaysia.

Puspadevi, S. (2015). Obstacles to construction growth. The Star Business News. Retrieved April 15, 2015, from www.thestar.com.my/business

PWD (2008). Generic JKR Project Risks, Ver 01. February 2008, Kuala Lumpur, Ibu Pejabat Jabatan Kerja Raya (JKR) Malaysia.

PWD (2012). *JKR Strategic Framework 2012-2015.* The Malaysia Public Works Department.

Pyke, D. and Tang, C. (2010). How to mitigate product safety risks proactively- Process, challenges and opportunities, *International Journal of Logistics Research and Applications* 13(4): 243-256.

Reason, J. (1990). *Human error.* New York: Cambridge University Press.

Riazi, S.R.M et al. (2011). The use of supply chain management to reduce delays: Malaysian public sector construction projects. In Proceedings of the 6th Nordic Conference on Construction Economics and Organisation in Society Volume 2, Danish Building Research Institute, Aalborg University, Copenhagen, Denmark, pp. 403-414.

Roosli, R. and O'Keefe, P. (2013). Post-disaster housing and management in Malaysia: A literature review. *International Journal of Disaster Resilience in the Built Environment Vol. 4(2), pp.168-181*

Roscoe, J.T. (1975). *Fundamental Research Statistics for the Behavioural Sciences, 2nd edition*. New York: Holt Rinehart & Winston.

Ruel, E., Wagner, W.E. & Gillespie, B.J. (2015). Pre-test and pilot testing. SAGE: The Practice of Survey Research: Theory and Applications.

Sale, J.E.M., Lohfeld, L.H., and Brazil, K. (2002). Revisiting the Quantitative-Qualitative Debate: Implications for Mixed-Methods Research. Quality & Quantity, 36, 43-53.

Sambasivan, M. and Soon, Y.W. (2007). Causes and effect of delay in Malaysian construction industry. *International Journal of Project Management,* 25 (5), pp: 517-526.

Sangoseni, O., Hellman, M. and Hill, C. (2013). Development and validation of a questionnaire to assess the effect of online learning on behaviors, attitude and clinical practices of physical therapists in United States regarding of evidence-based practice. *Internet J Allied Health Sci Pract* 11:1-12.

Saunders M, Lewis P and Thornhill A. (2007) *Research methods for business students, 4th edition*. Harlow: Pearson Education.

Segars, A.H. and Grover, V. (1998). Strategic information systems planning success: An investigation of the construct and its measurement. MIS Quarterly (22) 2, June, pp. 139- 163.

Sexton M. (2007). PhD research: Axiological purposes, ontological cages and epistemological keys. Research Institute for the Built and Human Environment Research Methodology Workshop, University of Salford.

Sharma, M., and Petosa, R. L. (2012). *Measurement and evaluation for health educators*. Jones & Bartlett Publishers.

Sheffi, Y. (2005), *The resilient enterprise: Overcoming vulnerability for competitive advantage*, Cambridge, MA: MIT Press

Sheffi, Y. and Rice, J.B. Jr (2005). A supply chain view of the resilient enterprise. MIT Sloan Management Review, Vol. 47 No. 1, pp. 41-8

Siang, L.C. and Ali, S.A. (2012). Implementation of risk management in the Malaysian construction industry. Journal of Surveying, Construction & Property Vol.3 Issue 1.

Smith, R.J. and Gavin, V. (1998). Risk identification and allocation saving money by improving contracts and contracting practices. Presentation to the ASCE Hong Kong International Group and Chartered Institute of Arbitrators, Hong Kong, March 1998.

Solomon, G (1993). Cost Analysis, Preliminaries, The Marketplace Effect. Chartered Quantity Surveyors. October, 9 – 1.

Stephenson, A. (2010). Benchmarking the Resilience of Organisations. PhD Thesis, University of Canterbury.

Storey, V. et al. (2000). A conceptual investigation of the electronic commerce industry. Communications of the ACM, (43) 7 (July), pp. 117-123

StrategicRISK Asia Edition (2014). Special report: Construction. AIG Asia Pacific. Retrieved March 13th, 2015 from www.strategic-risk-global.com/asia

StrategicRISK (2014). Risk innovation showcasing risk management maturity around Europe in Construction. Zurich International. Retrieved March 13th, 2015 from www.strategic-risk-global.com

Straub, D., Boudreau, M. C., and Gefen, D. (2004). Validation guidelines for IS positivist research. The Communications of the Association for Information Systems, 13(1), 63.

Svensson, G. (2000). A conceptual framework for the analysis of vulnerability in supply chains. *International Journal of Physical Distribution & Logistics Management,* Vol. 30 No. 9, pp. 731-50.

Swedberg, R. (2010). The structure of confidence and the collapse of Lehman Brothers, in Michael Lounsbury, Paul M. Hirsch (ed.) Markets on Trial: The Economic Sociology of the U.S. Financial Crisis: Part A (Research in the Sociology of Organizations, Volume 30) pp.71-114.

Sweis, G., et al. (2007). Delays in construction projects: The case of Jordan. *Int. J. Project Management*, Article in Press.

Tabachnick, B. G., and Fidell, L. S. (2007). *Using multivariate statistics* (5th edn.). Boston: Pearson Education.

Tan, T.H. (2010). Base lending rate and housing prices: Their impacts on residential housing activities in Malaysia. *Journal of Global Business and Economics*, 1(1): 1–14.

Tashakkori, A. and Teddlie, C. (1998). *Mixed Methodology: Combining Qualitative and Quantitative Approaches.* Applied Social Research Methods Series, Volume 46, Thousand Oaks: SAGE Publications.

Taylor, D. (2000). Demand amplification: has it got us beat?, Int. J. Phys. Distrib. Logist. Manage., 30(6), 515–533.

Toor, S.U.R. and Ogunlana, S.O. (2008). Problems causing delays in major construction projects in Thailand. Construction Management and Economics, 26(4), 395-408

Transparency International (2013). Corruption perceptions index 2013. Retrieved April 15th, 2015 from http://www.transparency.org/cpi2013/

Trochim, W.M.K. (2005). *Research Methods: The Concise Knowledge Base*. Atomic Dog Publication.

Tukamuhabwa, B.R. et al. (2015). Supply chain resilience: definition, review and theoretical foundations for further study. *International Journal of Production Research.* London: Taylor & Francis

Turner, B.A. (1978). *Man Made Disasters*. London: Wykeham

Vargo, J. and Seville, E. (2011). Crisis strategic planning for SMEs: finding the silver lining. *International Journal of production research*, 49(18), 5619-5635.

Wagner, S.M. and Bode, C. (2006). An empirical investigation into supply chain vulnerability, *Journal of Purchasing and Supply Management* 12(6): 301-312.

Wagner, S.M. and Neshat, N. (2010). Assessing the vulnerability of supply chains using graph theory, *International Journal of Production Economics* 126(1): 121- 129.

Wallace, W. (1971). *The Logic of Science in Sociology.* New York: Aldine deGrutyer.

