UNIVERSITY OF SOUTHAMPTON

FACULTY OF LAW, ART & SOCIAL SCIENCES

School of Management

A Concessionaire Selection Decision Model Development and Application for the PPP Project Procurement

by

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ABSTRACT

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The public-private partnership (PPP) arrangements require the optimization of risk allocation between the public and private sectors in order to achieve the best net present value (NPV). Many researchers mentioned that the risk events of a PPP infrastructure projects are interdependent over project life cycle. Sterman (1992) stated that a large-scale construction project that is complex and has highly dynamic and interdependent risks and uncertainties over long-term project life cycle. Williams (2002) also mentioned that the risk usually interact each other with nonlinear relationships over time in a complex project. Dey and Ogunlana (2004) contended that there is a need to analyze risk interactions of complex infrastructure projects such as build-operate-transfer (BOT) projects over their long-term project life. In modern approaches to PPP project risk management, experts assume risk factors are independent and ignore the risk interaction effects over project life cycle, so the project risks cannot be effectively managed and controlled. The researcher proposed a modelling approach that used a risk network model applying System Dynamics (SD) techniques to estimate risk interaction effects on project NPV over time. The researcher used another SD model built on the risk network model to estimate the beneficial effects of bidding proposals on project NPV over time and to see how efficiently the risk effects can be reduced and the NPV performance can be improved. Then, the researcher applied appropriate stochastic analyses including mean-variance, mean semi-variance, stochastic dominance and expected-loss ratio to compare range values of NPV among different bidding proposals. A capable PPP concessionaire with the best project NPV performance can hence be selected. An industry case was applied to demonstrate SD decision models. The SD decision models have been validated through the behaviour reproduction test and multivariate sensitivity analysis. This proved that the proposed approach is robust and applicable to address real world problems to evaluate the long-term performance of a PPP project concessionaire.

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Chapter 1 Introduction

1.1 Research Background

Officials in control of public works utilities such as electricity, water, sanitation, telecommunications and transportation infrastructure projects play a critical role in developing direct and indirect links to living standards and economic growth. According to the World Bank's global statistics (Table 1), Fay and Yaps (2003) reported that an estimated USD $370 billion per annum are needed in new investment for infrastructure projects from 2005 to 2010. This totals nearly 1% of the worldwide gross domestic product (GDP). Another USD $480 billion or 1.2% of global GDP is needed by officials for maintaining such projects. Thus, the total resources needed to maintain projects are approximately 2.1% of GDP, excluding any expenditures on rehabilitations or upgrades. However, in most countries, inefficiencies and losses are largely relative to the infrastructure investment. For example, the World Bank (1994) reported that until the 1990s, most developing countries relied on public sector monopolies to finance and operate their infrastructures. This reliance by officials on monopolies yielded disappointing results. Technical inefficiencies in power, water, roads, and railway systems have caused losses of approximately USD $55 billion a year in the early 1990s which is equivalent to 1% of the combined GDP of all developing countries. This figure represents a quarter of the annual infrastructure investment and twice the annual development financing for an infrastructure. With public provision, infrastructure services are often priced incorrectly to meet short-term political goals, thus leading to additional losses of USD $123 billion annually (World Bank, 2002). In addition, "public financing of infrastructure also represents a large fiscal burden on governments, consuming resources that might otherwise be available to meet other social needs. (Gray, 2001)"

Beginning in the late 1980s, officials in many countries turned to the private sector for both the management of existing infrastructure enterprise operations and for the financing of new infrastructure assets. Engaging the private sector officials in this capacity was expected to provide a number of benefits to all parties involved. These benefits included cost savings, risk mitigation, service and revenue improvement, as well as employment opportunities, and economic growth enhancement

(Work Bank, 1999b). This approach was called public-private partnership (PPP or P3). Kernagham (1993) defined PPP as "a cooperative venture between the public and private sectors, built on the expertise of each partner, that best meets clearly defined public needs through the appropriate allocation of resources, risks and rewards.". From 1990 to 2000, private financial participation in existing enterprises dominated investment trends, and accounted for USD$682 billion of investments (World Bank, 2002).

Table 1 The Expected Annual Investment Needs for Year 2005-2010 (Fay & Yepes, 2003)

	New		**Maintenance**		**Total**	
	US$Mn	**%GDP**	**US$Mn**	**%GDP**	**US$Mn**	**%GDP**
By income group						
Low Income	49,988	3.18%	58,619	3.73%	108,607	6.92%
Middle Income	183,151	2.64%	173,035	2.50%	356,187	5.14%
High income	135,956	0.42%	247,970	0.76%	383,926	1.18%
Developing countries by region						
East Asia & Pacific	99,906	3.67%	78,986	2.90%	178,892	6.57%
South Asia	28,069	3.06%	35,033	3.82%	63,101	6.87%
Europe & Central Asia	39,069	2.76%	58,849	4.16%	97,918	6.92%
Middle East & N. Africa	14,884	2.37%	13,264	2.11%	28,148	4.48%
Sub-Saharan Africa	13,268	2.84%	12,644	2.71%	25,912	5.55%
Latin America & Caribb.	37,944	1.62%	32,878	1.40%	70,822	3.02%
All developing countries	233,139	2.74%	231,654	2.73%	464,793	5.47%
World	369,095	0.90%	479,624	1.17%	848,719	2.07%

Dey and Ogunlana (2004) stated one of the most popular PPP delivery options is build-operate-transfer (BOT). The BOT was defined as a government contractor with a private-sector partner (the concessionaire), constructing an infrastructure facility and giving the private partner the right to operate within a certain concession period. At the end of the concession period, the private partner transfers ownership of the facility to the government (UN/ECE, 2000). Due to the following essential characteristics, there would be highly complex uncertainties throughout the project's duration (Ababutain, 2001; Dalmon, 2001; Esty, 2003; Kumaraswamy & Morris, 2002; Lang, 1998; Miller & Lessard, 2001 UN/ECE, 2002; Zhang et al., 2002):

- ***Project Long-term life.*** A BOT mega project is a long-term project with a specified concession period, usually 25 to 40 years or more. The longer the development time, the higher the likelihood that the project will be affected by surfacing events.
- ***Heterogeneous supply chain and risk.*** The supply chain of a BOT infrastructure project consists of work packages from various industries. For example, there are work packages from civil-work engineering, station construction, track systems, depots construction, electricity & machine core systems and operation & maintenance services involved in the Taiwan high speed rail system project. The manpower, materials and equipment are integrated with a corporate target to reduce system-integration risks and ensure efficiency. The heterogeneous risks during the design, construction and operation stages include finance, economy, technology, origination, contract management, politics, statutory regulation, environment, and so on.
- ***Private financing.*** In a BOT project, the concession contractor is responsible for securing long-term funding sources that usually last up to 20 years in order to ensure ongoing development and operation of the project.
- ***Risk sharing/allocation.*** The project risks are shared between public and private sectors through contracts and agreements. The concession contractor (project concessionaire) is the core of BOT project structure (Figure 1). Parties such as government authority (project owner), stakeholders (investor), subcontractors, and suppliers link to the concession contractor through the corresponding agreements/contracts. Furthermore, each party is dependent on the performance of all parties to the project collectively, not only its interlocking counterpart.
- ***SPV (Special Purpose Vehicle).*** The BOT concession contractor must provide an excellent SPV which is the mechanism in which diverse functions of finance, design, construction and operation are integrated, and a cooperative relationship is formed (Figure 1.1). In a traditional non PPP project, these functions are fragmented, and relationships among multiple participants are often confrontational.

1.2 Research Issues

Value for money (VFM) is a core objective for individuals involved in PPP projects (Allan, 2001; HM Treasury/UK, 2006; Whitfield, 2006). VFM is the optimum combination of whole project life costs and benefits under consideration to meet user requirement; not simply the lowest costs or cheapest prices (Allan; Grimsey & Lewis, 2005; HM Treasury, 2004a). A major purpose of the PPP arrangement is the transfer and allocation of risks to the party who is the most capable of efficiently managing these risks. The purpose of the PPP is to optimize risk allocation between public and private sectors for achieving the best project VFM (Allan; Davies, 2006; Grimsey & Lewis; HM Treasury, 2004b; United Nations, 2002). In many previous studies, researchers revealed that a critical component to the success of a PPP project was the selection of a private-sector partner who could provide the best overall arrangement throughout the PPP development process (Aziz, 2007; Chan et al., 2001; Zhang, 2005a). Researchers found that another important step toward success was the selection of a concessionaire who offered the best value monetarily yet who had the capability to deliver the required services (Zhang, 2004b, 2004a, 2005; Norment, 2007). However, the researcher found that the major lessons learned from current concessionaire-selection literature could be summarized with the following points:

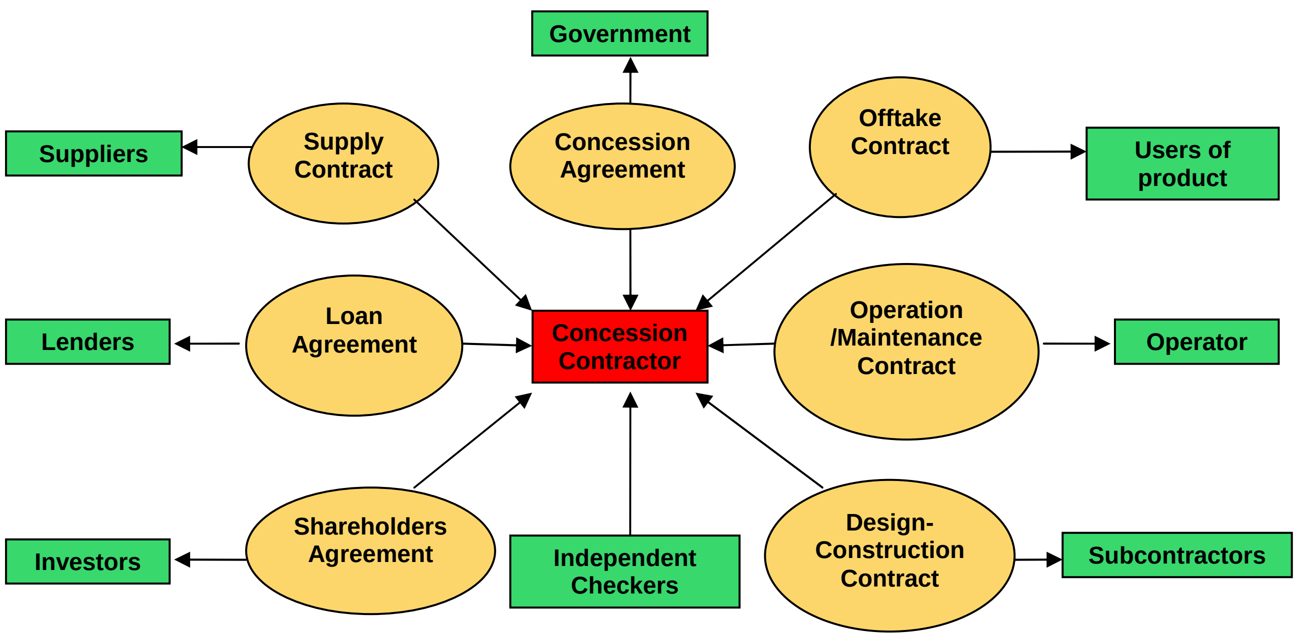


Figure 1 The Typical Structure of BOT Projects Modified from (Dalmon, 2001; Kumaraswamy & Morris, 2002; Lang, 1998)

- ***They miss a link between risk analysis and contractor selection.***

The prevailing contractor/bidding proposal selection process for PPP projects is usually divided at the point of the risk management. The features of a BOT project show that the concessionaire undertakes more commitments and assumes more risks than a mere contractor in a traditional procurement project (Zhang, 2005a). "The complexity of the BOT arrangement leads to increased levels of risk exposure for all parties, and gives rise to the need for a new perspective in risk analysis. The future development of this scheme is largely dependent on the risk management system. Therefore, it is necessary to evaluate a concessionaire's competence by integrating risk analysis into the selection process(Dey & Ogunlana, 2004)."

- ***They are unable to deal with semi-structured or unstructured real-world problems.***

The problems which officials of large infrastructures need to address in project development and assignment include finance, technology, economy, contract management, organization, politics, regulation, and so on. These problems are viewed as both heterogeneous and structured, as well as unstructured. In current studies, researchers are incapable of evaluating risks or simply ignore the unstructured and qualitative risk issues. For example, Liou and Huang (2008), in their use of the automated contractual-negotiation model, ignored the impact of non-financial risk factors on NPV. Deng (2004) did not investigate the impact of non-financial risk factors in the decision support system and the expert system for PPP project funding and cash flow management. Mackie et al. (2003) have criticized current approaches incorporating cost-benefit analysis (CBA) with claims that it is difficult to quantify non-monetary terms.

- ***They do not address interdependently dynamic and non-linear risk interactions.***

In reality, the risks of a mega PPP project are interdependent through nonlinear relationships over the long-term life cycle of the project (Sterman, 1992). However, in current practices, researchers assume that risk factors are independent. For example, the Washington State Department of Transport's *CEVP (Cost Estimate Validation Process) approach* (Reilly, et. Al, 2004), in the officials of the United Kingdom government in the *VFM Assessment Guidance' and 'Quantitative Assessment User Guide* (HM Treasury, 2004b; HM Treasury, 2004a) and the Australian government officials in the *Public Sector Comparator-Technical Note* (Partnerships Victoria, 2003) affirm these theories. Moreover, officials using the current approaches incorporate these approaches with multi-criteria decision making (MCDM) and make the assumption that the decision criteria are independent each other (ODPM, 2004;

Triantaphyllou, 2000; Xu & Yang, 2001). "Ignoring or underestimating correlations between variables will tend to understate outcome variance(Balcombe & Smith, 1999)" ; using such correlations may eventually lead to wrong judgments on the overall project risk estimates for bidding proposal selection.

- ***They ignore the uncertainty of outcomes.***

Officials using the current practices of bid comparison ignore the dispersion of outcomes, instead depending on deterministic outcomes only. Minor changes in underlying assumptions will cause the model to yield completely different results (Grimsey & Lewis, 2002, 2005; Ye & Tiong, 2000). It is necessary to move from single value estimates to range values estimates for PPP infrastructure projects (Grimsey & Lewis, 2005; Reilly, 2005; Reilly & Brown, 2004).

- ***They lack the global review of project life cycle.***

Multifaceted risks of cost, scheduling, quality, and the like develop over the life cycle of the project, and many of the current concessionaire-selection methods lack the inclusive scope which these complexities demand. For example, in some evaluations officials focus on the construction stage only, excluding the project design and the operation phase. This method would not yield cumulatively accurate data over the lifetime performance of the project (Scottish Government, 2005).

1.3 Research Objective

The objective of the thesis research is to develop a theoretical approach that is able to solve the common issues of the current PPP project concessionaire selection methods. The developed theoretical approach can build a decision support model that is specific to a particular PPP project for the public sector to choose a concessionaire which is capable of creating value for money.

1.4 Research Structure

The research structure is outlined below:

- Chapter 1 Introduction: In this chapter, the researcher introduced background information including the need for PPP project and contractor/bidding proposal selection, common selection issues, the research objective, and the research structure outline.
- Chapter 2 Literature Review: In this chapter, the researcher reviewed and discussed the characteristics of a PPP project and the PPP project contractor/bid selection.

- Chapter 3 Research Methodology: In this chapter, the researcher stated and identified the research questions, strategies and proposed methods.
- Chapter 4 Risk Factors and Causal Loop Diagrams: In this chapter, the researcher summarized the possible PPP project risks and their interdependencies with the causal loop diagrams (CLD).
- Chapter 5 Risks of Taiwan High Speed Rail (THSR) project: In this chapter, the researcher described the risk scenarios of the THSR project.
- Chapter 6 Risk Network Modelling: In this chapter, the researcher applied the System Dynamics technique to model risk effects, interactions, and feedback effects over project life.
- Chapter 7 Bidding Proposal Modelling: In this chapter, the researcher applied the System Dynamics technique to model risk reduction and feedback effects of bidding proposals over project life. .
- Chapter 8 Model Validation: In this chapter, the researcher reviewed the simulation results and applied tests to measure model performance.
- Chapter 9: Conclusions: Finally, in this chapter, the researcher summarized the research findings and suggested future options to address the problems identified in the research.

Chapter 2 Literature Review

2.1 Introduction to Public-Private Partnerships

The term, public-private partnerships (PPPs or P3s) has been used since the 1990s (Davies & Eustice, 2005). According to the UK Government officials, (HM Treasury, 2000, 2003b; House of Commons Library/UK, 2001), the term PPP is used to describe three types of scenarios:

1. The selling of government assets and services into wider markets;
2. The PPP procurement arrangements (including concessions);
3. The introduction of private sector ownership into state-owned businesses.