Waltz, C.F., and Bausell, R.B. (1983). *Nursing research: Design, statistics, and computer analysis.* Philadelphia: F. A. Davis.
Wedawatta, G. and Ingirige, B. (2016). A conceptual framework for understanding resilience of construction SMEs to extreme weather events. Built Env. Proj. Asset Manage., 6 (4), 428-443.
Wedawatta, G., Ingirige, B. and Amaratunga, D. (2010). Building up resilience of construction sector smes and their supply chains to extreme weather events. *International Journal of Strategic Property Management* 14 (4): 362–375.
Wilhite, D.A. and Svoboda, M.D. (1999). Drought early warning systems in the context of drought preparedness and mitigation. National Drought Mitigation Center, Lincoln, Nebraska U.S.A.
World Economic Forum (2014), *Global risks 2014* (9th ed.), World Economic Forum, Geneva, Retrieved August 15, 2014, from www.weforum.org/risks
Wu, X. and Ramesh, M. (2013). Market imperfections, government imperfections, and policy mixes: Policy innovations in Singapore. Policy Sciences, September.
Wynd, C.A., Schmidt, B., and Schaefer, M.A. (2003). Two quantitative approaches for estimating content validity. *Western Journal of Nursing Research,* 25, 508 – 518.
Xiao, T. and Yang, D. (2008), "Price and service competition of supply chains with risk-averse retailers under demand uncertainty", International Journal of Production Economics, Vol. 114 No. 1, pp. 187-200.
Yamane, T. (1967). *Statistics: An Introductory Analysis, 2nd Ed*. New York: Harper and Row.
Ye, K.M. AND Rahman, A. H. (2010). Risk of late payment in the Malaysian construction industry. International Scholarly and Scientific Research and Innovation, 4(5), 81-9.
Yin, K.Y. (2006). How to become a competent contractor, The Monthly Bulletin of the Institution of Engineers, Malaysia, 2: 38-39.
Yin, R.K. (2003). *Case study research: Design and methods, 3rd edition*. London: SAGE Publications.
Young, S. (2007). Comparing best practice cases in creating an environment conducive to development benefits, growth and investment. United Nations Conference on Trade and Development, Geneva, 24-25 September 2007
Zaini, O. (2000). Malaysian construction industry: Challenges and demands. In Malaysian Structural Steel Association Convention, Serdang.
Zait, A. and Bertea, P.E. (2013). Methods for testing discriminant validity. Management & Marketing, Volume IX, Issue 2/2011.
Zhao, M., Droge, C., and Stank, T. P. (2001), "The effects of logistics capabilities on firm performance: Customer-focused versus information-focus capabilities," *Journal of Business Logistics*, 22(2): 91-107.
Zohrabi, M. (2013). Mixed method research: Instruments, validity, reliability and reporting findings. Theory and Practice in Language Studies, 3(2), 254-262.
Zsidisin, G. et al. (2005). The dark side of supply chain management. Supply Chain Management Review, 9(2), 46–52.
Zsidisin, G., Panelli, A. & Upon, R. (2000). Purchasing organisation involvement in risk assessments, contingency plans, and risk management: an exploratory study. *Supply Chain Management: An International Journal,* Vol. 5, No. 4, (187-197)
Zsidisin, G. A. and Wagner, S. M. (2010). Do perceptions become reality? The moderating role of supply chain resiliency on disruption occurrence. *Journal of Business Logistics*, 31(2), 1-20.
Zurich (2011). Avoiding the Pitfalls of Supply Chain Disruptions. Supply Chain Risk Insights, 14-16.
Zurich (2014). Building supply chain resilience: The practicalities for the construction industry. Retrieved March 12th, 2016, from http://www.commercialriskeurope.com/uploads/files/whitepapers/Supply-Chain-Zurich-Jan-2015.pdf

APPENDIX

Appendix A – Case Study of Pharmaceutical Industry

The impact of interconnected risks to other industries was highlighted in Section 2.0. The objective of this case study is to show how the impact of risks can cascade and spread from one industry to another. A few years ago, the pharmaceutical industry was almost paralyzed due to the ripple effects from three major events; the Olympics, a hurricane and the financial crisis. The problem started when China shut a chemical plant to reduce air pollution for the Olympic Games in Beijing in August 2008. The following month, Hurricane Ike knocked out another chemical plant in Texas. Then Lehman Brothers failed, marking the start of the global financial crisis. Subsequently, new home construction and car sales dried up, fewer new carpets and new cars were being bought, which then caused the sinking demand for the main material called acrylonitrile. Acrylonitrile was used to produce plastic things like car parts and acrylic fibres for carpets (Zurich, 2011). Although it may seem like these events are completely irrelevant to the pharmaceutical industry, the acrylonitrile's by-product, acetonitrile was used by pharmaceutical companies to measure impurities in the drugs they make. Since acetonitrile, was just a by-product, its production had also dropped subsequently. As a result, pharmaceutical companies found themselves out of stock, and unable to continue clinical trials because of a lack of the solvent. Prices of acetonitrile also shot up as companies scrambled to get a few gallons (Zurich, 2011). This shows how events from completely unrelated sectors could also cause disruptions to other industry. It also shows just how interconnected risks have become in a global economy and how these risks are beyond an organisation's control.

Appendix B - Summary of disruption phases from previous literature

Table B1: Summary of disruption phases from previous literature

Authors (Year)	Disruption Phases			Area of Study
	Pre-Disruption	During Disruption	Post Disruption	
Asbjornslett and Rausand (1997)	1. Stable Situation	2. Disruption Time - Mitigation	3. New Stable Situation - Restoration & Restart - Final result	Assessing vulnerability of production system
Becker et al (2011)	1. Anticipate - Risk assessment - Forecasting	2. Recognise - Impact assessment 3. Adapt - Response - Recovery	4. Learn - Evaluation	Community resilience
Behdani (2013)	1. Risk Management - Risk identification - Risk quantification - Risk evaluation & treatment - Risk monitoring	2. Disruption Detection 3. Disruption Reaction	4. Disruption Recovery 5. Disruption Learning	Managing disruption risks in supply chain
Berg et al (2008)	1. Proactive Risk Management - Identify, evaluate, manage and monitor risks	2. Reactive Risk Handling - Incident/accident handling - Execution of contingency plans	3. Results and Outcomes - Achievement of business objectives - Cost of risks	Assessing supply chain risk management programs
Billa et al (2006)	1. Detection 2. Forecasting 3. Warning	4. Response	5. Reaction	Flood management planning

Authors (Year)	Disruption Phases (Cont'd)			Area of Study
	Pre-Disruption	During Disruption	Post Disruption	
Blackhurst et al (2005)		1. Disruption Discovery	2. Disruption Recovery 3. Supply Chain Redesign	Managing supply chain disruptions
Burnard and Bhamra (2011)		1. Detection 2. Activation 3. Response	4. Positive/Negative Adjustment 5. Organisational Learning	Organisational resilient response framework
Cockram and Van Den Heuvel (2012)	1. Pre-crisis Preparation	2. Crisis Response	3. Post-crisis Recovery	Crisis management
Cutter et al (2008)	1. Antecedent Conditions - Inherent vulnerability - Inherent resilience	2. Event - Immediate effects	3. Coping Responses	Community resilience to natural disasters
Ishak (2004)	1. Prevention 2. Mitigation 3. Preparedness	4. Disaster Impact 5. Response	6. Recovery 7. Development	Disaster planning and management
Ocal et al (2006)	1. Management before the crisis - Issues analysis - Early warning systems	2. Management during the crisis - Decision-making - Managing crisis plan	3. Management after the crisis - Feedback on performance - Strategic changes	Crisis management in construction industry

Authors (Year)	Disruption Phases (Cont'd)			Area of Study
	Pre-Disruption	During Disruption	Post Disruption	
Jaques (2010)	1. Crisis Preparedness - Planning processes - Systems, manuals - Training, simulations 2. Crisis Prevention - Early warning, scanning - Issue & risk management - Emergency response	3. Crisis Event Management - Crisis recognition - System activation/response - Crisis management	4. Post-crisis Management - Recovery, business resumption - Post-crisis issue impacts - Evaluation, modification	Issue and crisis management relational model
Mitroff et al (1987)	1. Proactive - Prevention - Preparation	2. Reactive - Coping	3. Recovery - Return to normalcy 4. Learning - Broaden detection - Redesign the organisational system	Crisis management model
Ponomarov and Holcomb (2009)	1. Readiness and Preparedness	2. Response and Adaption	3. Recovery/Adjustment	Elements of resilience
Pyke and Tang (2010)	1. Readiness	2. Responsiveness	3. Recovery	Mitigating product safety risks via 3Rs
Sheffi and Rice (2005)	1. Preparation	2. Disruptive Event 3. First Response 4. Initial Impact 5. Time of Full Impact	6. Preparation for Recovery 7. Recovery 8. Long-term Impact	Supply chain view of the resilient enterprise
Wilhite and Svoboda (1999)	1. Risk Management (Protection) - Preparedness - Mitigation - Prediction & early warning systems	2. Disaster - Impact assessment - Response	3. Recovery 4. Reconstruction	Drought preparedness and mitigation

Figure B1 below provides an example of an integrated model of handling disruptions by Sheffi (2005) as highlighted in Section 5.1. The description of the stages of disruptions are further discussed below (Sheffi, 2005):

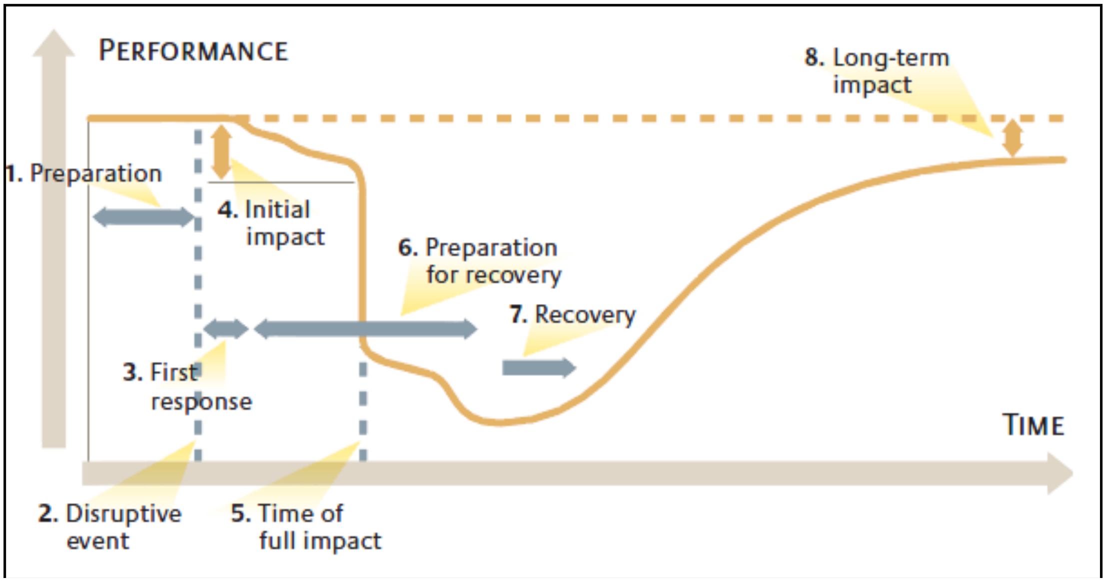

Figure B1: The eight stages of disruption (Sheffi, 2005)

1. Preparation
In some cases, a company can foresee and prepare for disruption, minimizing its effects. Warnings range from the 30-minute tornado alert General Motors Corp. received in Oklahoma on May 8, 2003, to the several months of deteriorating labor negotiations at West Coast ports that preceded the October 2002 lockout. In other cases, such as 9/11, there is little or no warning.

2. The Disruptive Event
The tornado hits, the bomb explodes, a supplier goes out of business or the union begins a wildcat strike.

3. First Response
Whether there's a physical disruption, a job action or an information technology disruption, first response is aimed at controlling the situation, saving or protecting lives, shutting down affected systems and preventing further damage.

4. Initial Impact
The full impact of some disruptions is felt immediately. Union Carbide Corp.'s chemical plant in Bhopal, India, went off-line immediately after the gas leak disaster in December 1984. Other disruptions can take time to affect a company, depending on factors such as the magnitude of the disruption, the available redundancy, and the inherent resilience of the organization and its supply chain. When inventories of critical parts ran out during the 2002 West Coast port lockout, it took New United Motor Manufacturing Inc., the joint venture of General Motors and Toyota, four days to halt production. During the time between the disruptive event and the full impact, performance usually starts to deteriorate.

5. Full Impact

Whether immediate or delayed, once the full impact hits, performance often drops precipitously.

6. Recovery Preparations

Preparations for recovery typically start in parallel with the first response and sometimes even prior to the disruption, if it has been anticipated. They involve qualifying other suppliers and redirecting suppliers' resources (as Nokia Corp. did in the aftermath of the 2000 fire in a Royal Philips Electonics NV manufacturing plant that disrupted its chip supply) and determining what parts are available and selling products built from those parts.

7. Recovery

To get back to normal operations levels, many companies make up for lost production by running at higher-than-normal utilization, using overtime as well as suppliers' and customers' resources. After the West Coast port lockout, NUMMI made up for its one-week plant closure and posted record sales by year's end despite the work stoppage.

8. Long-Term Impact

It typically takes time to recover from disruptions, but if customer relationships are damaged, the impact can be especially long-lasting and difficult to recover from. For example, the network of small-scale shoe factories in Kobe, Japan, responsible for some 34 million pairs of shoes a year, lost 90% of its business in the wake of that city's 1995 earthquake as buyers shifted to other Asian factories, and most buyers never came back.

Appendix C – Sample of the Questionnaire

UNIVERSITY OF SALFORD
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Project Overview

Working Title:
Resilience of the Malaysian Public Sector Supply Chain to Disruptions in Construction

The Problem:
Supply chains in construction face disruptions during project implementation that can cause poor project performance and deviations from project objectives (i.e. adverse weather conditions, information technology outage, new laws/regulations, accidents, competitive threats and transport network disruptions). Good resilience response strategies are needed to cope and thrive in these environmental conditions in order for the supply chain to overcome disruptions during project delivery.

Objectives of the Questionnaire:
Resilience is defined as the ability for the supply chain to survive, adapt and grow in the face of disruptions. This questionnaire will investigate two main factors,

i) **Vulnerability factors** - fundamental factors that make an enterprise susceptible to disruptions
ii) **Capability factors -** attributes that enable an enterprise to anticipate and overcome disruptions

Research Aim:
To develop a **resilience response framework** to achieve better preparedness and build supply chain resilience against supply chain disruptions in the effort to improve the Malaysian public sector projects delivery.

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SECTION 1: RESPONDENT'S PROFILE
(Please tick (/) where appropriate)

1. Department:

____

2. Profession :

Project Manager	
Engineer	
Architect	
Quantity Surveyor	
Contractor	

If other, please specify: ________________________

3. Working Experience:

< 3 years	
4-5 years	
6-10 years	
>10 years	

4. Which of the following project phase(s) are you involved in?

Planning	
Design	
Tender	
Construction	

If other, please specify: ________________________

SECTION 2: PAST EXPERIENCE OF DISRUPTIVE EVENTS IN PUBLIC PROJECTS
(Please tick (/) where appropriate)

1. How often do you face disruptions when dealing with public projects?

- ☐ Never
- ☐ Rarely
- ☐ Sometimes
- ☐ Often
- ☐ Always

2. What are the frequent disruptive event(s) faced by your organisation when dealing with public projects?

- ☐ Natural disaster/severe weather conditions
- ☐ Financial crisis
- ☐ Major accident/fire
- ☐ Fraud
- ☐ Regulatory issues
- ☐ Failure of key supplier/customer
- ☐ Transportation disruption
- ☐ Loss of critical services (i.e. electricity, water)
- ☐ IT system failures
- ☐ Quality problems
- ☐ Employee sabotage
- ☐ Technological change

If other, please specify:

3. How severe the most recent disruption was for your organisation?

- ☐ We dealt with it as part of business-as-usual
- ☐ It challenged us but was not overly disruptive
- ☐ It definitely challenged us and was moderately disruptive
- ☐ It definitely challenged us and was very disruptive
- ☐ It could have shut us down permanently
- ☐ Don't know

4. What were the critical effect(s) of disruptive events to your operation and project performance?

- ☐ Loss of productivity
- ☐ Decrease in profit
- ☐ Higher cost of operation
- ☐ Damage to operation facilities
- ☐ Reputation damage
- ☐ Delay in delivering products/services to customers
- ☐ Defects in quality
- ☐ Loss of skilled workers

If other, please specify:

5. Our organisation currently employs people in the following area(s).

- ☐ Risk management
- ☐ Crisis management
- ☐ Emergency management
- ☐ Business continuity management
- ☐ Disaster management
- ☐ None of the above

6. How do you suggest your organisation to anticipate, response and/or recover from disruptions in public projects?

- ☐ Planning
- ☐ Insurance
- ☐ Staff engagement & involvement
- ☐ Collaboration with supply chain members

Other further suggestions:

SECTION 3: SUPPLY CHAIN VULNERABILITY FACTORS

The statements below describe the vulnerability factors that currently challenge construction supply chain operations. **Please tick (/)** on the degree of your agreement or disagreement for each statement based on your experience working in **Malaysian public sector projects**.