However, there is no single definition or model for a public-private partnership (Abadie & Howcroft, 2004; Davies & Eustice, 2005). "If a narrow definition is taken, this can result in legislation which only applies to a narrow range of project types or structures, which may be of limited practical value. (Abadie & Howcroft)" Some widely used descriptions are:

- "The PPPs constitute an approach to introducing private management into public service by means of a long-term contractual bond between an operator and a public authority. Fundamentally, it secures all or part of the public service, so delegated by private funding and calls upon private sector know-how (United Nations, 2002)."
- "The term public-private partnership (PPP) is not defined at Community level. In general, the term refers to forms of cooperation between public authorities and the world of business which aim to ensure the funding, construction, renovation, management or maintenance of an infrastructure or the provision of a service (Office of the Deputy Prime Minister/UK, 2002)."
- "Public-private partnerships bring public and private sectors together in long term partnership for mutual benefit. The PPP label covers a wide range of different types of partnership including the Private Finance Initiative, the introduction of private sector ownership into state-owned businesses and selling Government services into wider markets and other partnership arrangements where private sector expertise and finance are used to exploit the commercial potential of Government assets (HM Treasury, 2000)."

- "A public-private partnership is a contractual agreement between a public agency (federal, state or local) and a private sector entity. Through this agreement, the skills and assets of each sector (public and private) are shared in delivering a service or facility for the use of the general public. In addition to the sharing of resources, each party shares in the risks and rewards potential in the delivery of the service and/or facility (The National Council/USA, 2006)."
- "A cooperative venture between the public and private sectors, built on the expertise of each partner, that best meets clearly defined public needs through the appropriate allocation of resources, risks and rewards (Canadian Council, 2006)."
- "Instead of the public sector procuring a capital asset by paying for it in full up front, the effect of a typical PPP structure is usually to create a single, standalone business, financed and operated by the private sector. The purpose is to create the asset and then deliver a service to the community, in return for payment commensurate with the service levels provided over the life of the asset. (Australian Council, 2004)."
- "It means a commercial transaction between an Institution and a private Party in terms of which the Private Party – (a) performs an Institutional function on behalf of the Institution; and/or (b) acquires the use of state property for its own commercial purposes; and (c) assumes substantial financial, technical and operational risk in connection with the performance of the institutional function and/or use of state property; and (d) receives a benefit for performing the Institutional function or from utilizing the state property, either by way of (i) consideration to be paid by the Institution which derives from a revenue fund or, where the Institution is a national government business enterprise, from the revenues of such Institution; or (ii) charges or fees to be collected by the Private Party from users or customers of a service provided to them; or (iii) a combination of such consideration and such charges or fees (National Treasury/South Africa, 2004)."

Public-private partnerships may undertake one or more combination of the following functions: design (D); build (B); finance (F); operate (O); maintain (M);own (O); transfer (T); lease (L); develop (D); buy (B), or refurbish (R) (World Bank, 2006). According to officials of the US Department of Transportation's Public Works Financing Projects (PWF), the major options for PPP procurement in transport projects worldwide are O&M (operations and maintenance contracts), DB (design, build), LDO (lease, Develop, operate), DBOM (design, build, operate, maintain), BOT (build, operate, transfer), DBFO (design, build, finance, operate), and BOO (build, own, operate) (AECOM Consult, 2005). The PPP functions as a bridge between traditional public procurement and full privatization. The risk allocation and responsibilities between public and private partners is shown in Figure Figure 2.1.1 and summarized in Table 2.1.1. (modified from HDR, 2005; Canada Government, 2003).

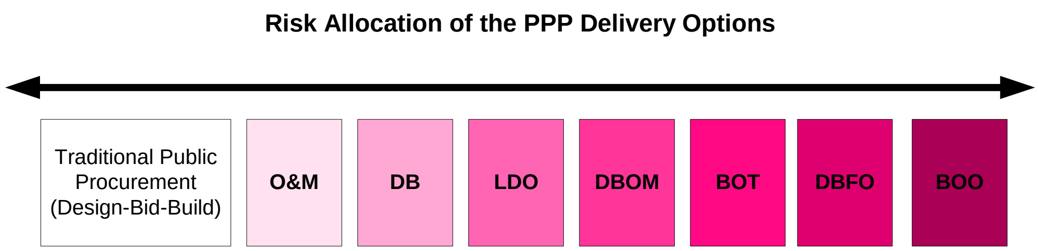


Figure 2.1.1 Risk Allocation for the PPP Delivery Options, modified from (HDR, 2005; The Canada Government, 2003)

Table 2.1.1 Risk Responsibilities of the PPP Delivery Options

PPP Options	Design	Construction	Financing	Ownership	Operations	Maintenance	Marketing
O&M	Public	Public	Public	Public	Private	Private or Public	Private or Public
DB	Private	Private	Public	Public	Public	Public	Public
LDO	Private	Private	Private then Public	Private or Public	Private	Private or Public	Private or Public
DBOM	Private	Private	Public	Public	Private	Private	Private or Public
BOT	Private	Private	Public /Private	Private then Public	Private	Private	Private
DBFO	Private	Private	Private	Private then Public	Private	Private	Private
BOO	Private	Private	Private	Private	Private	Private	Private

In addition to data shown in Figure 2.1.2 (Pakkala, 2002), the researcher found that a selection matrix diagram that used function synergy and financing scope may be a useful tool in choosing PPP delivery options. The function synergy that includes *segmented* options and *integrated* options is located on one axis. The researcher assumed the synergies may be found among four main function domains of design, construction, operations and finance. As shown in Figure 2.1.3 (Dinesen & Thompson, 2003), there may be four functionality synergies involved which include buildability, reliability, operability and full-risk transfer. By using the design-build (DB) project life cycle in which officials focus on integrating design and construction phases, officials may find this to be only choice for buildability. Alternatively, the build-operate-transfer (BOT) project life cycle which spans the entire life of a project to integrate design, construction and operation, may be the choice by officials for operability. Regarding finance, by using the BOT method, officials utilize public funding (internal funding) and private funding (external funding) which are located on the other axis. It is simple to determine which delivery options are integrated and which require private financing mechanisms. For example, if the goal is an integrated process with private financing, due to limited government allocations, then the client would consider the following delivery methods:

- Build-operate-transfer (BOT)
- Design-build-finance-operate (DBFO)

If the goal is a traditional and segmented delivery method, then the client would employ one of the following delivery methods:

- Design-build (DB)
- Operations and maintenance (O&M)

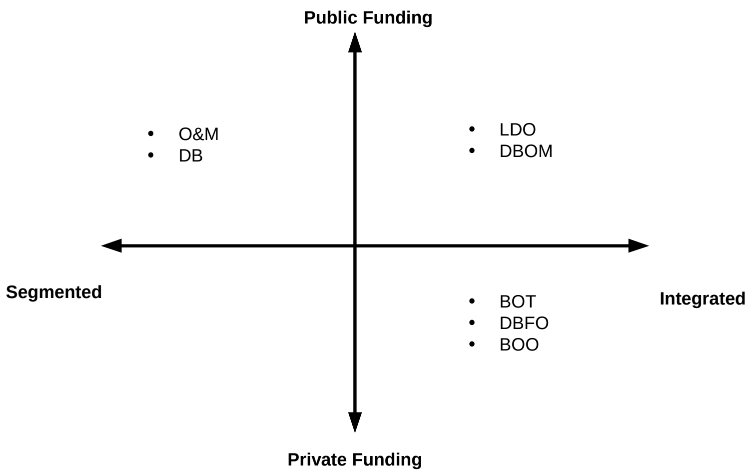


Figure 2.1.2 PPP Delivery System Choice(Pakkala, 2002)

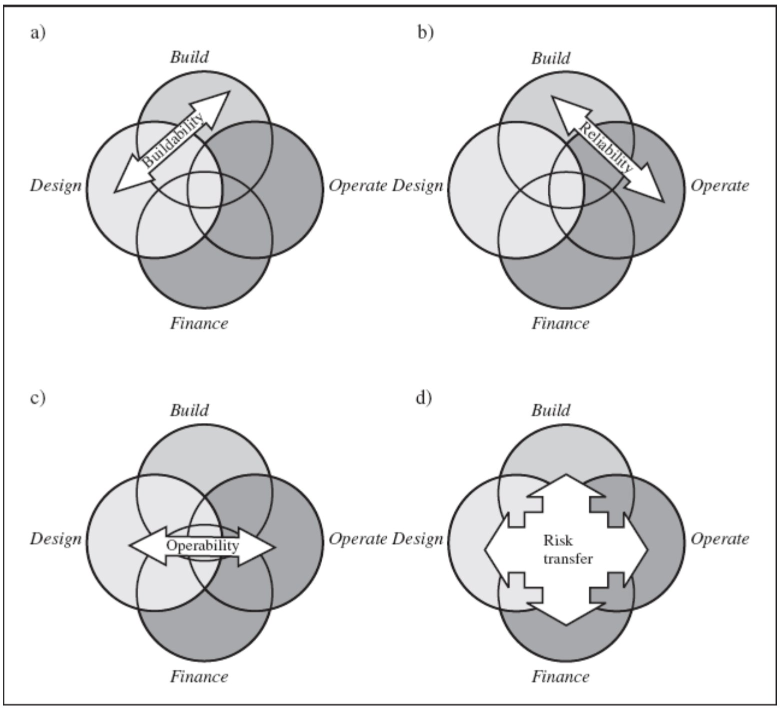


Figure 2.1.3 Synergies in An Accommodation Project: (a)between Design and Construction;(b) between Building Process and Operations Phase; (c)between Design and Operation;(d)Finance and Full Risk Transfer (Dinesen & Thompson, 2003)

2.2 Value for Money

Value for money (VFM) is defined as the optimal combination of whole life costs and benefits (quality or fitness for purpose) for the project (Allan, 2001; HM Treasury, 2004c) to meet user requirements. VFM does not simply mean the lowest costs or lowest price (HM Treasury, 2004c; United Nations, 2002). Researchers in current literature commonly describe the VFM as a core objective of PPP (Allan, 2001; Dinesen & Thompson, 2003; HM Treasury, 2003b; Infrastructure Australia, 2008a; United Nation, 2002). Allan stated that the PPP projects demonstrate the VFM concept from the perspective of the taxpayer as the client. The United Kingdom government officials stated that, “the Government only uses PPP where it can be shown to deliver value for money and does not come at the expense of employees’ terms and conditions” (HM Treasury/UK, 2006a)

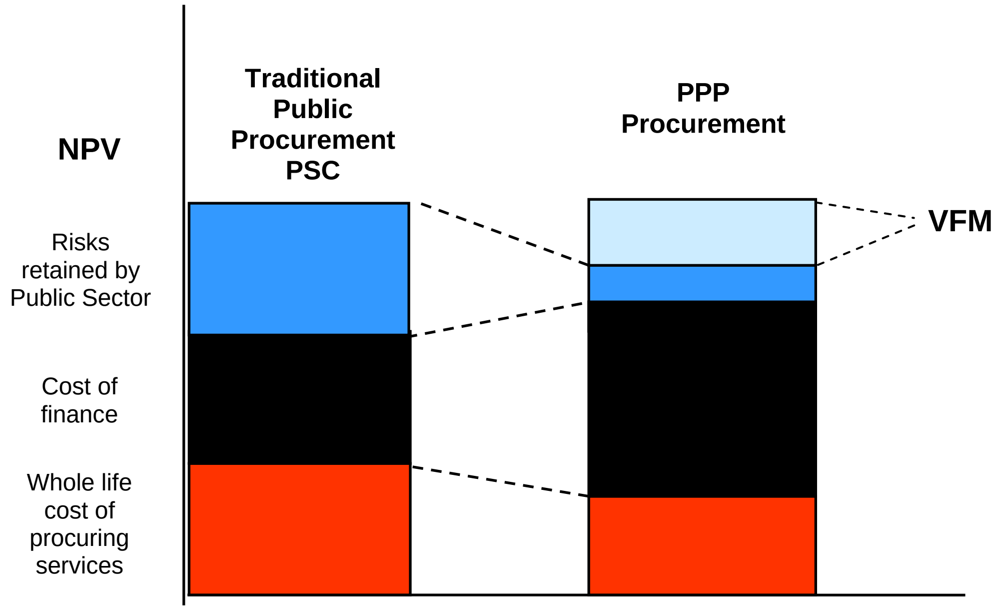


Figure 2.2.1 Value for Money (VFM) Demonstration(Skanska, 2004)

The VFM is indicated by the comparison of the project net present value (NPV) with both the PPP procurement options and the traditional public procurement options (Allan, 2001; Shaoul, 2002, 2005). The latter is called the public-sector comparator (PSC) which means that the net present value is based on the in-house skills, capability and public funding of public sector (Davies & Eustice, 2005). For example, in the PSC option, officials may allow for a design and build contract to construct an asset, and then procure annual operating and maintenance contracts for the ongoing maintenance of that asset (HM Treasury, 2004b). The PSC is a benchmark for quantitative analysis in VFM comparisons between PPP and traditional procurement (Grimsey & Lewis, 2005), particularly in the United Kingdom, the Netherlands, Canada, Australia, and New Zealand (Regan, 2005). In the Figure 2.2.1, the NPV has three cost components which consist of whole life costs, finance costs, and risk costs retained by public sector (Skanska, 2004). The NPV difference between the PSC and PPP options is considered the VFM. Allan (2001) stated there are two critical questions to be asked when determining PPP superiority over traditional models. First, does the project possess a positive NPV long-term? Secondly, is the NPV of PPP better than that of PSC? If so, the use of the PPP option then demonstrates superior VFM and the decision by officials is warranted. In other words, officials have indicated that the prerequisite for implementing PPP is evidence that whole life benefits of the project outweigh the risk costs of PPP procurement at a recognizable level. If PPP does not demonstrate superior VFM, then officials should use traditional procurement.

2.3 Debates on the Effectiveness of PPP

The pros and cons of PPP/PFI for public service delivery have been discussed. The PPP/PFI is generally favored within the current public sectors, in part because many of the PPP/PFI contracts take debt off the government's balance sheet (Gosling, 2008). Moreover, a majority of public projects by PPP/PFI schemes could deliver better public services over the traditional procurement. For example, the UK Government's report in year 2003, officials claimed that 88% of PFI schemes are delivered on time (HM Treasury, 2003), whereas 70% of non-PFI projects are delivered late and 73% are over budget. In another updated report in 2006 researchers investigated 500 projects including refurbished assets and transport assets that have entered the operational phase, and revealed that 79% of projects reported user satisfaction, 89% of projects reported that services closely followed contracts, and 96% of projects reported successful performance overall (HM Treasury/UK, 2006b; Partnerships UK, 2006). However, the experts of nonofficial organizations do not agree with the public sector officials' viewpoints. For instance, the UNISON's report in 2008 (Gosling, 2008) strictly criticized that the PPP has been marked by two significant failings, the creation of both huge profits and commercial failures for private sector contractors. No matter which one, the public sectors and taxpayers have been cheated.

Can the PPP approach really deliver VFM? The PPP approach is designed to produce value for money through four mechanisms: *risk sharing*, *private finance*, *output specification* (OS)/*performance based payment* (PBP), and *special purpose vehicle* (SPV). In the following sections the researcher introduces PPP mechanisms and examines the effectiveness of the PPP approach from the perspectives of PPP mechanisms.

2.3.1 Risk Sharing and Arguments

"Risk is central to PPPs and relates to nearly all aspects of the design, delivery, operation and efficient delivery of economic and social infrastructure services" (Regan, 2005). The PPP procurement process generally means that private sector officials presumably have a better capacity to manage project risks than the public sector officials in designing, constructing, operating, and maintaining its infrastructure (Davies & Eustice, 2005). Since risk is a real project cost, a structured PPP approach for risk and partnership management is likely to result in greater economic efficiency relative to the alternative in which risk is frequently ignored as an inevitable cost element (Allan, 2001). This is why the PPP arrangement for risk transfer is important in infrastructure development.

The best VFM is the optimal combination of the whole life costs and benefits of the projects. To achieve this, it is essential not to maximize risk transfer on a whole life basis, but rather to optimize risk allocation (APCC, 2002; CEPA, 2005; Maguire & Malinovitch, 2004). To manage risk in this manner involves formal identification, quantification, allocation, and mitigation of the risks associated with a particular PPP project (Allan, 2001). The allocation of responsibilities in PPP projects varies depending on the nature and objectives of the project. Once risks are identified and quantified, they are allocated to the partner with the most competence to manage those risks through a long-term contract design (Allan; Davies & Eustice, 2005; United Nations, 2002).