	Strategic Vulnerability	Strongly Disagree (1)	Disagree (2)	Neither agree nor disagree (3)	Agree (4)	Strongly Agree (5)
V1.1	We outsource our operations to many different suppliers*.	☐	☐	☐	☐	☐
V1.2	We rely on specialty sources or components in delivering our products/services.	☐	☐	☐	☐	☐
V1.3	Our products/services are threatened by frequent competitive innovations.	☐	☐	☐	☐	☐
V1.4	Our suppliers* /operation facilities are geographically concentrated at the same area and highly co-dependent.	☐	☐	☐	☐	☐
V1.5	Our services/ production operations are very complex.	☐	☐	☐	☐	☐

** Consider your suppliers to be the complete set of firms outside of your firm supplying raw materials, finished products, components, equipment or services required for your operations.*

	Management Vulnerability	Strongly Disagree (1)	Disagree (2)	Neither agree nor disagree (3)	Agree (4)	Strongly Agree (5)
V2.1	We have insufficient management control over our supply chain members.	☐	☐	☐	☐	☐
V2.2	Late information and decision making frequently affect our operation progress.	☐	☐	☐	☐	☐
V2.3	Errors or deficiencies in our operations are highly visible to stakeholders.	☐	☐	☐	☐	☐
V2.4	Continuous information flow is critical to our operations.	☐	☐	☐	☐	☐
V2.5	We often incur budget overruns and unplanned expenses during operation/ production.	☐	☐	☐	☐	☐

Personnel Vulnerability		Strongly Disagree (1)	Disagree (2)	Neither agree nor disagree (3)	Agree (4)	Strongly Agree (5)
V3.1	We have shortage of highly skilled workers.	☐	☐	☐	☐	☐
V3.2	We regularly face labor disputes or strikes during our operations.	☐	☐	☐	☐	☐
V3.3	Our workers sometimes operate in extreme or hazardous conditions.	☐	☐	☐	☐	☐
V3.4	We often face the loss of key personnel during operations.	☐	☐	☐	☐	☐

Process Vulnerability		Strongly Disagree (1)	Disagree (2)	Neither agree nor disagree (3)	Agree (4)	Strongly Agree (5)
V4.1	Our supply chain has a large number of members.	☐	☐	☐	☐	☐
V4.2	Our products/services face unpredictable demand shifts by client.	☐	☐	☐	☐	☐
V4.3	Raw materials for our product/design are scarce or in high demand.	☐	☐	☐	☐	☐
V4.4	The availability of our utilities (electrical power, water, sewer) for production is poor.	☐	☐	☐	☐	☐
V4.5	Some equipment/ product used in our operations are failure-prone.	☐	☐	☐	☐	☐
V4.6	Our production capacity is limited.	☐	☐	☐	☐	☐
V4.7	We have limited access to capacity to distribute products/services.	☐	☐	☐	☐	☐
V4.8	Our products/services often face quality problems.	☐	☐	☐	☐	☐
V4.9	We often face transportation disruption during our operation.	☐	☐	☐	☐	☐

	Supplier/Customer Disruptions	Strongly Disagree (1)	Disagree (2)	Neither agree nor disagree (3)	Agree (4)	Strongly Agree (5)
V5.1	Our suppliers* frequently face significant disruptions.	☐	☐	☐	☐	☐
V5.2	Our suppliers* have limited capacity in dealing with unplanned changes in demand.	☐	☐	☐	☐	☐
V5.3	We often face the loss of key supplier(s) during operations.	☐	☐	☐	☐	☐
V5.4	Our client(s) frequently face significant disruptions.	☐	☐	☐	☐	☐

* *Consider your suppliers to be the complete set of firms outside of your firm supplying raw materials, finished products, components, equipment or services required for your operations.*

	Technology Vulnerability	Strongly Disagree (1)	Disagree (2)	Neither agree nor disagree (3)	Agree (4)	Strongly Agree (5)
V6.1	The technology changes in our industry highly affect our services/ products design and performance.	☐	☐	☐	☐	☐
V6.2	We regularly face unforeseen technology failures in our operations.	☐	☐	☐	☐	☐

	Political/Legal Pressures	Strongly Disagree (1)	Disagree (2)	Neither agree nor disagree (3)	Agree (4)	Strongly Agree (5)
V7.1	Our operations are susceptible or vulnerable to political disruptions.	☐	☐	☐	☐	☐
V7.2	Our operations/products are subject to strict or changing Government regulations.	☐	☐	☐	☐	☐

	Environmental Factors	Strongly Disagree (1)	Disagree (2)	Neither agree or disagree (3)	Agree (4)	Strongly Agree (5)
V8.1	Social & cultural changes have had significant impact on our ability to provide our services.	☐	☐	☐	☐	☐
V8.2	Our facilities/operations are frequently exposed to adverse weather events or natural disasters.	☐	☐	☐	☐	☐
V8.3	Our operations are susceptible to a potential health pandemic affecting our employees.	☐	☐	☐	☐	☐
V8.4	Public opinion can exert significant pressure on our operations.	☐	☐	☐	☐	☐

	Physical Damage Disruptions	Strongly Disagree (1)	Disagree (2)	Neither agree or disagree (3)	Agree (4)	Strongly Agree (5)
V9.1	Our products are regularly stolen or vandalized.	☐	☐	☐	☐	☐
V9.2	We often face accidents during operations/productions (i.e. fire, workers accident).	☐	☐	☐	☐	☐
V9.3	Our facilities or personnel may be targets of terrorism or sabotage.	☐	☐	☐	☐	☐

	Market Pressures	Strongly Disagree (1)	Disagree (2)	Neither agree or disagree (3)	Agree (4)	Strongly Agree (5)
V10.1	Our operations often face severe price fluctuations.	☐	☐	☐	☐	☐
V10.2	Our services/products face strong price competition.	☐	☐	☐	☐	☐

	Liquidity/Credit Vulnerability	Strongly Disagree (1)	Disagree (2)	Neither agree or disagree (3)	Agree (4)	Strongly Agree (5)
V11.1	Changes in financial & economic policies highly affect our management of money and assets.	☐	☐	☐	☐	☐
V11.2	We have lack of financial resources to cover all potential needs.	☐	☐	☐	☐	☐

SECTION 4: SUPPLY CHAIN CAPABILITY FACTORS

The statements below describe the capability factors that enable an enterprise to anticipate and overcome disruptions. **Please tick (/)** on the degree of your agreement or disagreement for each statement based on your experience working in **Malaysian public sector projects.**

	Flexibility	**Strongly Disagree (1)**	**Disagree (2)**	**Neither agree or disagree (3)**	**Agree (4)**	**Strongly Agree (5)**
C1.1	Our finished products/ designs are flexible to changes.	☐	☐	☐	☐	☐
C1.2	Our supply contracts can be easily modified to change specifications, quantities and terms.	☐	☐	☐	☐	☐
C1.3	We have many alternative suppliers/sources for key inputs.	☐	☐	☐	☐	☐
C1.4	We can quickly increase capacity of storage and distribution services when necessary.	☐	☐	☐	☐	☐
C1.5	We can quickly reallocate orders to alternative suppliers & reallocate jobs between different people/ units.	☐	☐	☐	☐	☐
C1.6	We have a sophisticated inventory management system that combines demand projections and current orders.	☐	☐	☐	☐	☐
C1.7	We can quickly change the route and mode of transportation of the materials/products.	☐	☐	☐	☐	☐

	Capacity	**Strongly Disagree (1)**	**Disagree (2)**	**Neither agree or disagree (3)**	**Agree (4)**	**Strongly Agree (5)**
C2.1	We have significant excess capacity of materials, equipment and labor to quickly boost output if needed.	☐	☐	☐	☐	☐
C2.2	We maintain access to alternative facilities and equipment for back up in the event of disruption at the main facility.	☐	☐	☐	☐	☐
C2.3	We have reliable back-up utilities (electricity, water) for operation when the primary sources are disrupted.	☐	☐	☐	☐	☐

	Efficiency	Strongly Disagree (1)	Disagree (2)	Neither agree or disagree (3)	Agree (4)	Strongly Agree (5)
C3.1	We have effective preventative measures to minimize the waste of unnecessary production.	☐	☐	☐	☐	☐
C3.2	Our labor productivity is very high.	☐	☐	☐	☐	☐
C3.3	Our resources (labor, plant or material) are consistently utilized with no limiting bottlenecks.	☐	☐	☐	☐	☐
C3.4	We produce products/services with consistent quality.	☐	☐	☐	☐	☐
C3.5	Our equipment/products are very reliable and are not prone to failure.	☐	☐	☐	☐	☐

	Visibility	Strongly Disagree (1)	Disagree (2)	Neither agree or disagree (3)	Agree (4)	Strongly Agree (5)
C4.1	We are highly aware of future trends in the industry and the behavior of our competitors, technologies & markets.	☐	☐	☐	☐	☐
C4.2	We have effective information systems that accurately track all operations.	☐	☐	☐	☐	☐
C4.3	We have real-time data on location and status of supplies, finished goods, equipment and employees.	☐	☐	☐	☐	☐
C4.4	We have regular interchange of information among departments, suppliers, clients and other external sources.	☐	☐	☐	☐	☐

	Adaptability	Strongly Disagree (1)	Disagree (2)	Neither agree or disagree (3)	Agree (4)	Strongly Agree (5)
C5.1	We continually strive to further reduce lead-times for our operation/products.	☐	☐	☐	☐	☐
C5.2	We excel at seizing advantages from changes or disruptions in the market.	☐	☐	☐	☐	☐
C5.3	We develop innovative technologies to improve our operations.	☐	☐	☐	☐	☐
C5.4	We effectively employ continuous improvement programs.	☐	☐	☐	☐	☐

Anticipation		Strongly Disagree (1)	Disagree (2)	Neither agree or disagree (3)	Agree (4)	Strongly Agree (5)
C6.1	We monitor and recognize early warning signals of possible disruptions.	☐	☐	☐	☐	☐
C6.2	We effectively employ demand forecasting methods.	☐	☐	☐	☐	☐
C6.3	We monitor deviations from normal operations, including any near misses.	☐	☐	☐	☐	☐
C6.4	We have detailed contingency plans to deal with possible disruptions.	☐	☐	☐	☐	☐
C6.5	We have a formal risk management process.	☐	☐	☐	☐	☐
C6.6	We recognize new business opportunities and take immediate steps to capitalize on them.	☐	☐	☐	☐	☐

Recovery		Strongly Disagree (1)	Disagree (2)	Neither agree or disagree (3)	Agree (4)	Strongly Agree (5)
C7.1	We are very successful at dealing with crises, including addressing public relations issues.	☐	☐	☐	☐	☐
C7.2	We can quickly organize a formal response team of key personnel, both on-site and at the corporate level to deal with disruptions.	☐	☐	☐	☐	☐
C7.3	We have an effective strategy for communications in a variety of extraordinary situations.	☐	☐	☐	☐	☐
C7.4	We take immediate action to mitigate the effects of disruptions, despite the short-term costs.	☐	☐	☐	☐	☐

	Dispersion	Strongly Disagree (1)	Disagree (2)	Neither agree or disagree (3)	Agree (4)	Strongly Agree (5)
C8.1	Our organisation empowers on-site experts to make key decisions, regardless of level of authority.	☐	☐	☐	☐	☐
C8.2	Our operation/production facilities are distributed at various locations.	☐	☐	☐	☐	☐
C8.3	Our key inputs are sourced from a decentralized network of suppliers.	☐	☐	☐	☐	☐
C8.4	Our senior leaders are based at a variety of different locations.	☐	☐	☐	☐	☐
C8.5	Our products are sold to customers in a variety of geographic locations.	☐	☐	☐	☐	☐

	Collaboration	Strongly Disagree (1)	Disagree (2)	Neither agree or disagree (3)	Agree (4)	Strongly Agree (5)
C9.1	Our information flows transparently between supply chain members to facilitate collaborative decision-making.	☐	☐	☐	☐	☐
C9.2	Our clients are willing to delay their orders when our production capacity is hampered by disruptions.	☐	☐	☐	☐	☐
C9.3	We have proactive product life-cycle management programs that strive to reduce both costs and risks.	☐	☐	☐	☐	☐
C9.4	Our firm invests directly in our suppliers' or customers' operations, as well as other actions to share risks.	☐	☐	☐	☐	☐

	Organisation	Strongly Disagree (1)	Disagree (2)	Neither agree or disagree (3)	Agree (4)	Strongly Agree (5)
C10.1	We are a learning organization, regularly using feedback and benchmarking tools.	☐	☐	☐	☐	☐
C10.2	We strongly encourage teamwork and creative problem solving.	☐	☐	☐	☐	☐
C10.3	We train employees in a wide variety of skills.	☐	☐	☐	☐	☐
C10.4	We are capable of filling leadership voids very quickly in the event of disruptions.	☐	☐	☐	☐	☐

Market Position		Strongly Disagree (1)	Disagree (2)	Neither agree or disagree (3)	Agree (4)	Strongly Agree (5)
C11.1	Our clients can clearly differentiate our products/services from competitors' products.	☐	☐	☐	☐	☐
C11.2	Our products/services control a significant share of the market.	☐	☐	☐	☐	☐
C11.3	Our products/services have excellent customer recognition and a strong reputation for quality.	☐	☐	☐	☐	☐
C11.4	Our firm has strong, direct long-term relationships with each of our clients.	☐	☐	☐	☐	☐
C11.5	Representatives of our firm communicate effectively with our customers.	☐	☐	☐	☐	☐

Security		Strongly Disagree (1)	Disagree (2)	Neither agree or disagree (3)	Agree (4)	Strongly Agree (5)
C12.1	We employ layered defenses against deliberate threat and do not depend on a single type of security measure.	☐	☐	☐	☐	☐
C12.2	We employ strict restrictions of access to our facilities and equipment.	☐	☐	☐	☐	☐
C12.3	We have active security awareness programs that involve all personnel/employees.	☐	☐	☐	☐	☐
C12.4	We have a high level of information systems security to protect stored digital information.	☐	☐	☐	☐	☐

Financial Strength		Strongly Disagree (1)	Disagree (2)	Neither agree or disagree (3)	Agree (4)	Strongly Agree (5)
C13.1	We have significant insurance coverage for facilities, equipment, goods and personnel.	☐	☐	☐	☐	☐
C13.2	Our financial portfolio is very diverse.	☐	☐	☐	☐	☐
C13.3	We have significant financial reserves/funds to cover all potential needs.	☐	☐	☐	☐	☐

SECTION 5: IMPORTANCE OF FACTORS

What are the critical vulnerability areas that are currently affecting you and your supply chain operations? **Please circle** on the relative level of **importance** (scale of 1 to 5) of each factor based on your opinion.

Vulnerabilities		Not Very Important (1)	Minor Importance (2)	Moderately Important (3)	Important (4)	Critical (5)
V1.	Vulnerability in Strategic Decisions	1	2	3	4	5
V2.	Vulnerability in Management	1	2	3	4	5
V3.	Personnel/Staff vulnerability	1	2	3	4	5
V4.	Process/Operation vulnerability	1	2	3	4	5
V5.	Supplier/ Customer disruptions	1	2	3	4	5
V6.	Technology vulnerability	1	2	3	4	5
V7.	Political/legal pressures	1	2	3	4	5
V8.	Environmental factors	1	2	3	4	5
V9.	Physical damage disruptions	1	2	3	4	5
V10.	Market pressures	1	2	3	4	5
V11.	Liquidity/credit vulnerability	1	2	3	4	5

What are the critical factors that your organisation and supply chain need to improve/prioritize on to overcome the vulnerabilities above? **Please circle** on the relative level of **importance** (scale of 1 to 5) of each factor based on your opinion.

	Capabilities	Not Very Important (1)	Minor Importance (2)	Moderately Important (3)	Important (4)	Critical (5)
C1.	Flexibility in sourcing & order fulfillment	1	2	3	4	5
C2.	Capacity/availability of resources	1	2	3	4	5
C3.	Efficiency of operation	1	2	3	4	5
C4.	Visibility of supply chain operation	1	2	3	4	5
C5.	Adaptability in responding to challenges	1	2	3	4	5
C6.	Anticipation/ability to detect potential disruptions	1	2	3	4	5
C7.	Recovery from disruptions	1	2	3	4	5
C8.	Dispersion of resources	1	2	3	4	5
C9.	Collaboration with other entities for mutual benefits	1	2	3	4	5
C10.	Organisation's human resource structures & skills	1	2	3	4	5
C11.	Market position	1	2	3	4	5
C12.	Security against deliberate threats	1	2	3	4	5
C13.	Financial strength	1	2	3	4	5

END OF SURVEY

Thank you for your patience in completing this survey.

Letter of Invitation

Portfolio Management Office
Public Works Department Headquarters
Jalan Tun Razak
Kuala Lumpur
50400
Malaysia

Dear Sir / Madam,

Invitation to participate in research study

In reference to the title above, I am currently undertaking a research for a PhD degree at the School of the Built Environment, University of Salford in Manchester, UK.

I am conducting a research study on building resilience of Malaysian public sector supply chain to disruptions in construction. As supply chains in today's world are operating in a very dynamic and complex business environment, good resilience response strategies are needed to cope and thrive in these environmental conditions in order for the supply chain to overcome disruptions during operation.

The purpose of the survey is to therefore investigate the 'vulnerability factors' that make the Public Works Department (PWD) and its supply chain susceptible to disruptions in public projects, and the current 'capability factors' they have to anticipate and overcome disruptions. The outcome of this study is the development of an appropriate action plan required to utilize their supply chain capabilities and overcome their vulnerabilities in the effort to improve project performance.

I would be grateful if you could spend a few minutes to complete this survey as your professional views and opinions are very important to the research. Please be assured that your response will be treated confidentially and with anonymity as the data obtained will be used for the purpose of this research only.

If you have any question or concern about completing this survey, or more generally about my study, you may contact me or my supervisor through our contact details below.

Thanking you in advance for your time and input.