However, it is questionable if the PPP approach can really deliver VFM through appropriate risk transfer and allocation in some typical cases. For example, the private finance under PFI/PPP arrangement is usually high gearing. Especially in the UK, approximately 80% to 90% of financing for a DBFO project comes from debt providers (Yescombe, 2006). The debt finance is used against repayment including interest rate reflecting real risk costs, so it is not able to absorb unlimited risks (Davies & Eustice, 2005; Esty, 2003a). Also, the private project contractor usually conducts a series of fixed price subcontracts with certain limitations in terms of risk transfer and liquidated damages payable by sub-contractors on default for the concession contract (Davies, 2006; The Smith Institute, 2005). This makes it more difficult for the private project contractor to absorb the real risk costs. Under certain adverse events such as force majeure and national economic impacts on a project, the private project contractor might run into financial difficulties and fail to deliver services adequately (Flyvbjerg et al., 2003; Miller & Lessard, 2000). Davies (2006), Lonsdale (2005) and Gosling (2008) pointed out that in the event the project team fails to deliver the services to the standard specified and the private project contractor has failed to remedy this deficiency, the public sector should step in to take over the incomplete or underperforming project to ensure the delivery of services for public interests. In other words, when particular risks are transferred, it does not mean that risk transfer is absolute. Especially in the event of extreme project failure, the incomplete or underperforming assets could revert to the government. “Public authorities must not only be prepared to negotiate risk sharing, but also be ready to retain some risks and share excessive risks” (United Nations, 2002). To date, the Taiwan High Speed Rail (THSR) project is such a case. The global financial crisis that emerged since the end of 2008 made it a large revenue loss after a large decline in ridership demand. This risk event has made it difficult for the private project contractor (THSRC) to sustain operations. “Given its financial losses, the Minister of Transportation and Communications (the public authority of THSR) might consider training drivers themselves, which could prepare you to take over the operation” (Shan, 2009). It means that the risks could transfer back to the public sector in order to account for the termination liabilities at taxpayer’s cost to take the project ownership back (Golsing, 2008).

Davies and Eustice (2005) pointed out a typical case in which the risks might not be easy to transfer is when the asset life cycle is beyond the scope of the PPP/PFI project life cycle. The private PPP project provider cannot take the whole life cycle risk costs for the entire assets in such a circumstance. Such examples are that the public sector might engage a private PPP project provider to construct and maintain an office building, but the IT services are separately provided by an IT vendor (the third party); a private PPP project provider might be engaged to upgrade the existing rail line to a far wider network, but it doesn’t share risks for the existing rail line (PAC, 2005a). In such a circumstance, the procedures should be put in place to govern the interactions between the various providers (e.g., how the PPP project provider should respond to service failures). There should be a clear distinction between the risk responsibilities of the PPP project provider and third parties. Deloitte (2006) advocated a solution that the public sector authority might consider whether the scope of the PFI/PPP project could be widened to cover the whole life cycle services of both the existing projects and the expanding projects, so that the whole assets can be operated as an integrated whole. Then the whole life cycle risk costs can be transferred to a PPP project contractor for the best management.

The balance sheet treatment of PPP transactions is also an argument about risk allocation. The PPP/PFI arrangement transfers most of the project risks from the public sector to the private sector, so there may be an opportunity for a large number of PPPs to be off balance sheets for the public sector authority. This means that the assets of the project and related liabilities do not appear on the public sector’s balance sheet nor score against the overall national debt of the country (Allan, 2001; Davies & Eustice, 2005; House of Commons Library/UK, 2001; Spackman, 2002; UNISON, 2001). As addressed, many PPP infrastructure projects involve the upgrade and refurbishment of existing assets as well as the development of new facilities integrated within the existing assets as a whole. In this circumstance, the risks share of the private sector may not be sufficiently large enough to cover the entire assets. That is to say, the public sector officials still carry risk liabilities. Removing those obligations from the public sector's balance sheet entirely would arguably understate the public sector's likely future payments (Gosling, 2008; Maguire & Malinovitch, 2004; Spackman, 2002). The PPP/PFI projects are often designed for the private sector to receive payment from the public sector again the project output services which may be the majority of return on the private finance, both debt and equity, raised for project investment. Thus, in most circumstances, the public sector is going to pay out all or the vast majority of future project service payments. As a result, the off-balance sheet treatment would understate public sector's likely future payment and produce a significant cost to taxpayers (Gosling, 2008; Maguire & Malinovitch, 2004; Spackman, 2002).

Based on the lessons learned from the literature review concerning the risk sharing of PPP projects, it is known that the private sector is unable to absorb unlimited risks and that the risk transfer is not absolute when particular risks are transferred to the private sector. Eventually, the risk could transfer back to the public sector at a cost to the taxpayers and the project ownership would revert back to the public sector if the risks have made it difficult for the private sector to sustain project services. This is the case with the Taiwan High Speed Rail (THSR) project.

Based on the literature review, the researcher advocated that before awarding a PPP contract to a private sector bidder, the public sector officials need to look into the potential risks that could influence the PPP project performance. The risk factors were organized in Table 4.1.3. Then, the risk effects were modeled and a model simulation was performed to see the worse case scenario and best case scenario of project net present value (*NPV*) over time (see chapter 6). In particular, the worse case scenario simulation provide the public sector with the information about the possibility of project failure to help the public sector reduce the chance of taking risks back after awarding a PPP contract. A simulation case for Taiwan High Speed Rail project is shown in Figure 8.8.1, in Section 8.8.

2.3.2 Private Finance and Arguments

Under the PPP arrangement, the private sector officials can help provide new sources of investment, in particular through project financing at the private sector's risk (Prowle, 2006). The involvement of private finance is an important factor in the success of PPP/PFI, based on the fact that the public sector seeks to receive the best VFM by securing the benefits of private finance for PPP/PFI projects (HM Treasury, 2003a). In addition to spreading risk, the major benefit of private finance is to maintain a variety of sources of funding for PPP/PFI projects in securing VFM through competitive tension (Yescombe, 2006). A private sector party generally raises project funds both in equity and debt finance for PPP (Esty, 2003b). The PPP concessionaire is usually owned by one or more equity investors. Some of these shareholders may be the contractors in the consortium, who are performing construction, design or facilities management work on the project. Another source of capital is debt finance in the form of bank loans or bonds raised to pay for construction and operation of the project (Esty, 2003b). When the lenders consider financing a project, they exercise extensive due diligence which is aided by independent advisors in technical, insurance, legal and financial aspects of the PPP deal. Third-party due diligence is also a key benefit to ensure that a PPP project is feasible to secure VFM (Yescombe, 2006).

Davies and Eustice (2005) pointed out that the private sector's cost of finance including equity finance can reflect the specific risks of the project, on the grounds that the latter is being required to absorb many of the project's risks. In contrast, the public sector's cost of finance is the overall rate at which that authority can borrow funds (i.e., debt only, not equity), and therefore does not reflect the risks of the project. To the extent that those risks occur, there is no equity to absorb those risks, rather the public sector has to find further funds or take on further borrowings to finance completion of that project. However, the private finance for PPP/PFI projects is usually high-gearing finance so that more than 70% of total project finance is debt finance (Esty, 2003). In the United Kingdom, the debt finance is estimated to be 80% to 90% of total project finance (Spackman, 2002; Yescombe, 2006). Can the high-gearing private finance absorb the long-term PPP/PFI project risks? The opposing arguments querying the private finance only offer VFM in PPP/PFI procurement in circumstances where the benefits it brings outweighs any cost that are involved. Allan (2001), CEPA (2005), Davies and Eustice (2005), Regan (2005) and Gosling (2008) have revealed that the true cost of finance for the PPP/PFI deal is higher than that for traditional public procurement. As for the private finance, an insurance company will require the payment of a premium related to the actuarial value of the risk assumed, or a bank or other financial institution will adjust the interest rate charged to reflect the financing risk (Allan, 2001). The private sector's weighted cost of finance, both debt and equity together, is typically between 1% and 3% higher than the public sector's cost of debt on a nonrisk-adjusted basis (Davies & Eustice, 2005). On the other hand, it can be argued that the public sector authority's cost of debt finance is the appropriate rate, because that authority undertakes a portfolio of projects and therefore the borrowing rate should reflect the lower risk of this portfolio, not the risks of a particular project (Allan, 2001; Davies & Eustice, 2005). Obviously, private finance costs will be higher than public finance costs, so the key question is whether the private sector's cost efficient management will outweigh that incremental cost. The public sector also needs to consider how much higher private finance costs can be. If too large a premium or too high an interest rate is put on project risks, VFM will be significantly eroded (Allan, 2001; CEPA, 2005; Davies & Eustice, 2005; Regan, 2005).

The Taiwan High Speed Rail (THSR) project is a representative case to this debate. With high-gearing finance (70% of total financing is debt finance), the high interest rate for debt is creating the fact that the operating revenues cannot cover the large debt invested during the construction stage. Moreover, the global financial crisis that emerged at the end 2008 produced a large revenue loss in the project particularly after a large decrease in ridership demand occurred. The total deficit expanded to NT$67.5 billion at the end of 2008, accounting for almost 65% of NT$105.3 billion in corporate capital (Shan, 2009). Both risk events have made it difficult for the THSRC private project contractor to sustain operations. This is a result of the fact that the transport projects need sufficient income (revenue) during the operation stage to outweigh high outcome (private finance for the cost of constructing infrastructure) that occurred during construction stage to create VFM. When the demand for the services generated by the transport projects is less than projected, the resulting lower revenue would lead to financial difficulties so that the private project contractor's capability in cost efficient management will be eroded. VFM will then be significantly eroded.

Based on the lessons learned from the literature review concerning the private finance of PPP projects, it is known that the private finance costs could possibly exceed the public finance costs. Whether a PPP project is able to create VFM will depend on if the private sector's cost efficient management will outweigh that incremental cost.

Based on the research, the researcher advocates that the PPP project NPV should be modeled over time to see whether the private sector's cost efficient management which was shown in the bidding proposal will outweigh the private finance costs. The project NPV was molded in the Section 6.1.7. This includes project finance model for equity and debt finance (see Section 6.1.2) and the relevant cost and revenue models (see Section 6.1). For example, based on the simulation results for Taiwan High Speed Rail case shown in Figure 8.8.1, the Section 8.8, the researcher supported the fact that the VFM is significantly eroded when the operating revenues cannot cover the large project finance costs spent during the construction stage.

2.3.3 OS/ PBP and Arguments

The output specification (OS) is the document in which the public sector officials delineate in output terms, what they need from the long-term services and any associated facilities (4Ps, 2005). Output specification is the tool used by the public sector officials to define the required private sector services and outputs for PPP projects. A well-drafted output specification is essential for the successful delivery of long-term services.

Private sector innovation is especially critical for PPP projects in which the private provider is expected to generate better management than the public sector in-house services (Davies & Eustice, 2005). Thus, the output specification is vital for the public sector to maintain VFM while encouraging the private sector to create innovation for the PPP deals. Public service requirements are normally framed as an output specification with a broadly defined objective that allows the private sector to produce innovative and cost-effective solutions, as compared to the technical and narrow specifications included in many traditional agreements (Allan, 2001; Davies & Eustice, 2005; UN/ECE, 2000). "Output specification defines what the required services are, but they do not specify how they should be delivered" (Cuttaree, 2008). For example, define the service requirement of a rail transportation project in terms of routing, capacity and operational quality instead of how it is to be achieved.

The essence of the PPP arrangement is the procurement of services. The robustness of performance based payment (PBP) system is an important source of assurance to government officials that the private party is meeting the obligations to deliver services (Infrastructure Australia, 2008b).The PBP mechanism is fundamental to the PFI/PPP contract, as it puts into financial effect the allocation of risk and responsibility between the public parties and the private parties. The PBP mechanism should include appropriate incentives for the private sector to deliver the service in a manner that gives best value, and promotes partnership working (4Ps, 2005).

The PBP mechanism is present to ensure that the public sector officials' objectives for the project are being delivered; it should be linked to the outcomes and outputs for the project that are set forth in the output specification. Payments vary depending on whether the services have met the performance outcome mandated in the output specifications. The key to a successful PBP mechanism is the relationship and interdependency between the output specification and the PBP mechanism. Therefore, it is important that these are developed in conjunction with one another (4Ps, 2005). The output specification should clearly and comprehensively indicate what is required as well as the standards that are to be achieved in order to reduce the uncertainty faced by both the public sector and the private sector providers. It is also vital that communication between the public and the private parties clarify how performance against output specification is measured and monitored (UN/ECE, 2000; Aziz, 2007).

However, "Does the public sector have sufficient capacity and skills to adopt the PPP approach?" is an extensively debated issue (Regan, 2005). It is argued that the major purpose to adopt PPP deal is that the public sector officials want to obtain benefits from the off-balance sheet treatment rather than if it has sufficient capacity and experience to adopt it (Gosling, 2008). The public sector officials should be capable of structuring the desired service output specifications that are clearly stated and measurable so that the private sector parties can have a clear understanding how to achieve the government officials' policies and objectives. In addition, the public sector should be capable of measuring and monitoring the performance of the private sector to ensure the service requirements are met (European Commission, 2003; Regan, 2005).

An essential concern with long-term PPP contracts is the level of flexibility in changing output specification. The project services will inevitably change during a long-term PPP contract. Especially for a transportation project, it has a long-term life that involves difficulties in reflecting trends in regional economic development and growth. Therefore, the frequent change in output specification to meet economic trends might be desirable for a public authority (Thomson et al., 2005). On the other hand, to achieve VFM and certain level of cost benefits, a rigid output specification is usually set by public sector officials for the life of a PPP project. Service requirements should be very specific in terms of service standards and performance requirements to ensure that the contract documentation is clear, and not prone to different interpretations (4Ps, 2005). The PPP long-term contracts are therefore inflexible due to the difficulties of changing requirements (CEPA, 2005; Davies & Eustice, 2005;

Deloitte, 2006; European Commission, 2003; Thomson et al., 2005; Yescombe, 2006). Furthermore, all relevant parties must agree to any changes to the contracts and these changes may involve a considerable increase of costs to the public sector. As a result, the level of frequent change in a long-term output specification that is desirable for a public authority is relatively limited (4Ps, 2005; Davies & Eustice, 2005; Deloitte, 2006). The level of flexibility possible in changing output specifications will influence the PPP project performance which was addressed as risk factor “inflexible contract arrangements” (see Table 4.1.3) and was discussed in Appendix V29 and Appendix VI29.

Another key concern relative to output specification and PBP mechanism is that the public sector may lose management control for PPP projects. The PFI/PPP management approaches are designed for the private sector officials to have increased power of the management control of outputs than the public sector so that they are shielded from regular political and administrative interference which is one of the common causes of cost overruns and delays (Davies, 2006). Although the public sector officials may still intervene through contract change mechanisms, all relevant parties must agree any changes to the contract (4Ps, 2005; Davies & Eustice, 2005; Deloitte, 2006). All of these imply that the public sector’s ability for day-to-day control over the management of public sector services is limited. This is against the proponents’ points of view that a superior position of government to plan and coordinate infrastructure supply in the broader interests of both community and economy is necessary (Regan, 2005).

The level of flexibility possible in changing output specifications will influence the PPP project performance which was addressed as risk factor “inflexible contract arrangements” (see Table 4.1.3) and was discussed in Appendix V29 and Appendix VI29. Based on the lessons learned from the literature review concerning OS and PBP of PPP projects, the output specification is vital to maintaining VFM while encouraging the private sector to create innovation for the PPP deals. The public sector officials should be capable of structuring the desired service output specifications, and measuring and monitoring the performance of the private sector to ensure service requirements are met. In the research, the researcher assumed that the public sector had sufficient capability and skills to formulate the service specifications and measure and monitor PPP project performance. Under this condition, a methodology was developed to select a PPP contractor who can produce the best VFM among the bidders (the private sectors).

As for performance based payment, it is developed in conjunction with the output specification to ensure the performance outcome can meet output specification. Payments varied depending on whether the services performed met the performance outcome mandated in the output specifications. In the research, the transportation project was used as a case study to develop a PPP contractor selection methodology. The revenues of a transportation project are generated from end users, instead of the public sector. Therefore, there was no payment mechanism for a transportation project in the research, but revenue and penalties mechanism against project performance outcome were discussed in the Section 6.1.3, 6.2.3, and Appendixes V3 and V32. The lack of a payment mechanism is identified as one of the limitations of the study, yet presents an opportunity for future research.

2.3.4 Special Purpose Vehicle and Arguments

The private partner (concessionaire) is usually a consortium formed by multiple companies. This type of consortium provides an excellent special purpose vehicle (SPV) which incorporates finance, design, construction and operation in a cooperative relationship. In many traditional project models, these functions are fragmented and often result in tension among participants (Zhang, 2004b). Usually, the SPV is a joint venture between an experienced construction contractor and a facilities management or service operations company experts capable of running and maintaining the asset. Other contractors required for delivery of outputs specified in the contract also join the SPV. A key function in structuring SPV for PPP arrangement is obtaining private financing for ongoing operations (Zhang, 2004a; Zhang, 2004b; Zhang, 2005).