Kind regards,
Nurul Afroze Zainal Abidin
PhD Candidate
School of the Built Environment
University of Salford
n.a.b.zainalabidin@edu.salford.ac.uk

Supervisor:
Dr. Bingunath Ingirige
Senior Lecturer / Director
Centre for Disaster Resilience
School of the Built Environment.
University of Salford
M.J.B.Ingirige@salford.ac.uk

Participant Information Sheet

Study Title:
Resilience of Malaysian Public Sector Supply Chain to Disruptions in Construction

I would like to invite you to take part in a research study. Before you decide you need to understand why the research is being done and what it would involve for you. Please take time to read the following information carefully. You are completely free to decide whether or not to take part in this research. In order to become a participant, you must meet the following criteria:

1. You must work in one of these organisations: (a) Government sector; (b) private consultancy firm; (c) private contracting firm;
2. You must have the experience working with public projects in Malaysia.

What is the purpose of this study?

The Problem:
Supply chains in today's world are operating in a very dynamic and complex business environment. Like other industries, supply chains in construction face disruptions during project implementation such as adverse weather conditions, information technology outage, new laws/regulations, accidents, competitive threats and transport network disruptions that cause poor project performance and deviations from project objectives. In Malaysia, the local public construction projects are facing disruptive events that cause time and cost overruns, resulting in loss of revenue and poor reputation of the Government entities. Good resilience response strategies are therefore needed to cope and thrive in these environmental conditions in order for the supply chain to overcome such disruptions during operation.

Objectives of the Questionnaire:
Resilience is defined as the ability for the supply chain to survive, adapt and grow in the face of disruptions. This questionnaire will investigate two main factors in assessing the construction supply chain's resilience to disruptions,

i. **Vulnerability factors** - fundamental factors that make an enterprise susceptible to disruptions;
ii. **Capability factors -** attributes that enable an enterprise to anticipate and overcome disruptions.

Research Aim:
To develop a **resilience response framework** to achieve better preparedness and build supply chain resilience against supply chain disruptions in the effort to improve the Malaysian public sector projects delivery.

Do I have to take part in the study?

It is up to you to decide whether or not to take part, as participating in this study is completely voluntary and you may withdraw at any time you wish, without giving a reason. This information sheet contains description of the study, and the attached consent form will need to be signed by you to show you agree to take part.

What will I have to do if I take part in the study?

Questionnaire:
Complete an electronic questionnaire (or postal questionnaire if required). The questionnaire should take approximately 10 minutes to complete.

Interview (optional):
If you wish, you may also agree to undertake a face to face interview at a venue and time suitable to you (subject to research timescales). The interview questions will be sent to you before the interview is conducted to offer enough time for you to think of the subject matter. It will take approximately 45 minutes and will be recorded upon your consent for transcription purposes, after which time the recording will be deleted. A number of 10 to 15 professionals working in Malaysian public projects will undertake this interview.

What are the possible benefits of taking part?

The development of the action plan in the resilience response framework will help the professionals working in public projects to have a clear understanding of their supply chain vulnerabilities and strengthen their capabilities to anticipate, respond and adapt to disruptions in the effort to improve public project performance.

Will my taking part in the study be kept confidential?

We can assure you that the data shall be treated confidentially and anonymity of both the respondent and company will be ensured at all times. Data stored electronically will be on a password protected computer and soft copies data will be stored in locked filing cabinets, accessed only by the researcher. The collected data may be kept for possible use in future research up to a maximum of 3 years from the researcher's graduate award before they will be destroyed. All publications of data will be written in a way so as to disguise the identity of the research participants involved unless prior consent has been obtained. A copy of the survey result can be provided to you upon request.

Who is organising or sponsoring the research?

The study is part of the PhD research degree at the School of the Built Environment, University of Salford in Manchester, UK.

Further information and contact details:

Nurul Afroze Zainal Abidin
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School of the Built Environment
University of Salford
n.a.b.zainalabidin@edu.salford.ac.uk

Dr. Bingunath Ingirige
Senior Lecturer / Director
Centre for Disaster Resilience
School of the Built Environment.
University of Salford
M.J.B.Ingirige@salford.ac.uk

Participant Consent Form

Title of study: Resilience of Malaysian Public Sector Supply Chain to Disruptions in Construction

Researcher: Nurul Afroze Zainal Abidin

Please tick the appropriate boxes	**Yes**	**No**
Taking Part		
I have read and understood the Participant Information Sheet and have had the opportunity to ask any questions.	☐	☐
I understand that my taking part is voluntary; I can withdraw from the study at any time and I do not have to give any reasons for why I no longer want to take part.	☐	☐
I agree to take part in the questionnaire phase of this study.	☐	☐
I will complete the questionnaire electronically/postal copy (delete as appropriate).	☐	☐
I agree to take part in the subsequent face to face interviews.	☐	☐
I agree for the interview to be recorded. This is to facilitate transcription of the data after which time the recording will be deleted.	☐	☐
I want to view the interview transcript for approval purposes. Any required alteration to the transcript will be notified to the researcher within 10 working days of receipt. After which time the transcript will be deemed to have received my approval.	☐	☐
Use of the information I provide for this project		
I understand that if I decide to participate in this research, then the results obtained from this research may be kept for possible use in future research up to a maximum of 3 years from the researcher's graduate award.	☐	☐
I understand my personal details such as phone number and address will not be revealed to people outside the project.	☐	☐
I understand that my words may be quoted in publications, reports, web pages, and other research outputs.	☐	☐

____________________	____________________	__________
Name of participant	Signature	Date
____________________	____________________	__________
Researcher	Signature	Date

Project contact details for further information:
Nurul Afroze Zainal Abidin (n.a.b.zainalabidin@edu.salford.ac.uk)

Appendix D – Semi-structured Interview Questions

(Adapted from Pettit et al, 2010 and McManus, 2008)

Part 1: Pre-Disruption Phase

1. What are the methods that you use to prepare for potential disruptions?
2. What types of security do you employ to protect against threats? (natural disasters, disruptive events, deliberate threats)
3. How do you anticipate disruptions?
4. How do you determine the possible treatment and response plan for potential disruptions?

Part 2: During Disruption

Please briefly describe some examples of recent disruptions that you have faced during your operation in delivering Malaysian public sector projects.

2.1 Disruption Detection
1. When was the disruption first identified?
2. Did you have any warning?
3. How was the disruption first identified?
4. Who were the first to identify the problem? Who else was affected? Were you/your company/supplier prepared?

2.2 Immediate Impact
1. What was the immediate impact of the disruption?
2. When, if at all, did your customers notice any negative impacts? How?
3. Does this type of event happen often?

2.3 Reactive Response
1. What was the initial response to the disruption? What were your initial thoughts and actions?
2. Was this completely successful?
   i. Yes – Were there any other responses taken later?
   ii. No – What other responses were necessary?
3. Did any of your actions make the problem worse?
4. Was your primary concern is the length of time that the disruption would last or the severity of the disruption?

Part 3: Post-Disruption Phase

3.1 Disruption Recovery
1. What are key roles that you play during recovery operations?
2. Do you inform your clients of current or projected disruptions? What was your clients' reaction?
3. Are your preparedness plans used during recovery or are they heavily modified each time?
4. Did the organisation manage to identify the root cause of this disruption?

5. How long did it take to overcome the disruption? Did you return to your original state (processes, relationships, resources) or move into a new and more desirable state?

3.2 Long-Term Impact

1. Were you able to quantify the total impact of the disruption? (i.e. through financial, performance or customer service/satisfaction)
2. Once the initial disruption was resolved, were there any longer term impacts?
3. Is there any positive affects/change that has created opportunities to the supply chain?

3.3 Learning

1. Following a disruption, do you discuss the event and create an after-actions report?
2. What did your company learn from this disruption? Are the lessons learned communicated to the entire workforce?
3. How did the firm change following this disruption (policy, structure, etc.)?
4. How long did it take to implement these changes, or have procedures reverted to previous methods?
5. What types of issues can impede implementation of improvements/changes?
6. How can the members in your supply chain (consultants, contractors, suppliers, clients) help you to be prepared for a disruption?
7. How can they help you respond to an event?
8. Do they provide any insight into future events or trends?
9. Who else can assist you in responding to an event?