However, it is argued, “Does sufficient private sector expertise exist to warrant the PPP approach?” (Davies & Eustice, 2005). Under PPP arrangement, a SPV should have the capabilities to add value to the delivery of public services. Hence, PPP should only be applied to projects where the private sector has the competencies to meet the service standards required by the public sector. In addition, there should also be multiple potential private providers who can offer different proposals and ideas that will increase and promote continual improvement in the delivery of public services. So the fundamental questions concerning the private sector’s competence for PFI/PPP arrangement are as follows:

1. Is it possible for the private sector to deliver services better and more efficiently than the public sector? The private sector contractor should have proven additional management skills to realize service improvements and efficiency gains.
2. Are there sufficiently numbers of potential private sector bidders that allow for an effective competition?
3. Are the private sectors bidders experienced in pricing life cycle costs?
4. Are the private sectors contractors able to managing and absorbing the particular risks of projects? (Davies & Eustice, 2005; Zhang, 2004a; Zhang, 2004b):

Furthermore, Gosling (2008) criticized the concept that by contracting with the public sector contractors through SPVs, contractors are able to turn ignore a difficult or unprofitable contract, possibly without incurring financial penalties. Because the SPV is likely to own no assets of its own, contract failure may not lead to the enforcement of any penalties agreed as part of the contract.

Gosling (2008) further criticized the concept that stand-alone companies have no financial liability falling on the companies if the SPV collapses which is beyond the value of their shareholding and any guarantees which they might have provided. Shareholders usually each own less than 50% of the SPV and so have no need to show its assets and liabilities on their own balance sheets. By using a name which is unconnected to that of the shareholders, any of the shareholders in the SPV would not be affected in the event of commercial failure on the part of the SPV.

As stated in Section 2.4.2, THSRC (the SPV of Taiwan High Speed Rail) is struggling to stay viable amid mounting losses due to the current global financial crisis and the high interest rate for debt. The SPV was NT70.2 billion in debt as of the end of June 2009, compared with a capitalization of NT105.3 billion (Tan, 2009). The SPV was seeking NT80 billion (2.5 billion USD) from creditor banks to keep it afloat, but creditors were reluctant to approve new loans because the shareholders in the SPV refused to increase equity finance for SPV’s heavy losses. This would signal the failure of Taiwan's biggest build-operate-transfer (BOT) project, under which the contracting firm agreed to build the rail line and run it for 35 years before transferring ownership to the government (Chen, 2009a). The THSR services have great economic benefits since the train links the capital Taipei and southern Kaohsiung city. The transportation service will allow people to move out of cramped urban areas, integrating the island’s core western corridor into a modern megalopolis. According to the THSR contract, the government officials now must take over the entire project, assuming full financial responsibility if the

THSRC fails either during construction or at any time during the following two decades of operations before the scheduled transfer. The opposition-dominated members of the legislature indicated a desire to eliminate the public responsibility in June 2001, but it the agreement was already finalized (Chen, 2009b). The SPV has become responsible for debt now, and its consortium members (shareholders) have refused to take any further financial risks (increase equity finance). It is very controversial that the government officials are going to take over the SPV, but taxpayers will continue to fund the THSR project regardless. A PPP model- BOT clearly has not worked in this vital case (Huang, 2009).

Based on the lessons learned from the literature review concerning the SPV of PPP projects, it is arguable whether the private sector contractor is able to deliver services better and more efficiently than the public sector resources. In the research, it was assumed that there are at least three private sector bidders to assure effective competition (see the Section 3.3). Under this assumption, the researcher advocated a methodology that compared PPP project NPV of the private sector contractors (3 bidding proposals) with that of public sector (a base case) to determine whether the private sector contractors could create VFM (i.e., the bidding proposals can produce better project NPV than the base case) [see chapter 7]. In addition, as addressed in the Section 2.3.1, the potential risk effects were modeled to show the worst case scenario and best case scenario of the project NPV of the bidding proposals over time. Using this model tested whether the private sectors contractors were able to manage and absorb the particular risks of projects. For example, the risk effects concerning a SPV's debt and equity finance were modeled to see how the changes of debt-equity ratio would influence project NPV.

As addressed in the Section 2.3, an effective PPP approach is evidenced when whole life benefits of the project outweigh the risk costs through VFM assessment. Therefore, in addition to examining the effectiveness of PPP approach from the perspectives of PPP mechanisms, the research further discusses the debates on VFM assessment methods such as the PSC approaches from the technical perspective in Section 2.4.

2.4 Issues of VFM-based Bids Evaluation

There are many objectives in applying risk assessment to the PPP bid evaluation process. Cooper et al. (2005) indicated:

1. To provide an initial indication of where the major risks might arise in the project, prior to receipt or detailed examination of tender responses, based on a set of creditable assumptions about how project might be conducted;
2. To develop a risk baseline against which individual tender response can be compared;
3. To assist the project team to focus on potential risk areas in their evaluations of offers;
4. To provide a risk profile for each tender offer submitted, developed on a consistent and justifiable basis; and
5. To provide a documented audit trail of the project team's assumptions about potential risk areas and their reasons for adjusting their assessments in the light of individual tender responses.

Given the United Kingdom officials' extensive study and use of PPP procurement (Allen, 2001), the researcher focused on the UK-style PSC approach for bid evaluation, which undertakes whole life-cycle risk costs with risk and uncertainty analysis for PSC-PPP VFM tests.

2.4.1 Critics on VFM Assessment Approaches

The general critics on the risk analysis approaches and tools state the following issues relative to the VFM assessment approach:

- ***CBA vs. CEA?***

Cost benefit analysis (CBA) is an important tool for socio-economic assessment. Traditionally, proponents of this tool have focused on economic efficiency, particularly by providing policy makers with an indication of net benefits associated with a government project or policy. Economic efficiency is a measure of net contribution of an activity or project to overall social welfare (Huang, 2001). As for PPP procurement, objective is to assess whether a given project or bid proposal is value for money (Stahr, 2006). Applying the whole-life cycle costing with the discounted cash-flow analysis and risk analysis to calculate PSC for NPV is the major tasks of CBA. However, in CBA parties relies on the ability to measure costs and benefits in monetary terms which creates problems for projects in which the majority of benefits cannot be readily monetized (Huang; Mackie, Nellthorpe & Laird, 2003).

By using the CBA approach, officials attempt to quantify benefits and costs in money terms to a large extent, whereas the cost-effectiveness analysis (CEA) approach is a cost-minimization technique (Watson, 2005). The CEA approach is a useful tool officials use for project screening or ranking which often incorporates multi-criteria decision making (MCDA) to weigh multiple outcomes in obtaining a single composite measure. However, when officials use this tool they rely on a subjective decision which is not inherently superior to CBA. Furthermore, this method has a shortcoming in that it is unlikely to produce consistent comparisons from project to project by different groups or experts (Lebo & Schelling, 2001). The CEA approach is widely used by officials to appraise investments in the social sector, such as health and education projects, and has rarely been used in the transport sector. This is due to the hypothesis that transport investments are generally economic in nature and should therefore be economically measured (Mackie et al., 2003).

- ***Is NPV a reliable measure criterion for bid evaluation?***

In using CBA as the economic appraisal method for the PPP infrastructure projects, the measure criteria often includes the net present value (NPV), the internal rate of return (IRR), benefit-cost ratios (BC), and the payback period. Decisions made during the payback period do not factor the time value of money, whereas others incorporate the time value of money, using discounted cash flow methodology (Ye & Tiong, 2000).

The NPV is the present value of all benefits for each period within the project life appropriately discounted, minus the present value of all costs discounted at the same rate for the same period (Park & Sharp-Bette, 1990). Throughout bids comparison, officials use the NPV to provide the best criteria for decision making without the extreme care inherent in (Watson, 2005).

A BC ratio is that of present value of benefits to the present value of costs. The rule here is to reject any bid with a BC ratio of less than 1, and rank bids in order of their BC ratio (Park & Sharp-Bette, 1990). A shortcoming of a BC ratio is the possibility of its artificial changes in the accounting for benefits and costs. A positive benefit is equivalent to a negative cost, and vice visa. Adding to the costs is equal to subtracting from the benefits, and vice visa. Either choice is correct. However, the BC ratio would be increased or decreased artificially, depending on this arbitrary accounting decision (Watson, 2005).

The payback period is defined as the time it takes for the cumulative present value of benefits to equal that of cumulative present value of costs. In general, shorter payback periods are better. This can, however, be misleading in that it ignores everything that happens after the payback point. It is quite possible for a project to have a shorter payback period but lower NPV, and vice visa. As shown in Figure 2.4.1(Watson, 2005), Bid A has a quicker payback, but Bid B reaches a higher NPV.

<u>Example 2.4.1</u>

	Benefits	Costs	Benefit-cost ratio
Bid A	$180	$100	180/100 = 1.8
Bid B	$190	$100	170/150 = 1.9
Artificial change for Bid A	$130	$50	130/50 = 2.6

Note: before artificial change, the BC ratio for Bid A = 1.8, which is lower than that for Bid B = 1.9. By netting $50 out of the benefits for Bid A rather than listing it as a cost. Then the BC ratio for Bid A will change to be 2.6, which get larger than Bid B.

Even though the CBA incorporated with NPV is preferred for public sector to evaluate the large-scale infrastructure projects, there are some studies (Zhang, 2004b, 2004a; Zhang et al., 2002) which have shown that the NPV measure only emphasizes financial appraisal and ignores analysis on such multiple-criteria as techniques, management, legislation, environment, and the like. Grimsey and Lewis (2005) stated that financial evaluations with discounted cash flow analysis related to cost estimates are incomplete bases to draw conclusions about the viability of PPP, and more emphasis needs to be given to non-financial elements in long-term evaluation. Grimsey and Lewis proposed applying a CEA with MCDA to incorporate qualitative and non-monetary data for bid comparisons. As discussed, the CEA with MCDA would produce subjective and inconsistent decision, which is not preferred to CBA with NPV. By employing the CBA with NPV for a transport project’s bids evaluation, officials have found the challenge is to convert all qualitative and non-monetary effects other than financial effects into monetary terms and carry out a risk analysis for the qualitative risk impact and uncertainty over the project life cycle. This is because officials will combine overall effects of both monetary and non-monetary factors for the project’s NPV. However, approaches such as group expert judgment and statistic techniques can help to quantify subjective and qualitative data and covert non-monetary terms to monetary terms in an objective and systematic manner. This is discussed in Chapter 3: Research Methodology.

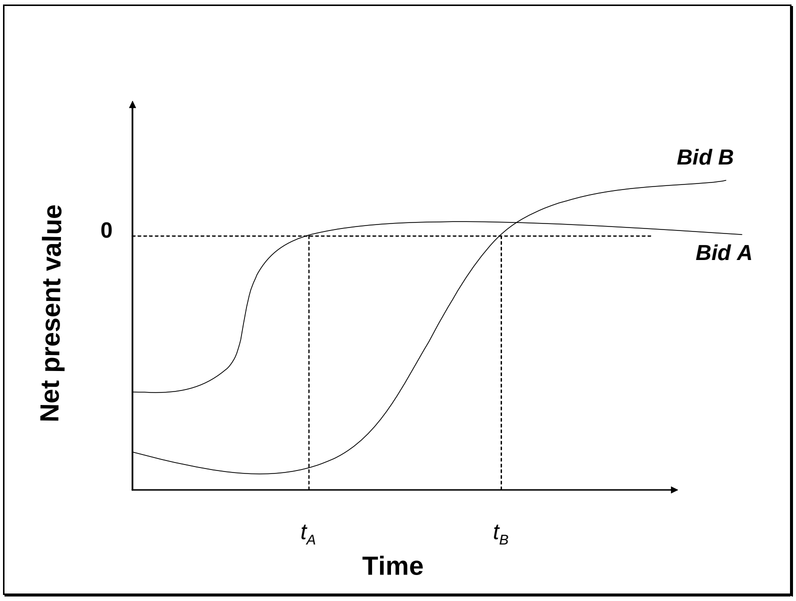


Figure 2.4.1 Payback Period Compared for Two Bids (Watson, 2005)

The Internal Rate of Return (*IRR*) is defined as the interest rate that makes the *NPV* of a cash flow equal to zero (Park & Sharp-Bette, 1990):

$$NPV(IRR) = \sum_{n=0}^{L} \frac{F_n}{(1+IRR)^n} = 0$$

Where

NPV: net present value;
IRR: the internal rate of return;
F_n: the net cash flow at the nth year;
L: project life.

It is often used in practice and knowing a return is intuitively appealing. It is a simple way to communicate the value of a project to someone who doesn't know all the estimation details. However, *IRR* is unreliable in the following situations (Hartman, 2007; Park and Sharp-Bette, 1990; Park, 1997; Peterson and Fabozzi, 2002; Ross, et al., 2008; Yaffey, 1992):

1. Non-conventional cash flows: cash flow signs change more than once;
2. Mutually exclusive projects: If the acceptance of any one precludes the acceptance of any of the

others.

Conventionally a project is ideally assumed to have an initial outflow (initial negative investment) in the beginning but have subsequent inflows (return) in the later stages. If only one cash flow sign changes this means the *IRR* generates a unique result (Figure 2.4.2). But in the real world, the cash flows may change sign more than once. In a complex project like PPP infrastructure project this is such a case. When for the *IRR* is solved for, the root of the above equation *NPV (IRR) = 0* is solved and when the x-axis is crossed more than once, there will be more than one return that solves the equation. This means that there are multiple solutions to *IRR*. If multiple IRRs are calculated, none are then reliable. Figure 2.4.3 shows the nonconventional cash flows and indicates there is no single *IRR* or there are multiple *IRRs* in the various timing. Since multiple solutions that are each valid and $IRR \neq IRR_1 + IRR_2 + ..IRR_n$, the *IRR* for multiple projects comparison (the selection of bidding proposals is in such a case) makes no sense (No any *IRR* can be suitably picked in consistently comparison of multiple projects).

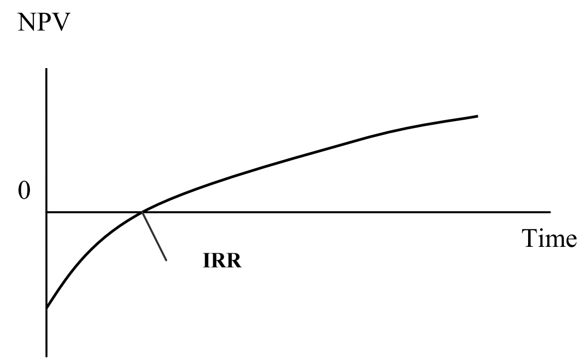


Figure 2.4.2 A Conventional Project Cash Flow Has An Unique IRR

IRR is unreliable in comparison of mutually-exclusive projects. Table 2.4.2 is an example with mutually-exclusive projects. Intuitively, the project would be chosen with the higher *IRR* and the higher *NPV*. But as for this example, there is a conflict between *IRR* with *NPV*. Note that although the Project B (the small budget project: -$400) has the greater *IRR* (22.17%), the Project A (the large budget project: -$500) has a greater *NPV* ($64.05). Choosing the alternative with the highest *IRR* (Project B has higher *IRR*) does not maximize shareholder wealth (Project B has lower *NPV:* $60.74). Project A has a smaller *IRR* (19.43%) but it is a larger project, thus generating greater value to the firm

(Project A has higher *NPV*). This example indicates that the *IRR* is difficult to use in selecting the optimal scale of investment, but *NPV* can directly measure the increase in value of a project to the firm.

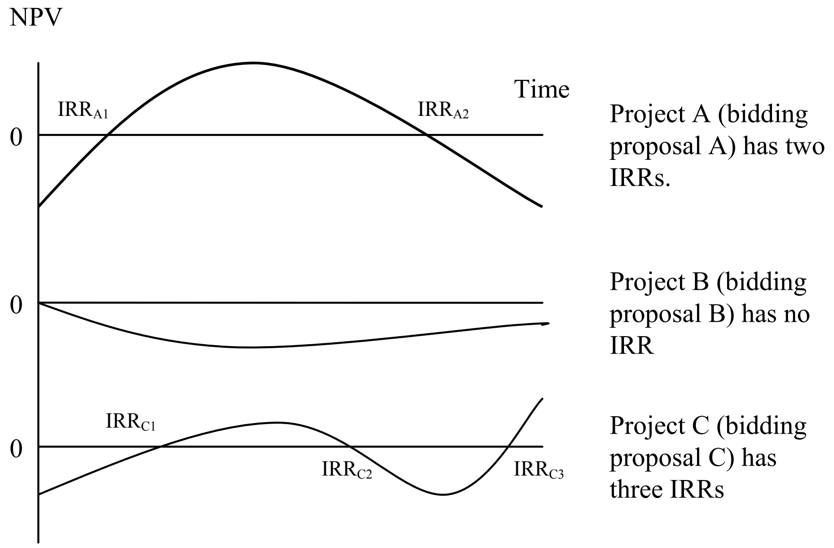


Figure 2.4.3 Non-conventional Cash Flows: No Solutions or Multiple Solutions to IRR

Table 2.4.2 The Cash Flow Example With Two Mutually Exclusive Projects (Ross, et al., 2008)

Period	0	1	2	IRR	NPV
Project A	-$500	$325	$325	19.43%	$64.05
Project B	-$400	$325	$200	22.17%	$60.74

The *IRR* is also unreliable in two situations: multiple solutions to *IRR*, and mutually exclusive projects. In this thesis, the researcher focuses on the selection of bidding proposals for the PPP infrastructure projects. The PPP infrastructure projects are generally considered complex projects that there are multiple *IRRs*. The selection of bidding proposals refers to the comparison and selection of multiple mutually exclusive projects offered by the bidders. Both are in such a case that the *IRR* decision rule is unreliable. Therefore, this thesis promotes *NPV* instead of *IRR* to measure project performance for PPP contractor selection. Whenever there is a conflict between *NPV* and another decision rule, *NPV* should always be used (Park, 1997; Park & Sharp-Bette, 1990; Ross et al., 2008; Yaffey, 1992).

- ***Are risk costs independent?***

Williams (2005) pointed out that overall project complexity can be characterized by structural complexity and uncertainty (Figure 2.4.2). The structure complexity is characterized by project size and interdependence of elements, and the uncertainty is featured by uncertainty in goals and respective methods. Multiplying effects of both structural complexity and uncertainty will consequently lead to complexly dynamic behaviour. The major risks inherent in each hierarchical work breakdown structure (WBS) of a complex project often cut across activities and work packages, and the uncertainties in the WBS items are interdependently compounded. In reality, a mega PPP project has usually a long-term life cycle with risk interactions (Miller & Lessard, 2000, 2001).

Unfortunately, spreadsheets used in current methods for PPP project risk estimates or bids evaluation often indicate that risk costs are independent; each cost is analyzed separately. Furthermore, risks and uncertainties are not evaluated against WBS so that the risk compounding effects among WBS items are ignored. For example, the UK government officials (HM Treasury) currently developed a VFM quantitative evaluation spreadsheet called the *Spreadsheet*, as a standard modelling tool to assist procurement authorities undertaking a quantitative analysis to support the VFM decision (HM Treasury, 2004c, 2004b), on which the input risk variables of the Spreadsheet are independent. There are no breakdown costs for each WBS item. There is also no any assessment of risk costs arising from the interacts of WBS items.

A causal-effect technique to model the risk cost network for inter-relationships of risk events may be more efficient than spreadsheets used in the current practices. System Dynamics (SD) is a technique which models non-linear behaviour, time-delay effects and causal feedback of risk events for a complex project over time (Williams, 2002), which will be further described in Chapter 3: Research Methodology.

2.4.2 Critics on Need of the PSC

The PSC is a benchmark to measure whether bids represent value for money for the public sector and whether risk transfer generally improves VFM. However, the opponents of PPP procurement have criticized the design of the PSC process indicating that it encourages project managers to use PSC to pass PPP project rather than monitor VFM for the taxpayer (Turner, 2002). The major suspicions of the use of PSC for VFM tests are based on the following questions: Is the PSC is costly? and Is the PSC is so subjective as to be easily manipulated?

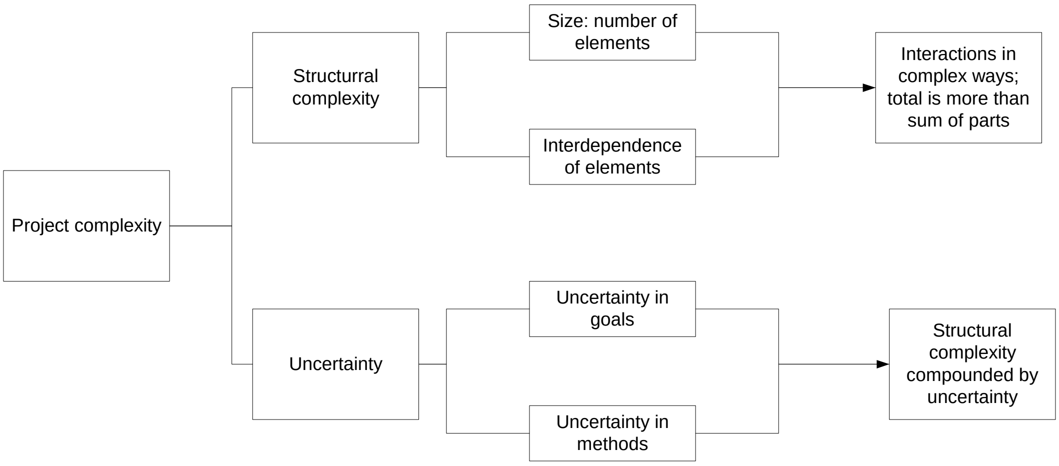


Figure 2.4.2 Dimensions of Project Complexity(Williams, 2002)

- ***Is the PSC costly?***

The purpose of PSC is to offer the opportunity for government officials to secure better VFM and use greater innovation in the delivery services. Therefore, the PSC must have a defensible estimate of what the cost to government would be if the services were provided through a more traditional means of procurement (Partnerships Victoria, 2003a). Therefore, the level of analytical detail should be sufficient to provide a meaningful comparison between the PSC and bids and the differences between them. However, arriving at such realistic estimates can be a costly and complex task, not dissimilar to the preparation of business plan (Grimsey & Lewis, 2005).

- ***Is the PSC so subjective that it can be easily manipulated?***

The PSC calculation is a theoretical one calculation of what the project might cost using the public procurement route, with many unknowns attached to the costing due to limited availability of the historical data, particularly with respect to the evaluation and treatment for risk likelihood and impact. It is therefore argued that the PSC is an entirely hypothetical figure that is used by officials to estimate the cost of publicly financed projects to deliver equivalent benefits to the PPP option without any real market test (Shaoul, 2002; Turner, 2002). This is easily swayed by assumption and whatever its users require it to show (Blyth, 2002; Shaoul, 2005).

Many studies have demonstrated that "the lowest-price wins bid" in the traditional public procurement, sacrificing the quality of project performance (Holt, 1998; Holt et al., 1995; Wong, Proverbs & Holt, 2002). "The central proposition should always be that PPP should only be pursued where it delivers value for money (VFM), where VFM is the optimum combination of whole life cost and quality (or fitness for purpose) to meet the user's requirement, and does not always mean choosing the lowest cost bid" (HM Treasury, 2004c). Practical experience in very large infrastructure transactions in Australia has shown officials that the cost of private sector service delivery may sometimes be even lower than the raw PSC. For completeness and quality assurance, the full PSC should always be the quantitative benchmark (Partnerships Victoria, 2001b). As described in the current theory of *Engineering Economics* (Park & Sharp-Bette, 1990), PSC acts as a baseline, base case or correct criterion to compare multiple project alternatives and diagnose whether they are VFM. "The PSC provides a consistent benchmark and evaluation tool to ensures that all projects are tested in a like for like way and are subjected to a broadly similar and systematic test for protecting VFM (Grimsey & Lewis, 2005)."

Use of PSC as benchmark by officials saves costs and time in efforts to estimate broader social benefits which are the same between PPP and traditional public procurements. Therefore, the PSC approach may not be the best first approach, but a cost-effective compromise between a full cost-benefit analysis of all project options, as in Germany, and simply selecting the best private bid, as in France (Grimsey & Lewis, 2005).

Secondly, objective assessment depends on the data availability and the quality of historical records. The history of PPP schemes is still young, and the life cycle of PPP projects is usually more than 20 to 30 years in length, so such data has not been accumulated. In addition, the PPP projects are usually unique with specific risks (Bloomfield et al., 1998; Dey & Ogunlana, 2004; Gerrard, 2001; Li & Zou, 2008). Therefore, some form of subjective assessment is necessary to some extent. Subjective judgment is also needed by officials to transform existing information into available forms for a specific PPP project (Dey & Ogunlana, 2004). In the event of computing with imperfect information, the likelihood and impact of risk can be assessed subjectively, but in a systematic manner, by incorporating the approaches such as group expert judgment and statistic techniques. Furthermore, undertaking sensitivity analysis to estimate PSC is a useful way of understanding the impact of changes in these variables on the overall project NPV (Guikema & Milke, 2003; Reilly, 2005; Tanczos & Kong, 2001). These methods will be discussed and illustrated by a case in Chapter 8.

Some researchers (Demirag, Dubnick, & Khadaroo, 2004; Pollock et al., 2005; Shaoul, 2002; Turner, 2002) argued using the PSC for VFM tests to focus on PPP projects in health sector, especially in the UK. In the PPP health and school projects in the UK, officials seem to achieve less reasonable efficiency gains than those for road and prison projects. Grimsey and Lewis (2005) drew conclusions from Allen (2001) for two reasons. First, unlike road projects, the core and ancillary for the PPP health projects in the UK remain segmented, perhaps reducing some of the potential for innovation. Second, for road projects there is a single government agency handling the contracting however in the health industry the private sectors must contact a number of bodies such as National Health Services (NHS) trusts and other governing councils.

However, there is no evidence to conclude the PSC for VFM testing will have bad effects on PPP health project performance. Actually, an updated statistics report (HM Treasury/UK, 2006a) by UK HM Treasury officials associated with UK Partnerships and 4PS companies has indicated that the various types of PPP projects, including health projects, can effectively meet VFM. This also shows that PSC is an important tool to ensure VFM, but ongoing improvement for the PSC and VFM tests is necessary.

2.4.3 Critics on Choice of the Discount Rate

The non-systematic risks are associated with only a particular asset, company, or segment of the market. They are known as specific risks because they exert an impact on specific components of the market. Examples of activities which can introduce specific risks to a particular company include the introduction of a new product, changes in management, etc. Since specific risks do not affect the entire market, investors that are affected by specific risks can diversify into a range of other activities in order to avoid such risks (Akintoye et al., 2001; Partnerships Victoria, 2003b).

On the other hand, the systematic risks are also known as non-specific risks, and concern changes in broad economic conditions that affect a whole market. Examples of market risks include changes in consumer spending, level of industrial output, interest rates, exchange rates, energy prices, high-impact weather effects, etc. Market risks affect all equities to some extent and cannot be completely avoided. An investor cannot avoid through a diversified portfolio of assets. Therefore, the investor will need to seek a premium where they are required to assume systematic risks. This risk premium increases the investor's cost of capital (Akintoye et al., 2001; Partnerships Victoria, 2003b).

The discount rate reflects the time value of money and the premium that is required by investors in the project to compensate them for the systematic risk inherent in the project, thereby converting future cash flows into equivalent present cash flows and allowing VFM to be measured between options on a consistent basis (NSWG, 2007).

NPV is often sensitive to the discount rates. Even small changes in application of the discount rate will probably change the outcome and the best bid for VFM (Grimsey & Lewis, 2005). The first argument is based on narrow and fiscal perspectives rather than broad and social perspectives of government (Watson, 2005). Some public authorities use their long-term borrowing rate as a proxy for the discount rate on the grounds that they will use additional borrowing to fund incremental expenditures (Grimsey & Lewis). It is the expected social benefit returns of the project and the risks associated with them, rather than the costs of debt for public or private financiers which determine the cost of capital (Partnerships Victoria, 2003b).

Another argument is that government officials should use a single discount rate. If government officials applied an average discount rate across all projects, this would benefit risky projects by demanding a return lower than their risk warranted, and undercut low risk projects by demanding excessive returns from them. Government officials would therefore over-invest in risky projects, and under-invest in low risk projects (Broadbent, Gill & Laughlin, 2003; Broadbent & Laughlin, 2003; Grout, 2003; Partnerships Victoria, 2003b). The PSC is based on the government reference project which assumes that all systematic risks inherent in the project are retained by government officials. The discount rate for PSC calculation is generally determined on this basis. In contrast, with a PPP delivery mechanism, systematic risks may be transferred to the private sector. Therefore, when the project is delivered in conjunction with the private sector party, government cash flows are likely to be subject to less systematic risk and uncertainty than the PSC. Broadbent et al. (2003) and Grout contended under these circumstances a higher discount rate should be used for the PPP than for PSC. Failure to do so will result in the overestimation of PPP NPV relative to PSC.

The UK central government officials have applied 3.5% in real terms before tax for social time preference rate (STPR) as the overall discount rate for future benefits and costs, as regulated in the revised *Green Book* (HM Treasury, 2003a). "The STPR is defined as the value society attached to present, as opposed to future, consumption"(HM Treasury, 2003a). This represents the rate that members of society are willing to pay for receiving something now rather than in the future. The formula of STPR is as follows:

$STPR\ (r) = \rho + \mu g$ (2.4.1)

Where ρ: the pure time preference rate (this is simply society's utility or preference for consumption now rather than in the future);

μ: the elasticity of marginal utility of consumption;

g: the annual growth per capita consumption (HM Treasury, 2003a).

Concerning the second argument, taking a direction different from the UK officials' approach that adopted an overall discount rate, the Victoria/Australia government officials developed a set of adjusted discount rates for bid evaluation, based on the *capital asset pricing model* (*CAPM*) (Partnerships Victoria, 2003b). A benefit of the *CAPM* approach is that that the cost of capital/discount rate recognized is specific to each project and is a function of risk for the specific project (Grimsey & Lewis, 2005). The formula of *CAPM* is shown (2.4.2)

$R_a = R_f + \beta_a(R_m - R_f)$ (2.4.2)

Where:

- R_a : the resulting discount rate (project rate), where the cost of capital of (or required return on) assets whose risk class is designated by the asset beta or systematic risk;
- R_f : the risk-free rate;
- R_m: market return;
- β_a: the asset beta, which reflects the degree to which asset returns (i.e., returns of a particular project) are expected to vary with returns of the market as a whole (for example, a well-diversified portfolio of assets or projects), otherwise known as the systematic risk. It is calculated as below:
  - $\beta_a = \delta_{am}/\delta_m^2$

    where:

    β_a is the beta for asset '*a*';

δ_{am} is the covariance of returns of asset 'a' compared to market returns;

δ_m^2 is the variance of market returns.

- R_m-R_f : the market risk premium (MRP) that an investor would expect to receive before investing in an asset exactly correlated with the market (Partnerships Victoria, 2003b).

For each project, an asset beta is determined, assuming that government officials are undertaking the project directly and retain all of the systematic risks inherent in the project. Theoretically, each project has a different level of systematic risk and therefore should have a unique asset beta. However, for the majority of projects, the marginal benefits from calculating a unique asset beta are outweighed by costs (Partnerships Victoria, 2003b). For this reason, the majority of projects have been categorized into three broad risk bands shown as Table 2.4.1 (Partnerships Victoria, 2003b). Each risk band has been assigned a beta value, assuming that government adopts all the systematic risk inherent in the project's cash flows.

Once the asset beta and project rate are developed, they are used to determine discount rates for PSC construction and bid evaluation. For the PPP projects which transfer material systematic risk to a private party, different discount rates should be used to calculate the PSC and to assess private sector bids, based on the level of systematic risks transferred to the private sector. The Australia Victoria government officials' discount rate methodology for PSC and bid evaluation depends on whether the government's net cash flows from the project are positive, that is net cash inflow, or negative, that is, net cash outflow (Partnerships Victoria, 2003b):

- Projects with net cash inflows: Where the net cash flows to the government are positive, a conventional use of *CAPM* is appropriate, that is, the higher the systematic risk inherent in government's cash flows, the higher the discount rate applied to those specific cash flows. The discount rate used to calculate the PSC is based on the assumption that government retains all the project's systematic risks. So, as shown in Figure 2.4.3 (Partnerships Victoria, 2003b), the resulting discount rate (R_a) is defined as the project rate. The discount rate used to assess private sector bids in such projects is calculated against systematic risks between government and the private sector. As government's cash flows will be subject to less systematic risk than estimated for the PSC, the beta calculated for the cash flows bid by the private sector will be less than the asset beta. Accordingly, as shown in Figure 2.4.4, the discount rate used by officials to assess the private sector bids will be reduced linearly relative to the project rate, depending on the proportion of the systematic risk transferred.

- Projects with net cash outflows: When calculating discount rates for net cash outflow projects, a more risky net cash outflow would be assigned a higher discount rate, resulting in a lower net present cost (*NPC*). This would make the higher risk project seem preferable to a lower risk project. Therefore, in ranking net cash outflow alternatives, the risk-free rate should be used to discount government's PSC cash flows, as shown in Figure 2.4.5 (Partnerships Victoria, 2003b). On the other hand, the transfer of more systematic risk to the private sector represents a better outcome for government (PSC is better than bids). Therefore, for discounted cash flow analysis, a higher beta and a higher discount rate should apply to government's net cash outflows where the greater systematic risk is transferred to the private sector. The higher discount rate results in a lower NPC (i.e., a higher NPV) to government. Conversely, lower risk accepted by the private sector is a less preferable outcome for government. The lower discount rate leads to a higher NPC (i.e., lower NPV) to government. As shown in Figure 2.4.4, the discount rate used to assess the private sector bids will be increased linearly from the risk-free rate, depending on the proportion of the systematic risk transferred.