Appendix E - Breakdown of the computed items' content validity ratio and index

Table E1: Breakdown of the computed items' content validity ratio (CVR) results

Vulnerability Factors	Expert Judges 1	2	3	4	5	CVR $\frac{ne - N/2}{N/2}$
Strategic Vulnerability						
V1.1 Degree of outsourcing to different suppliers	1	1	1	2	2	1.00
V1.2 Reliance upon specialty sources in delivering products/services	2	2	2	2	1	1.00
V1.3 Threat by competitive innovations	2	1	2	1	2	1.00
V1.4 Concentration of suppliers/operation facilities at the same area	1	1	1	2	2	1.00
V1.5 Complexity of services/production operations	1	2	2	2	1	1.00
	CVI (Average value of items):					1.00
Management Vulnerability						
V2.1 Inadequate management oversight	1	2	2	2	2	1.00
V2.2 Late information and decision making	1	2	2	2	2	1.00
V2.3 Visibility of errors or deficiencies to stakeholders	1	2	2	1	2	1.00
V2.4 Reliance upon information flow in operations	2	2	2	1	1	1.00
V2.5 Budget overruns/Unplanned expenses	2	2	2	2	2	1.00
	CVI (Average value of items):					1.00
Personnel Vulnerability						
V3.1 Shortage of skilled workers	2	2	2	2	2	1.00
V3.2 Labor disputes or strikes	1	2	1	2	1	1.00
V3.3 Operating in extreme or hazardous conditions	0	2	1	1	1	0.60
V3.4 Loss of key personnel	0	2	1	2	2	0.60
	CVI (Average value of items):					0.80
Process Vulnerability						
V4.1 Large number of members in supply chain	1	0	1	1	2	0.60
V4.2 Unpredictability of demand by client	1	2	1	2	2	1.00
V4.3 Scarce or limited raw material availability	2	2	2	2	1	1.00
V4.4 Poor availability of utilities (electrical power, water, sewer) for production	2	2	2	2	2	1.00
V4.5 The use of failure-prone equipment/product	1	2	2	1	2	1.00
V4.6 Limited production capacity	1	2	2	1	2	1.00
V4.7 Limited distribution capacity	1	2	2	0	1	0.60
V4.8 Product quality problem	2	2	2	1	2	1.00
V4.9 Transportation disruption during operation	1	2	2	1	1	1.00
	CVI (Average value of items):					0.91

* Where ne = number of experts selected "1=essential" or "2=important, but not essential", N = total number of experts
* Rating of the degree of relevancy (0='irrelevant'; 1= 'useful but not essential'; 2= 'essential')

Table E1: Breakdown of the computed items' content validity ratio (CVR) results (cont'd)

Vulnerability Factors	Expert Judges 1	2	3	4	5	CVR $\frac{ne - N/2}{N/2}$
Supplier or Customer Disruptions						
V5.1 Suppliers face frequent disruptions	1	2	2	1	1	1.00
V5.2 Suppliers have limited capacity in dealing with demand changes	1	2	1	0	2	0.60
V5.3 Loss of key supplier	1	1	1	0	2	0.60
V5.4 Customer face frequent disruptions	1	2	2	2	2	1.00
	CVI (Average value of items):					0.80
Technology Disruptions						
V6.1 Technology changes in the industry	2	0	2	1	2	0.60
V6.2 Unforeseen technology failures	2	0	2	0	2	0.20
	CVI (Average value of items):					0.40
Political or Legal Pressures						
V7.1 Exposure to political disruptions	1	2	0	2	2	0.60
V7.2 Political/Regulatory changes affecting operation	2	1	2	2	2	1.00
	CVI (Average value of items):					0.80
Environmental Factors						
V8.1 Exposure to natural disasters	1	2	2	2	2	1.00
V8.2 Health pandemic/spread of disease affecting employees	0	2	1	0	1	0.20
V8.3 Pressure from public opinion/reputation	1	1	2	1	2	1.00
	CVI (Average value of items):					0.73
Physical Damage Disruptions						
V9.1 Products regularly stolen or vandalised	1	1	2	2	2	1.00
V9.2 Accidents during operation (i.e. fire, workers accident)	1	1	2	1	2	1.00
V9.3 Terrorism & sabotage	0	1	1	1	1	0.60
	CVI (Average value of items):					0.87
Market Pressures						
V10.1 Fluctuations in prices	2	2	2	2	2	1.00
V10.2 Price pressures from competition	2	2	2	1	2	1.00
	CVI (Average value of items):					1.00
Liquidity or Credit Vulnerability						
V11.1 Finance policies & procedures affecting management of money & assets	1	1	2	2	2	1.00
V11.2 Lack of financial resources	1	2	2	2	2	1.00
	CVI (Average value of items):					1.00

* Where ne = number of experts selected "1=essential" or "2=important, but not essential", N = total number of experts
* Rating of the degree of relevancy (0='irrelevant'; 1= 'useful but not essential'; 2= 'essential')

Table E2: Breakdown of the computed items' content validity index (I-CVI) and scale content validity index (S-CVI)

Vulnerability Factors	Expert Judges 1	2	3	4	5	I-CVI $\frac{N_{3 \text{ or } 4}}{N}$
Strategic Vulnerability						
V1.1 Degree of outsourcing to different suppliers	3	3	4	4	3	1.00
V1.2 Reliance upon specialty sources in delivering products/services	3	3	3	4	4	1.00
V1.3 Threat by competitive innovations	4	3	4	3	4	1.00
V1.4 Concentration of suppliers/operation facilities at the same area	3	3	4	4	3	1.00
V1.5 Complexity of services/production operations	3	4	4	4	3	1.00
	S-CVI (Average value of items):					1.00
Management Vulnerability						
V2.1 Inadequate management oversight	3	4	4	4	3	1.00
V2.2 Late information and decision making	3	4	4	3	4	1.00
V2.3 Visibility of errors or deficiencies to stakeholders	3	4	4	4	3	1.00
V2.4 Reliance upon information flow in operations	4	4	3	3	3	1.00
V2.5 Budget overruns/Unplanned expenses	3	3	4	3	4	1.00
	S-CVI (Average value of items):					1.00
Personnel Vulnerability						
V3.1 Shortage of skilled workers	4	4	4	4	4	1.00
V3.2 Labor disputes or strikes	3	4	3	4	3	1.00
V3.3 Operating in extreme or hazardous conditions	2	4	3	4	3	0.80
V3.4 Loss of key personnel	4	2	3	4	4	0.80
	S-CVI (Average value of items):					0.90
Process Vulnerability						
V4.1 Large number of members in supply chain	3	1	3	3	4	0.80
V4.2 Unpredictability of demand by client	3	4	3	4	4	1.00
V4.3 Scarce or limited raw material availability	4	4	4	4	4	1.00
V4.4 Poor availability of utilities (electrical power, water, sewer) for production	3	3	3	3	3	1.00
V4.5 The use of failure-prone equipment/product	4	3	4	4	4	1.00
V4.6 Limited production capacity	3	4	4	3	4	1.00
V4.7 Limited distribution capacity	4	4	3	2	3	0.80
V4.8 Product quality problem	4	4	4	3	4	1.00
V4.9 Transportation disruption during operation	3	4	4	3	3	1.00
	S-CVI (Average value of items):					0.96

* Where $N_{3 \text{ or } 4}$ = number of experts rated "3=quite relevant" and "4=very relevant", N = total number of experts
* Rating of the degree of relevancy and clarity in measuring the construct (1=not relevant, 2=somewhat relevant, 3=quite relevant and 4=very relevant)

Table E2: Breakdown of the computed items' content validity index (I-CVI) and scale content validity index (S-CVI) (cont'd)

Vulnerability Factors	Expert Judges 1	2	3	4	5	I-CVI $\frac{N_{3 \text{ or } 4}}{N}$
Supplier or Customer Disruptions						
V5.1 Suppliers face frequent disruptions	3	4	4	3	3	1.00
V5.2 Suppliers have limited capacity in dealing with demand changes	3	3	3	1	4	0.80
V5.3 Loss of key supplier	3	3	3	1	4	0.80
V5.4 Customer face frequent disruptions	3	4	4	4	4	1.00
	S-CVI (Average value of items):					0.90
Technology Disruptions						
V6.1 Technology changes in the industry	4	1	3	4	3	0.80
V6.2 Unforeseen technology failures	3	1	4	1	3	0.60
	S-CVI (Average value of items):					0.70
Political or Legal Pressures						
V7.1 Exposure to political disruptions	3	4	2	4	4	0.80
V7.2 Political/Regulatory changes affecting operation	4	3	4	4	4	1.00
	S-CVI (Average value of items):					0.90
Environmental Factors						
V8.1 Exposure to natural disasters	3	4	4	4	4	1.00
V8.2 Health pandemic/spread of disease affecting employees	1	3	3	1	3	0.60
V8.3 Pressure from public opinion/reputation	3	3	4	3	4	1.00
	S-CVI (Average value of items):					0.87
Physical Damage Disruptions						
V9.1 Products regularly stolen or vandalised	3	3	3	4	4	1.00
V9.2 Accidents during operation (i.e. fire, workers accident)	3	3	4	3	4	1.00
V9.3 Terrorism & sabotage	1	3	3	3	3	0.80
	S-CVI (Average value of items):					0.93
Market Pressures						
V10.1 Fluctuations in prices	4	4	4	4	4	1.00
V10.2 Price pressures from competition	4	4	4	3	4	1.00
	S-CVI (Average value of items):					1.00
Liquidity or Credit Vulnerability						
V11.1 Finance policies & procedures affecting management of money & assets	3	3	4	3	4	1.00
V11.2 Lack of financial resources	3	4	4	4	4	1.00
	S-CVI (Average value of items):					1.00