These two approaches used to setting the discount rate between UK and Australia governments appear to be different, but the underlying principle is the same for both. The UK officials' STPR model is only for risk-free discount rates, whereas the Australian officials' CAPM model reflects project risk. The choice of discount rate depending on risk allocation of a specific project provides professionals with a more systematic way to analyze discounting cash flow, because discount rates are generally very sensitive to the outcomes (NPV).

In practice, accuracy of the discount rate calculation will yield marginal benefits unless the cash flows can also be forecast to the same degree of accuracy. For most PPP projects, this will likely prove time-consuming, and for minimal gain (Heald, 2003). To minimize the bias on discounting cash flow analysis due to the variability of discount rates, a sensitivity analysis should be performed by changing discount rate variables for project rate to the risk-free rate for discount cash flow analysis to amend bid evaluation.

Table 2.4.1 Broad Risk Bands for PPP Projects(Partnerships Victoria, 2003b)

Risk band	*Project sectors* and example projects	Asset beta	Real risk premium*	Real discount rate**
Very low	***Accommodation and related services*** Aged care housing Public housing Hospital facilities Correctional facilities	0.3	1.8	5.0% (4.8% rounded to nearest whole number)
Low	***Water, transport and energy*** Wastewater treatment plants Water infrastructure Hospital car parking Hospital energy plants Road projects (non-toll)	0.5	3.0	6.0%
Medium	***Telecommunications, media and technology*** Entertainment Telecommunications and IT Knowledge economy	0.9	5.4	8.0% (8.4% rounded to nearest whole number)

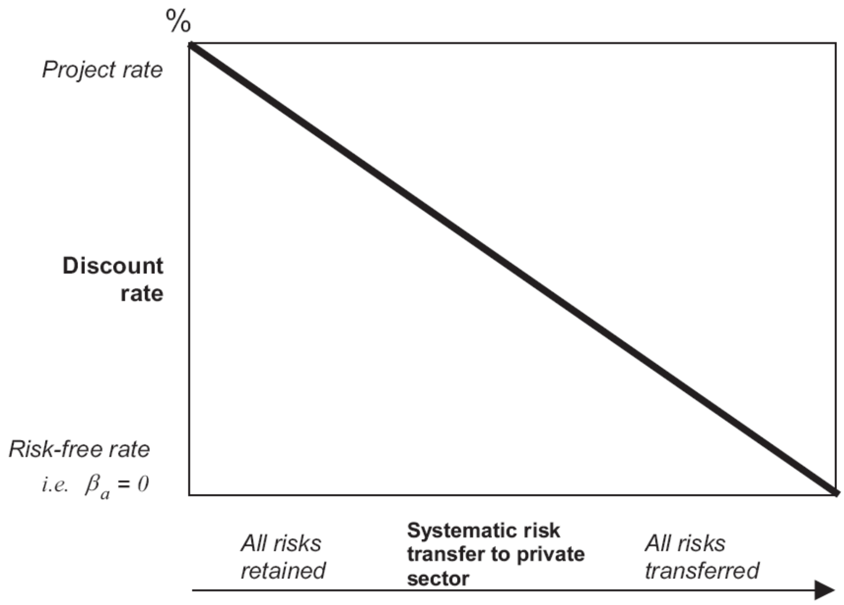


Figure 2.4.3 Discount Rate Calculation: Net Cash Inflows to Government(Partnerships Victoria, 2003b)

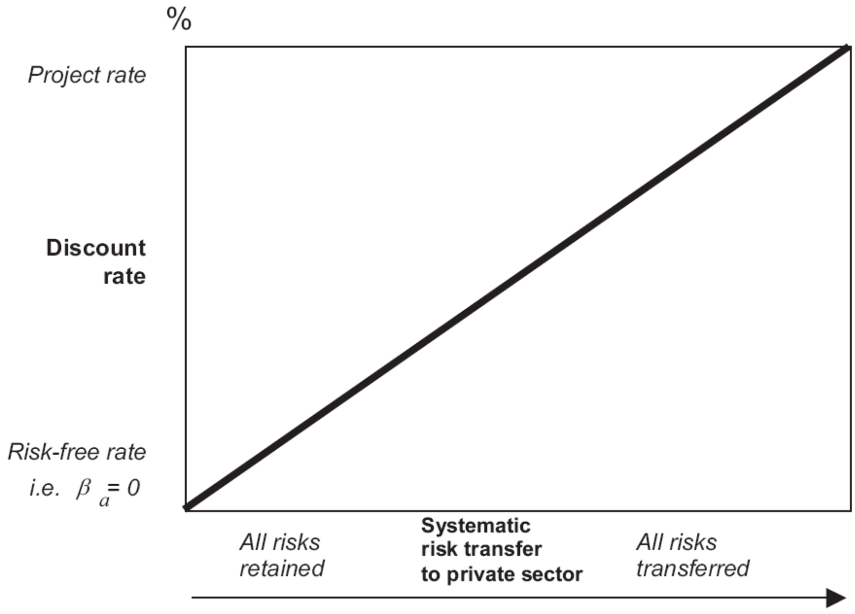


Figure 2.4.4 Discount Rate Calculation: Net Cash Outflows to Government (Partnerships Victoria, 2003b)

2.4.4 Critics on Uncertainty and Optimism Bias

There are two components of uncertainty included in the risk distribution: the inherent uncertainty in the risk variable itself, and the uncertainty arising from the expert's lack of knowledge of the risk variable (Partnerships Victoria, 2003a). This uncertainty is more important than risk, especially for risk transfer that is key element in VFM tests for the PPP-PSC bid comparison (Grimsey & Lewis, 2004, 2005; Shaoul, 2005). "Not only is uncertainty a palpable tension but turbulent events burst out and interact."(Miller & Lessard, 2000) This means the longer the project life cycle, the higher the probability that the project will be affected by emergent events. The VFM is projected at the point of PSC comparison, and actual outturn costs may differ from those projected by the PSC. When these costs fall well below the level of projections, then VFM will not be maintained. Most large-scale PPP contracts span 20 to 30 years minimum. Over a long period, the impact of cost projections on the public sector could be significant (Grimsey & Lewis, 2005). Significant uncertainties of risk impacts should be defined (Reilly, 2005).

Shaoul (2005) stated that the measurement and methodology of risk transfer for PPP-PSC bid comparison is problematic because all possible outcomes cannot be predicted and weighted. Grimsey and Lewis (2005) maintained that at a practical level governments officials traditionally do not budget well for systematic risks or uncertainty, and consequently PSC calculations only contain project specific risks, never accounting for error. The public sector might be able to ignore uncertainty across a portfolio but bidders for a PPP project cannot ignore such uncertainties.

A study conducted by officials of the Washington Department of Transportation (WSDOT) found that recognition of a future cost estimate to involve substantial uncertainty was almost never realized. This will cause significant cost overrun if the uncertainty is ignored in the cost estimating process (Reilly, 2005; Reilly & Brown, 2004; Reilly et al., 2004). There are substantial and costly biases in many cases. For example, the Boston, Massachusetts's artery/tunnel project in the US had 196% of cost overrun; the Great Belt rail tunnel in Denmark had 110% cost overrun; the Channel tunnel in the UK and France had 80% cost overrun; the Oresund link, in Denmark had 70% cost overruns (Flyvbjerg et al., 2003a; Flyvbjerg et al., 2003b; Flyvbjerg et al., 2004). Among the large-scale projects, the Apollo Aerospace program in the United Stated was successful in that there was only 5% cost overrun based on USD \$21 billion budgeted. This is because the cost estimates by officials were based on the realism of risks, costs, and contingencies. Officials' original budget estimate included \$8 billion of contingencies (Flyvbjerg et al., 2003a).

"Optimism bias is the demonstrated systematic tendency for appraisers to be over-optimistic about key project parameters, which can arise in relation to capital costs, works duration, operating costs, under delivery of benefits, etc." (HM Treasury, 2003c) Optimism bias is represented as Formula (2.3.3) (Mott MacDonald, 2002):

$$Optimism\_bias = 100 \times \frac{(Actual - Estimated)}{Estimated}\% \quad (2.4.3)$$

Mott MacDonald (2002) indicated that optimism bias is caused by a failure to identify and effectively manage project effects of uncertainty. Additionally, optimism bias for a project decreases through its project life-cycle. The Torpedo diagram, as shown in Figure 2.4.5 (Partnerships Victoria, 2003a), indicates these effects of uncertainty. For early estimates, the typical average deviation (confidence range) is larger than in definite estimates made when design is complete and the project fully defined (Schexnayder, Weber & Fiori, 2003). Because the estimator always lacks complete information, estimates always incorporate some uncertainty. Uncertainty is greatest during the early project stages (e.g. the preliminary assessment stage in the Torpedo diagram). Ideally, as the project progresses, the strategies for risk mitigation and management would be in place and the potential for certain project risk areas is likely to decrease with time. For example, Figure 2.4.5 showed that the step-down between the PSC and the PV contract (the PPP contract of Victoria/Australia government) represented the VFM outcome (the confidence range of outcome was narrowed) through bids competition and negotiation, although there is some uncertainty associated with the retained risks. Final outturn cost would be unknown until the contract is awarded. It is therefore important to recognize that probabilities and uncertainties in cost prediction vary during the project procurement process and so do the measures of likely cost outcome and variability (Schexnayder et al., 2003).

"The information to estimate the expected values of costs, revenues, and effects, and the most likely development, including the associated variances is required to give decision makers a more realistic view of the likely outcome of projects, instead of the incomplete and misleading view on which decisions are often based today" (Flyvbjerg et al., 2003a). To minimize inherent optimism bias, making empirically based adjustments to the estimates of a project's costs, benefits, and duration is recommended (HM Treasury, 2003a, 2003c; Schexnayder et al., 2003). For example, two empirical studies based on the data from past similar projects have been carried out by Mott MacDonald and Dr Bent Flyvberg. Table 2.4.2 (Mott MacDonald, 2002) and Table 2.4.3 (Flyvbjerg, 2004) shows the adjustment ranges for the estimates of cost and/or time overrun for different categories of projects. Dr Flyvjberg presented different percentiles for probability distribution of optimism bias. In addition, researchers in the PWC study (PWC, 2002) showed that taking account of various factors the rate of return bids seems to be 1.7% above what one would expect, given the benchmarks used. All of them provide valuable references for the estimation of risk factor probability distribution.

Furthermore, the Monte Carlo simulation is currently regarded by professionals as a powerful technique in analyzing cash-flow problems. It is useful when there are many variables with significant uncertainties (Reilly, 2005). The more complex the project and the more risks and uncertainty that are associated with it, the more valuable will be the Monte Carlo analysis (Dey & Ogunlana, 2004; Stahr, 2006). There are two methods of determining the distribution of individual variables entering the NPV calculation. One method is based on fitting a distribution to the historical data of the variable. If historical data is not applicable or not available, then expert assessment is utilized, as described above (Stahr, 2006; Watson, 2005).

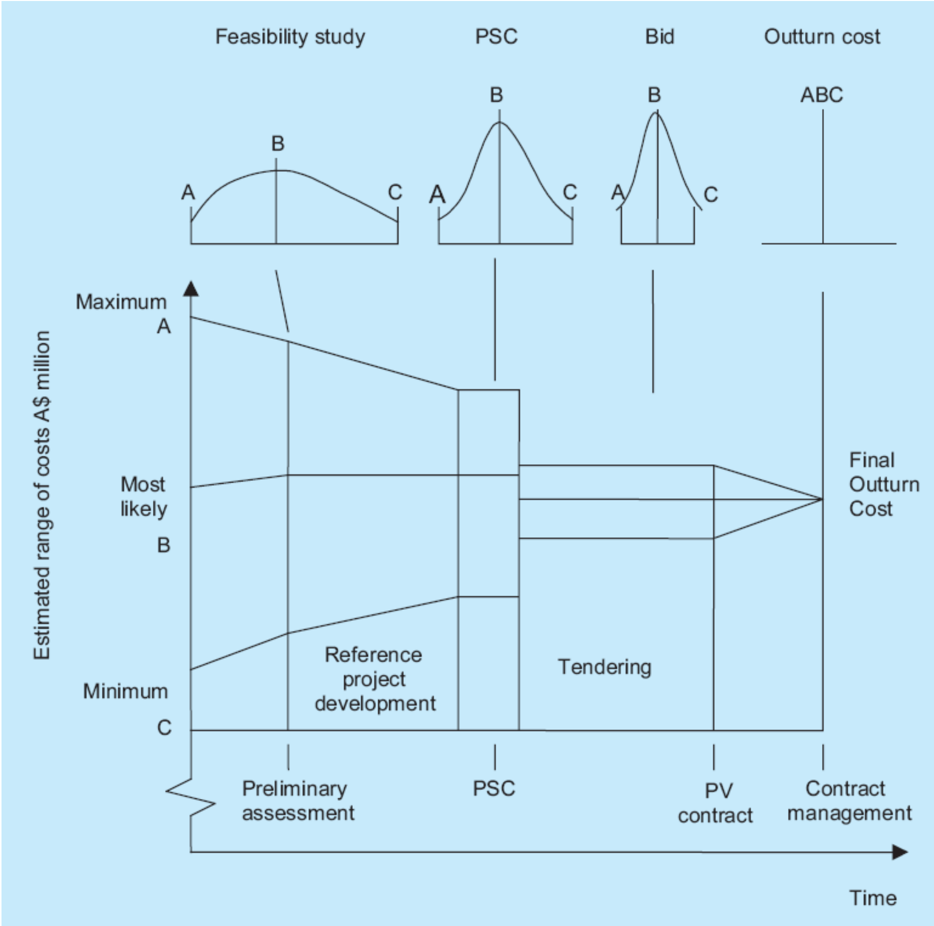


Figure 2.4.5 Torpedo Diagram Concerning Risk Analysis and Management

Table 2.4.2 Recommended Adjustment Ranges for Different Categories of Projects (Mott MacDonald, 2002)

Project Type	Optimism Bias (%)²			
	Works Duration		Capital Expenditure	
	Upper	Lower	Upper	Lower
Standard Buildings	4	1	24	2
Non-standard Buildings	39	2	51	4
Standard Civil Engineering	20	1	44	3
Non-standard Civil Engineering	25	3	66	6
Equipment/Development	54	10	200	10
Outsourcing	N/A	N/A	41*	0*

Table 2.4.3 Recommended Adjustment Ranges for Transport Projects (Flyvbjerg, 2004)

Category	Types of projects	Applicable optimism bias uplifts				
		50% per-centile	60% per-centile	70% per-centile	**80% per-centile**	90% per-centile
Roads	Motorway Trunk roads Local roads Bicycle facilities Pedestrian facilities Park and ride Bus lane schemes Guided buses on wheels	**15%**	24%	27%	**32%**	45%
Rail	Metro Light rail Guided buses on tracks Conventional rail High speed rail	**40%**	45%	51%	**57%**	68%
Fixed links	Bridges Tunnels	**23%**	26%	34%	**55%**	83%

2.4.5 Critics on the Bids Comparison

A critical argument by professionals and analysts is that VFM usually reduces a choice between two very large net present values, with the small difference between them reliant on the risk transfer calculations included in the PSC. Minor changes in the underlying assumption will cause the model to give completely different results (Grimsey & Lewis, 2005). Choosing whether the best VFM option is a single number or a range of NPV values is essential. For example, the preferred bidder in the building project of Ministry of Defense (MoD) in the UK had offered a price slightly below the cost of PSC and was spuriously accurate. As shown in Figure 2.4.6 (NAO, 2002), the PPP bid price is £746.1 million and the expected PSC value is £746.2 million. Based on the point estimate, the PPP deal was accepted since it was lower than the expected PSC value. On the other hand, the range of PSC values ranges from £690m (the 2.5th percentile of PSC distribution) to £807m (the 97.5th percentile of PSC distribution), falling within the 95% confidence level with 5% chance that actual cost would fall outside of this range. Based on the 95% confidence interval, there is no significant evidence to accept the PPP deal, since it falls within the range of PSC. For this reason, the HM Treasury (UK) officials drew the conclusion, "recent NAO's (National Audit Office, UK) reports have highlighted that in some instances the related Procuring Authorities had treated the PSC as a single pass/fail test to justify the choice of a PPP procurement route, and potentially striven for spurious accuracy…, suggesting that public sector managers should in future ensure that value for money decisions are not based on one-dimensional comparisons of single figures" (HM Treasury, 2003b). Ye and Tiong (2000) wrote that current practices for bids comparison ignore the outcomes dispersion and depend on deterministic outcomes only. The officials at the Washington Department of Transportation (USA) showed that it was necessary to move from single value cost estimates to ones that are valued as ranges of probable cost for infrastructure projects (Reilly, 2005; Reilly & Brown, 2004; Reilly et al., 2004;).

Full statistical analysis of outcomes using the Monte Carlo simulation, incorporating sensitivity analysis and worst/best case scenario analysis, gives more realistic risk analysis and representation in terms of range (confidence intervals) of possible outcomes, and provides the most detailed comparisons (Akintoye et al., 2001; Grimsey & Lewis, 2005; Stahr, 2006; Watson, 2005). Based on these facts, officials using the VFM comparison between the PSC and PPP bids should consider a range of potential outcomes for PPP procurement. This spread of values (outcome dispersion) highlights the volatility of the project and introduces risk exposure to VFM evaluation. Nevertheless, some methods such as mean-variance, Stochastic dominance and expected-loss ratio were developed to account for dispersion of outcomes of multiple risky projects ranking.

The mean-variance rule applies only two criteria. The mean-represented outcome and variance (risk) is a scalar measure of variability of outcomes (Oryczak, 2000). If Bid A has an expected NPV (ENPV) the same as or higher than that of Bid B, and has a lower variance of NPV (VNPV) than B, Bid A is preferable; If Bid A has a ENPV the same as or lower than that of Bid B, and a higher VNPV than B, Bid A is the better option. As shown in the Figure 2.4.7 (Park & Sharp-Bette, 1990), the efficiency frontier is a curve drawn through the points representing bids that are not dominated by some other project. Any point below and to the right of the efficiency frontier represents a bid dominated by one on the frontier (Park & Sharp-Bette). Bid A and Bid C dominate both Bid B and Bid E, since they have higher ENPV and lower VNPV than Bid B and Bid E. But both Bid A and Bid C fall on the efficiency frontier; they don't dominate each other. The strategy to choose Bid A and Bid C is subject to decision-makers' risk preference (risk-averse, risk-neutral, or risk-seeking).

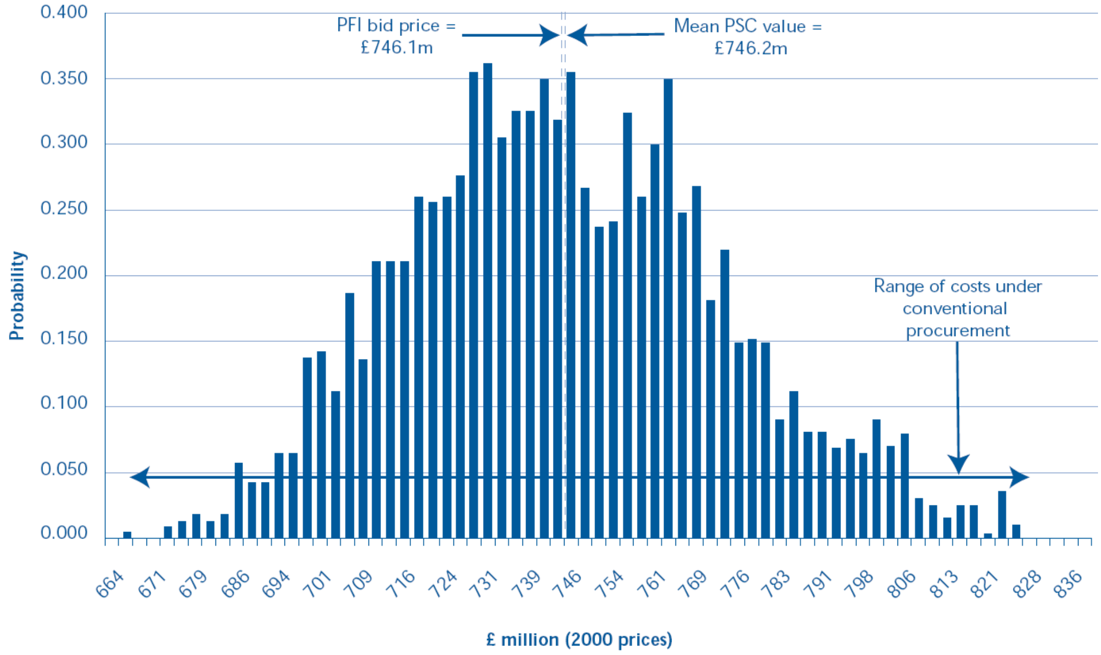


Figure 2.4.6 The PSC Distribution and PPP Bid Price(NAO, 2002)

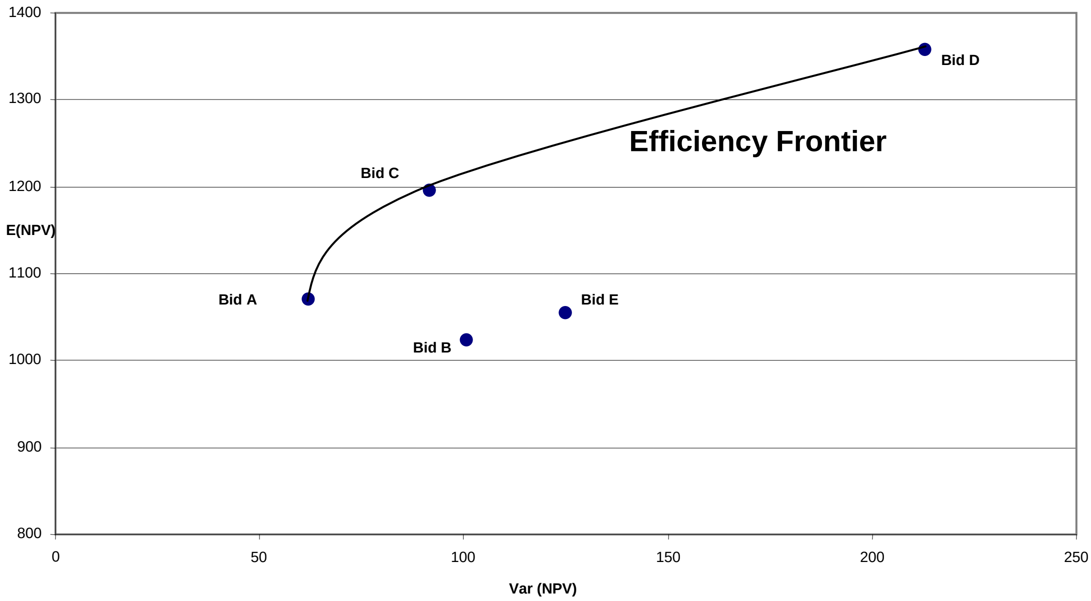


Figure 2.4.7 Mean-variance Plot for Bid Comparisons(Park & Sharp-Bette, 1990)

However, the mean-variance rule has shortcomings in that if the outcomes are not distributed normally, the model solutions may become unreliable. "Typical dispersion statistics used as risk measures may lead to some efficient solutions, stochastically dominated by other feasible solutions (Oryczak, 2000)."

Stochastic dominance is used to analyze mutually exclusive projects by comparing their entire cumulative distribution of possible outcomes (Oryczak, 2000). As shown in Figure 2.4.8 (Watson, 2005), the probability that any specified positive NPV of Bid B exceeds that of Bid A. The decision maker should always prefer Bid B over Bid A. As shown in Figure 2.4.9 (Watson, 2005), the cumulative probability distribution curves for Bid A and Bid B intersect. Therefore, the comparison is guided by the expected NPV. If the ENPV numbers are similar, the risk profile of each bid should be considered. The *risk-adverse* decision-makers might be attracted by the possibility of lesser loss and will therefore be inclined to choose Bid A. On the other hand, the *risk-seeking* decision-makers will be attracted by the possibility of higher return and therefore might choose Bid B.

Stochastic dominance is superior to mean-variance in that it shows a complete picture of uncertainty, and also accounts for extreme values (Oryczak, 2000). However, the Stochastic dominance computationally is very difficult especially second-degree and third-degree Stochastic dominance. (Oryczak, 2003).

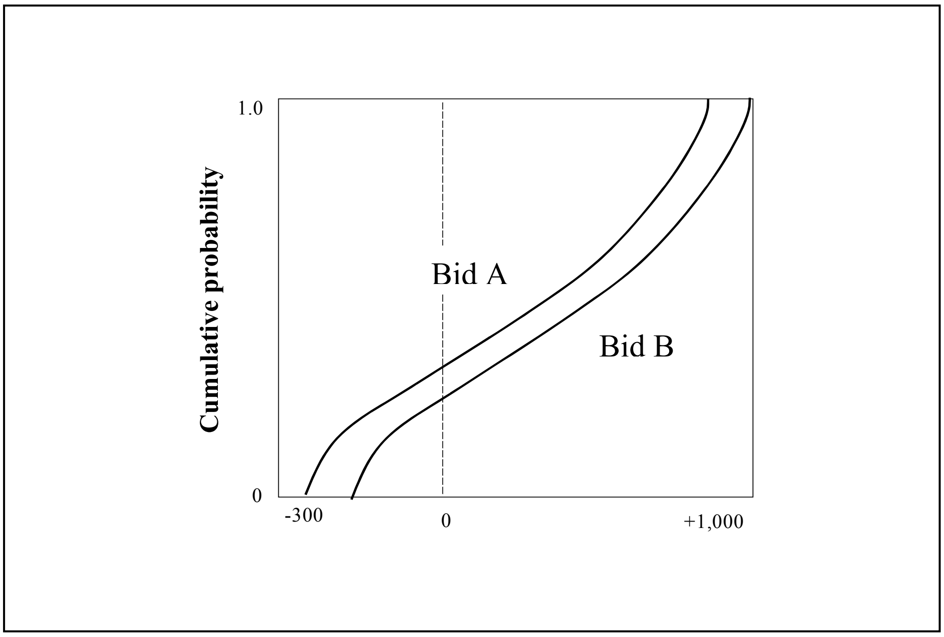


Figure 2.4.8 The NPV Cumulative-probability Distribution Curves for Two Bids Comparison (Watson, 2005)

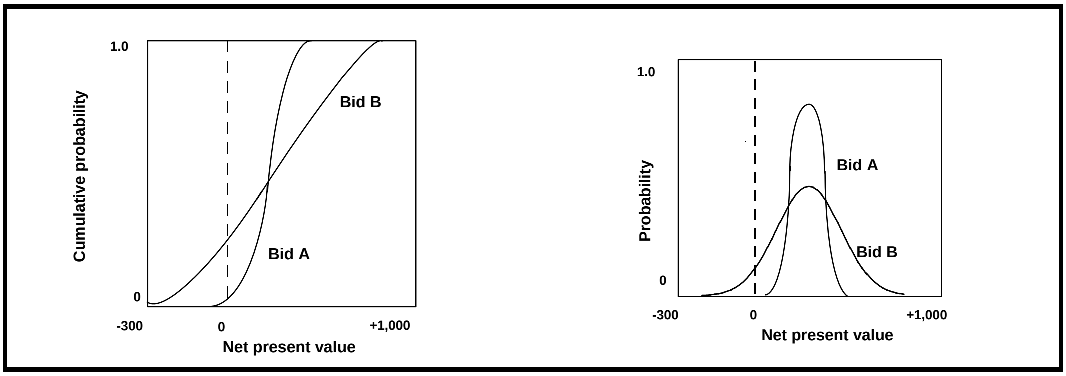


Figure 2.4.9 : The Intersected Curves of Cumulative-probability Distribution for Two Bids (Watson, 2005)

One measure that is particularly useful in summarizing of the overall level of risk in public investment is the expected-loss ratio (ELR), which refers to (Limbu et al., 2006; Stahr, 2006; Watson, 2005):

$$ELR = L/(L+G) \quad (2.4.4);$$

Where L: the probabilities of *the expected loss;*

G: the probabilities of *the expected gain;*

As shown in Figure 2.4.10, the expected value of all losses (L) is defined as the proportion which equates to the area B under NPV probability distribution that is less than 0 or any specified value used to define loss. The expected value of gain (G) is defined as the proportion under NPV probability distribution that is greater than 0 or any specified value that is used to define loss. The area A shows all possible NPV values which are under the curve of the NPV probability distribution. This denotes the area A = L+G.

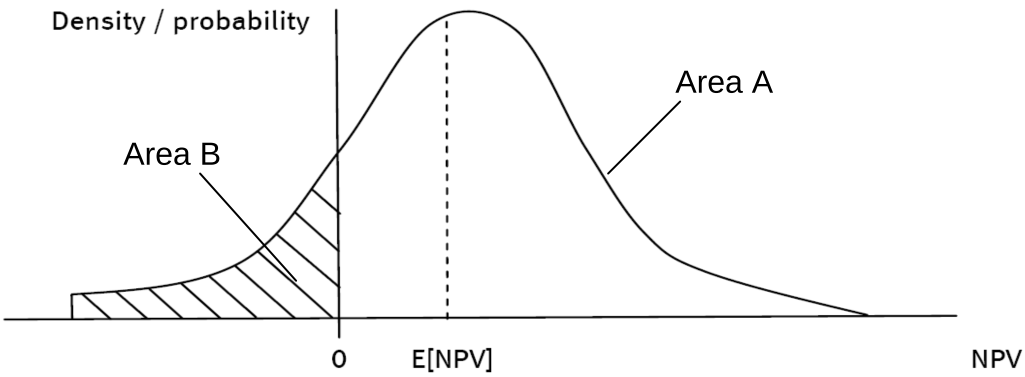


Figure 2.4.10 The Display of the Expected –Loss Ratio(Stahr, 2006)

Deciding which methods are appropriate to compare PSC and bids depends on the outcome distribution and the risk utility (risk-averse, risk-neutral, or risk seeking) of the project client to select a preferred bidder. If outcome distribution is normal distribution, a combination of mean-variance/mean-semi-variance, Stochastic dominance, and the expected-loss ratio for multiple-checking bids ranking can ensure the selection of the preferred bidder. If the outcome distribution is not normal distribution, the Stochastic dominance and the expected-loss ratio are more applicable than the others.

Chapter 3 Research Methodology

3.1 Research Questions

The research issues with regard to bid evaluation for PPP procurement are summarized in Table 3.1.1, which references material from the literature review discussed in the Chapter 2. As shown in Table 3.1.1, the *Argumentation* column summarizes the discussion about what issues have been resolved and remain unresolved. The *Research gaps* column shows the unsolved issues and the corresponding research actions. The research gaps will be then converted into the research questions in order to arrive at a solution.

From Table 3.1.1, seven research questions were produced. These research questions are:

1. What are the generic risk events inherent in the PPP transport projects over project life?
2. How can the risk interdependencies and interactions be modeled over the PPP transport project life cycle?
3. How can the qualitative effects be converted into quantitative effects while using CBA to analyze NPV for the PPP transport projects?
4. How can the risk interrelationships be quantified?
5. How can the probability distribution for risk effects be estimated?
6. How can the probability distribution of project NPV be estimated with overall compounding downside and beneficial effects over project life?
7. What are the suitable methods that can be used to compare the NPV range values among bidding proposals to choose a preferred bidding proposal?

Table 3.1.1 The Issues Learned from the Literature and Their Corresponding Argumentation, Research Gaps, and Research Questions

Issues learned from the literature	Argumentation	Research gaps	Research questions
1. Are risks independent? How can the relationship of risks be identified if they are not physically independent?	As the literature review discussed in Chapter 2, the risks may not be independent in reality.	There is a need to investigate which risks would have impact over PPP project life, and to model their physical interaction effects on project so that we can estimate risk costs accurately.	1 What are the generic risk events inherent in the PPP projects over project life? 2 How can we model the risk interrelationships of the PPP projects?
2. Is there a general failure to estimate risk costs and uncertainty in the mega transport projects? Should Cost-Benefit Analysis (CBA) or Cost-effectiveness Analysis (CEA) be applied to evaluate VFM for PPP bidding proposals? Which one is appropriate?	As discussed in Chapter 2, the estimation for risk costs and uncertainty is not dealt with well for the mega transport projects. Either CBA or CEA approach has its own advantages and limitations. The CEA is a cost-minimization and a very useful tool for both project screening and project ranking (Watson, 2005). However, CEA with multi-criteria decision making (MCDM) causes more often the corruption or other failure issues in practice since it's very subjective when the committee members of bid-evaluation make a rating for each criterion (Lebo & Schelling, 2001). On the other hand, CBA attempts to quantify benefits and costs in money terms as far as possible (Watson, 2005), which is an important tool for socio-economic assessment of government projects and policies. In general, the CBA takes advantages over the CEA for the PSC-based bid-evaluation. That's because the estimates for the broader benefit effects like social benefits can be omitted from the CBA approach since they are the same while comparing NPV for the PPP procurement with the traditional public procurement (the PSC) (Grimsey & Lewis, 2005). Furthermore, there is the widely belief that the transport investment impact are mainly economic in nature and should be measured (Mackie et al., 2003). However, the major challenge for the CBA is to convert qualitative risk effects in non-monetary term into quantitative effects in monetary term.	There is a need to convert qualitative risk effects in non-monetary term into quantitative effects in monetary term and estimate effect probability when we apply CBA to evaluate VFM for the PPP bidding proposals.	3 How can we quantify the qualitative risk effects (see section 6.2), while using CBA for cash flow analysis? 4 How can we quantify physical risk interrelationships?