* Where $N_{3 \text{ or } 4}$ = number of experts rated "3=quite relevant" and "4=very relevant", N = total number of experts

* Rating of the degree of relevancy and clarity in measuring the construct (1=not relevant, 2=somewhat relevant, 3=quite relevant and 4=very relevant)

Appendix F – Results of Corrected Item-Total Correlation

Table F1: Corrected Item-Total Correlation of Vulnerability Factors

Vulnerability Factors		Corrected Item-Total Correlation
V1. Strategic Vulnerability		
V1.1	Degree of outsourcing to different suppliers	0.38
V1.2	Reliance upon specialty sources in delivering products/services	0.56
V1.3	Threat by competitive innovations	0.44
V1.4	Concentration of suppliers/operation facilities at the same area	0.41
V1.5	Complexity of services/production operations	0.32
V2.3	Visibility of errors or deficiencies to stakeholders	0.65
V2. Management Vulnerability		
V2.1	Inadequate management oversight	0.40
V2.2	Late information and decision making	0.57
V2.3	Reliance upon information flow in operations	0.36
V2.4	Budget overruns/Unplanned expenses	0.37
V3. Personnel Vulnerability		
V3.1	Shortage of skilled workers	0.65
V3.2	Labor disputes or strikes	0.69
V3.3	Loss of key personnel	0.67
V4. Process Vulnerability		
V4.1	Unpredictability of demand by client	0.71
V4.2	Scarce or limited raw material availability	0.68
V4.3	Poor availability of utilities (electrical power, water, sewer) for production	0.84
V4.4	The use of failure-prone equipment/product	0.78
V4.5	Limited production capacity	0.75
V4.6	Limited distribution capacity	0.76
V4.7	Product quality problem	0.61
V4.8	Transportation disruption during operation	0.71
V5. Supplier or Customer Disruptions		
V5.1	Suppliers face frequent disruptions	0.81
V5.2	Suppliers have limited capacity in dealing with demand changes	0.75
V5.3	Loss of key supplier	0.65
V5.4	Customer face frequent disruptions	0.83
V5.5	Large number of members in supply chain	0.30
V6. Technology Disruptions		
V6.1	Technology changes in the industry	0.20
V6.2	Unforeseen technology failures	0.20

V7. Political or Legal Pressures	
V7.1 Exposure to political disruptions	0.53
V7.2 Political/Regulatory changes affecting operation	0.53
V8. Environmental Factors	
V8.1 Exposure to natural disasters	0.63
V8.2 Health pandemic/spread of disease affecting employees	0.62
V8.3 Pressure from public opinion/reputation	0.83
V8.4 Operating in extreme or hazardous conditions	0.65
V9. Physical Damage Disruptions	
V9.1 Products regularly stolen or vandalised	0.32
V9.2 Accidents during operation (i.e. fire, workers accident)	0.41
V9.3 Terrorism & sabotage	0.51
V10. Market Pressures	
V10.1 Fluctuations in prices	0.60
V10.2 Price pressures from competition	0.60
V11. Liquidity or Credit Vulnerability	
V11.1 Finance policies & procedures affecting management of money & assets	0.58
V11.2 Lack of financial resources	0.58

Table F2: Corrected Item-Total Correlation of Capability Factors

Capability Factors	Corrected Item-Total Correlation
C1. Flexibility	
C1.1 Product commonality (modularity, interchangeability)	0.67
C1.2 Multiple sources	0.73
C1.3 Alternate distribution channels	0.92
C1.4 Multi-sourcing	0.91
C1.5 Fast re-routing of requirements	0.87
C2. Capacity	
C2.1 Reserve capacity (materials, assets, labor, inventory)	0.12
C2.2 Redundancy (assets, labor)	0.34
C2.3 Backup energy sources/communications	0.70
C3. Efficiency	
C3.1 Labor productivity	0.83
C3.2 Asset utilization	0.85
C3.3 Product variability reduction	0.86
C3.4 Failure prevention	0.71
C4. Visibility	
C4.1 Business intelligence gathering	0.56

C4.2	Products, Assets, People visibility	0.69
C4.3	Collaborative information exchange	0.73
C5. Adaptability		
C5.1	Process Improvement, Lead time reduction	0.62
C5.2	Seizing advantage from disruptions	0.66
C5.3	Alternative technology development	0.62
C5.4	Learning from experience, Reengineering	0.57
C6. Anticipation		
C6.1	Monitoring early warning signals	0.69
C6.2	Forecasting	0.63
C6.3	Deviation, Near-miss analysis	0.76
C6.4	Contingency planning, Preparedness	0.60
C6.5	Recognition of opportunities	0.60
C7. Recovery		
C7.1	Crisis management	0.72
C7.2	Resource mobilization	0.85
C7.3	Consequence mitigation	0.79
C8. Dispersion		
C8.1	Distributed decision-making	0.40
C8.2	Distributed capacity & assets	0.48
C8.3	Decentralization of key resources (including data)	0.73
C8.4	Geographic dispersion of markets	0.56
C9. Collaboration		
C9.1	Communications - internal, external	0.61
C9.2	Postponement of orders	0.70
C9.3	Risk sharing with partners	0.61
C10. Market Position		
C10.1	Market share	0.48
C10.2	Brand equity	0.93
C10.3	Customer relationships	0.80
C10.4	Customer communications	0.59
C11. Security		
C11.1	Access restriction	0.79
C11.2	Employee involvement in security	0.65
C11.3	Cyber-security	0.31
C12. Financial Strength		
C12.1	Insurance	0.67
C12.2	Portfolio diversification	0.87
C12.3	Financial reserves & liquidity	0.53

Appendix G – Ethical Approval

MEMORANDUM

Academic Audit and Governance Committee

College of Science and Technology Research Ethics Panel (CST)

To	**Nurul Abidin Zainal (and Dr Bingu Ingirige)**
cc:	**Professor Hisham Elkadi, Head of School of SOBE**
From	**Nathalie Audren Howarth, College Research Support Officer**
Date	**19/06/2015**

Subject: **Approval of your Project by CST**

Project Title: **Resilience of Malaysian Public Sector Supply Chain to Disruptions in Construction**

REP Reference: **CST 15/26**

Following your responses to the Panel's queries, based on the information you provided, I can confirm that they have no objections on ethical grounds to your project.

If there are any changes to the project and/or its methodology, please inform the Panel as soon as possible.

Regards,

Nathalie Audren Howarth
College Research Support Officer

Appendix H – List of Publications

Abidin, N.A.Z. and Ingirige, B. (2018). The Dynamics of Vulnerabilities and Capabilities in Improving Resilience within Malaysian Construction Supply Chain. Construction Innovation Journal (Accepted).

Abidin, N.A.Z. and Ingirige, B. (2017). Identification of the "Pathogenic" Effects of Disruptions to Supply Chain Resilience in Construction. 7th International Conference on Building Resilience; Using scientific knowledge to inform policy and practice in disaster risk reduction, ICBR2017, 27 – 29 November 2017, Bangkok, Thailand

Ali, F., Ingirige, B. and Abidin, N.A.Z. (2017). Assembling and (Re)Assembling Critical Infrastructure Resilience in Khulna City, Bangladesh. 7th International Conference on Building Resilience; Using scientific knowledge to inform policy and practice in disaster risk reduction, ICBR2017, 27 – 29 November 2017, Bangkok, Thailand

Zainal, N.A. and Ingirige, B. (2015). Building Resilience of Construction Supply Chain to Disruptions: Development of a Conceptual Framework. The 12th International Postgraduate Research Conference. MediacityUK, Manchester, UK.

Zainal, N. (2014). Evolving Resilience Indicators in the Malaysian Construction Supply Chain: A Literature Review and Synthesis. Book of Abstracts of the 4th International Conference on Building Resilience. Salford, UK.

Zainal, N. A. (2011). Industrialised Building System (IBS) Risks in Malaysian Public Sector Projects. 1st IBEA Conference 2011 Proceedings: Innovation and Integration – Science, Technology and Policy in the Built Environment. London South Bank University, UK.