2. What are the criteria that are useful to evaluate and compare bidding proposals under BCA approach?	As the literature review discussed in Chapter 2, when we apply CBA as the economic appraisal approach to estimate cash flow for PPP bidding proposals, the NPV is a much more reliable decision rule than Internal Rate of Return (IRR), Benefit-cost Ratios (BC ratios), and Payback Period when we compare VFM for PPP bidding proposals for a risky project (Ye & Tiong, 2000; Watson, 2005).	None	None
3. Is preparing the PSC (Public Sector Comparator) costly?	As the literature review discussed in the Chapter 2, the PSC approach may be itself not a first best approach but a cost-effective comprise between a full cost-benefit analysis of all project options and simply selecting the best private bid (Grimsey & Lewis, 2005). The estimate costs for the PSC are therefore not supposed to be a research question in the research. The research uses the PSC approach for bid evaluation.	None.	None.
4. Is the PSC is so subjective that it can be easily manipulated?	As the literature review discussed in the Chapter 2, the current risk cost estimates usually ignore outcomes uncertainty. It ignores the outcomes dispersion and depends on deterministic outcomes only. Minor changes in the underlying assumption will cause the model to give completely different results (Grimsey & Lewis, 2002, 2005; Ye & Tiong, 2000). Therefore, the PSC in terms of risk cost estimates is supposed to be so subjective that it can be easily manipulated (Blyth, 2002; Turner, 2003; Shaoul, 2005). It is necessary to move from 'single value' estimates to 'range values' estimates for PPP infrastructure projects (Grimsey & Lewis; Reilly, 2005; Reilly & Brown, 2004;).	There is a need to apply appropriate methods that are able to measure the probability distribution of risk variables.	5 How can we estimate probability distribution of risk effects?
5. Are the discount rates applied properly and consistently when the cash flow analysis is performed to estimate NPV for comparing the PSC with bidding proposals?	As discussed in Chapter 2, there is a need to apply the different discount rates for the PSC and PPP bidding proposals respectively so that the discounted cash flow for them can be analyzed consistently since they have different risk allocation (Broadbent et al., 2003; Grount, 2003). However, the current literature has discussion about how to calculate the different discount rates that are appropriate and consistent when the discounted cash flow analysis is performed to estimate NPV for comparing the PSC with bid proposals.	None.	None.

6. Should a single number or a range of NPV values be examined to choose the preferred bidding proposal with the best VFM?	As discussed in Chapter 2, basing on a range of NPV values than a single NPV value is more reliable to evaluate VFM for PPP options, since a range of NPV values highlight the NPV volatility and introduce risk exposure into VFM evaluation for selecting the preferred bidding proposal (Akintoy et al., 2001; Reilly & Brown, 2004; Stahr, 2006).	Thus there is a need to estimate the probability distribution for project NPV with overall downside and beneficial effects over time. Moreover, there is a need to find appropriate methods to make a consistent decision-making among the different ranges of NPV values for selecting the preferred bidding proposal.	6 How can we estimate the probability distribution of an overall project NPV with compounding downside and beneficial effects over project life? 7 What are the suitable methods that we can compare the NPV range values between bidding proposals to choose a preferred bidding proposal?

3.2 Research Strategy

As shown in Figure 3.1, the researcher utilized multi-strategy research to combine a single case study incorporated with quantitative and qualitative research strategies as the overall research strategy. In the following subsections, the view of points of using multi-strategy and single case study as the overall research strategy are discussed. Individual research strategies and methods for each question are also discussed.

3.2.1 Multi-Strategy Research

Bryman (2001) contended that a research strategy can be used to form two distinctive clusters: quantitative and qualitative research. If researchers focus on the connection between theory and research and between epistemological and ontological considerations, this will suffice. In Table 3.2.1, the researcher outlined the differences between quantitative and qualitative research in these three areas. In the quantitative research strategy, the researcher emphasizes quantification in collecting and analyzing data. In principal orientation, the researcher applies a deductive approach to test theories; in epistemological orientation, the researcher bases on a positivist approach inherent in the national sciences; in ontological orientation, the researcher embodies a view of reality as an external, objective reality. Alternatively, in the qualitative research, the researcher emphasizes words rather than quantification in collecting and analyzing data. In principal orientation, the researcher applies an inductive approach to generate theories; in epistemological orientation, the researcher rejects positivism by relying on individual interpretation of reality; in ontological orientation, the researcher embodies a view of reality as a constant projection of individuals' perception of creation.

Table 3.2.1 Fundamental Differences between Quantitative and Qualitative Research Strategies (Bryman, 2001)

	Quantitative	Qualitative
Principal orientation to the role of theory in relation to research	Deductive; Testing of theory	Inductive; Generation of theory
Epistemological orientation	Natural science model; Positivism	Interpretivism
Ontological orientation	Objectivism	Constructionism

However, there have been many arguments that the above research is based on the philosophical and unprofessional orientations. Bryman (2001) contended that research methods cannot be determined straightforward from the stance of epistemology or ontology since the distinguishing features between quantitative and qualitative research is ambiguous. Bryman wrote that qualitative research has been employed by researchers in many studies to test rather than generate theories, or to both test and generate. Bryman criticized that the contrast between natural and artificial settings for qualitative and quantitative research is frequently exaggerated. Payne and Payne (2004) also contended that the logical consistency of philosophical orientations and research strategies and methods are easily over-emphasized. They said of Platt's study of American sociology that, "general theoretical/methodological stance are just stances: slogans, hopes aspirations, not guidelines" (Platt, 1996). Furthermore, Walliman (2006) pointed out that the distinctions between quantitative and qualitative research are helpful in describing and understanding reality, and are not necessarily mutually exclusive. In these studies, these researchers Bryman, Payne and Payne, and Walliman concluded that the conditions listed in Table 3.2.1 do not fit many examples of reality. It is normal for many examples of research that combine both of quantitative and qualitative research strategies to examine different aspects of research problem. Quantitative research can be carried out from an interpretivist perspective, just as qualitative research can be carried out from the perspective of natural science. Quantitative methods have been used in some qualitative research and qualitative studies can be carried out using the opposite approaches.

Hammersley (1996), Morgan (1998), and Bryman (2001) promoted the multi-strategy research that combines both quantitative and qualitative methods. Hammersley proposed three types of multi-strategy research which included: *facilitatio*n referring to using one research strategy to aid another research strategy; *complementarity* referring to the use of both quantitative and qualitative strategies to investigate different aspects of research; *triangulation* referring to the use of quantitative research to validate qualitative research findings or vice versa. Morgan proposed four possible types of research strategies that were based on two dimensions of criteria which are defined as: *priority* referring to the decision to use either quantitative or qualitative approaches for gathering data; *sequence* referring to priorities and logic in the research process. Bryman developed a variety of research strategies by combining Hammersley and Morgan's propositions.

The objective of the thesis research is to develop a theoretical approach that is able to solve the common issues of the current PPP project concessionaire selection methods. The developed theoretical approach can build a decision support model that is specific to a particular PPP project for the public sector to choose a concessionaire which is capable of creating value for money. It investigates different aspects of a phenomenon for the research, which includes determining which risk factors will affect NPV for the PPP projects, interpreting the risk interactions over time, measuring and analyzing the overall risk effects on net present value over project life cycle, and developing the theoretical method for bids selection. It is necessary to employ the multi-strategy research that combines quantitative and qualitative research with different priorities and sequence, as the previously proposed by Hammersley (1996), Morgan (1998) and Bryman (2001). They will be further described in the following sections.

3.2.2 Questions Oriented Strategies

As shown in Table 3.2.2, Yin (2003) proposed five major research strategies: experiments, surveys, archival analysis, histories and case studies; and developed a method to determine when to use each strategy. Three conditions should be considered: (a) the type of research questions, (b) the extent of control a researcher has over actual behavioural events underlying each and (c) the degree of focus on contemporary as opposed to historical events.

Table 3.2.2 Relevant Situations for Different Research Strategies (Yin, 2003)

Research Strategy	Form of Research Question	Requires Control of Behavioural Events	Focuses on Contemporary Events?
Experiment	What? How? Why?	Yes	Yes
Survey	What? Who? Where? How many? How much?	No	Yes
Archival records	What? Who? Where? How many? How much?	No	Yes/No
History	What? How? Why?	No	No
Case Study	What? How? Why?	No	Yes

The basic types of research questions have been generally categorized as who, what, where, how, and why. (Hedrick, Bickman, & Rog, 1993 as cited by Yin, 2003) As for what questions, Yin pointed out that there will be two possibilities. First, some types of what questions are exploratory. It would be a justifiable to conduct an exploratory study to develop pertinent hypotheses and propositions for further inquiry. For the first type of what questions, any of the five research strategies can be used, for example, an exploratory survey, an exploratory experiment, or an exploratory case study. Secondly, some types of what questions are in form of a, how much or how many line of inquiry. Identifying such outcomes is more likely to favor survey or archival records analysis strategies than others. For example, a survey can address the what questions. Yin wrote that how and why questions are more explanatory than others, because such questions "deal with operational links needing to be traced over time rather than mere frequencies or incidence." Thus, studies, histories, and experiments are preferred strategies for how and why questions.

As shown in Table 3.2.2, further distinctions among various research strategies reflect the extent of the researcher's control over behaviour and the degree of focus on contemporary events. For example, histories are a preferred strategy for how and why questions when there is virtually no access or control because the historical methods deal with past events. Often there are no relevant people remaining alive from that historical period to testify. Thus, evidence that relies heavily on primary documents, secondary documents, and cultural and physical artifacts is useful here. On the other hand, the case study method is preferred when the relevant behaviour cannot be manipulated in any other manner than examining contemporary events. Even though case studies and history strategies can overlap, case study is more advantageous than historical methods in dealing with a full range of evidence sources such as documents, artifacts, interviews and observations. Historical methods are limited in this manner. Finally, Yin (2003) demonstrated that the experiment strategy is complete "when an investigator can manipulate behaviour directly, precisely, and systematically".

Yin (2003) concluded that "even though each strategy has its distinctive characteristics, there are large overlaps among them" Yin further stated that, "to some extent, the various strategies are not mutually exclusive". Yin even suggested that multiple strategies can be applied to any given study. For example, a survey can be applied within a case study or a case study within a survey.

Based on data in Table 3.2.1 and Table 3.2.2, the researcher developed research strategies and methods for each research question as well as the rationales to explain why the particular strategies and methods were used (Table 3.2.3).

Table 3.2.3 Research Strategies for Each Research Question

Research question 1	What are the generic types of risks inherent in the PPP transport projects over project concession period?
Research strategy	Qualitative research
Research method	Literature survey incorporates descriptive analysis
Rationales	This is a What question to explore the phenomena of generic types of risk events that are currently inherent in the PPP transport projects. The current empirical studies have investigated this phenomenon by case studies, statistic analysis and descriptive analysis. There is no researcher access to or control of actual phenomena. As discussed in Table 3.2.2, the survey and archival record analysis are preferred research strategies. However, to explain the meaning of nature of generic risk events is different from individual to individual. A qualitative research strategy with the literature survey and descriptive analysis are applicable to the research question. A literature survey was conducted to collect the secondary data from the previous empirical studies that have explored and interpreted the generally and commonly recognized risk factors and events in the PPP transport projects. The researcher reorganized and defined a set of the generic types of risk factors and events over the whole PPP transport project life cycle from the collected secondary data based on the researcher's own rational interpretation.

Research question 2	How can the risk interdependencies and interactions be modeled over the PPP transport project life cycle?
Research strategy	Qualitative and quantitative research
Research method	Literature survey, interview survey, and questionnaire survey, computer-aided cause-effect modelling and statistic analysis.
Rationales	This is a How question to explain the phenomena about the cause-effect for risks and their interactions over the PPP project life cycle, and a How much question used to measure the phenomenon of physical risk interaction effects. There was no researcher access to or control over actual phenomena. However, these phenomena were perceived to be very dynamic and complex so that they were supposed to be difficult to be directly observed, investigated, traced and explained by nature laws, but rather they are able to be explored and learned from the events which have ever existed in the historical PPP projects and the experience of project practices. As discussed in Table 3.2.2, the preferred research strategies are case studies, historical analyses, archival records analyses, and surveys. Therefore, literature survey, interview survey, questionnaire survey, computer-aided cause-effect modelling and statistic analysis are applicable to the research question. The Taiwan High Speed Rail project was applied to demonstrate the development of the proposed theoretical approach. A literature survey was conducted to obtain the secondary data from the previous empirical studies, which can provide the physical interaction scenarios for PPP project risk events. Since each PPP project is unique, the secondary data about the risk interrelationships were not supposed to be so close to the reality of a particular PPP project selected for model demonstration. Therefore, the researcher inquired into the opinions of informants who are experienced and expert in the selected project by interview survey as a complementary approach for evidence convergence to reduce the gap between the investigated phenomena of secondary data and reality. Then, the collected data from both of the secondary data and informants' opinions will be interpreted for the risk cause-effect interrelationship over the particular PPP project life cycle by computer-aided cause-effect modelling. After all, a statistic analysis was performed to formulate the physical risk interrelationships.

Research question 3	How can the qualitative effects be quantified while using CBA to analyze NPV for the PPP transport projects?
Research question 4	How can the physical risk interrelationships be quantified?
Research question 5	How can the probability distribution for risk effects be estimated?
Research strategy	Quantitative research
Research method	Questionnaire survey with statistic analysis
Rationales	This was a How much question to measure the phenomenon of qualitative risk effects. There was no researcher access to or control over actual phenomena. Since each PPP project may be very unique and the historical data are inadequate, the qualitative risk effects and probability are supposed to be very different from project to project. Hence, the phenomenon for qualifying qualitative risk effects and probability depends on the subjective belief, perception, experience, judgment and prediction of the informants who are experienced and expert in selected project case. A questionnaire survey was designed for sampling from a group of informants who are experienced and expert in the selected project case. Then, with suitable statistic techniques, the sampled data analysis took variability of subjective judgment into account to measure the qualitative risk effects and their probability.

Research question 6	How can the probability distribution for project NPV be estimated with overall compounding downside and beneficial effects over project life?
Research strategy	Quantitative research
Research method	Computer-aided cause-effect modelling and simulation
Rationales	This was a How much question to measure the phenomenon for overall compounding downside and beneficial effects on project NPV. The rationales for this question were generally the same as those for research question 4. A computer-aided cause-effect modelling and simulation will be conducted to estimate the overall NPV profile arising from the interactions between downside and beneficial effects over project life.

Research question 7	What are the suitable methods that can be used to compare the NPV range values among bidding proposals to choose a preferred bidding proposal?
Research strategy	Qualitative research
Research method	Literature survey
Rationales	This was a What question to explore the phenomena for the approaches that are useful for risky projects comparison. The rationales for this question were generally the same as research question 1. A literature survey was conducted to investigate the approaches and their advantages and disadvantages for risky project comparison.

3.3 Theoretical Approach and Assumption

The objective of the thesis research is to develop a theoretical approach that is able to solve the common issues of the current PPP project concessionaire selection methods. The developed theoretical approach can build a decision support model that is specific to a particular PPP project for the public sector to choose a concessionaire which is capable of creating value for money. The Taiwan High Speed Rail project was applied to demonstrate the decision model developed by the proposed theoretical approach.

As shown in Figure 3.3.1, the theoretical approach used is summarized below:

1. Investigate the generic risk factors. Explore using literature survey, the generic risk factors that have created downside effects on PPP project performance during concession periods.
2. Model causal loop diagrams. Model and interpret the risk interdependencies and interactions by literature survey, interview survey, and System Dynamics modelling technique.
3. Estimate risk effects and probability. Estimate and quantify qualitative risk effects using questionnaire surveys by group expert judgment. Infer risk effect probability distribution by probability fitting.
4. Formulate the functional relations of risk variables for risk network modelling by multiple-regression analysis.
5. Estimate the overall NPV probability distribution. Model the compounding effects for combination of both downside feedback loop effects arising from the project risk network and beneficial feedback loop effects arising from the bidding proposals over project life through the System Dynamics modelling technique; estimate the probability distribution for project NPV time-profile by running Monte Carlo simulation.
6. Apply decision theories to compare NPV range values. Using the literature survey, investigate and apply appropriate decision methods to compare NPV probability distribution among the bidding proposals.

The proposed theoretical approach in building a decision support model for concessionaire selection was based on the following assumptions:

1. The proposed theoretical approach for PPP project concessionaire selection method is developed from the perspective of public sectors.
2. The public sector has undergone investment feasibility analysis, which indicates that the PPP approaches are better than traditional approaches for infrastructure project procurement.
3. The public sector officials have sufficient capability and skills to set up PPP project service specifications, to evaluate and determine which bid ensures the best value for the money, and to conduct and manage a long-term PPP contract relationship with the private sector officials.
4. There are no market failure problems. At least three private sectors have sufficient expertise to perform a PPP approach. That is to say, candidates selected through a prequalification process are experienced in the infrastructure project life costing and project risk management.

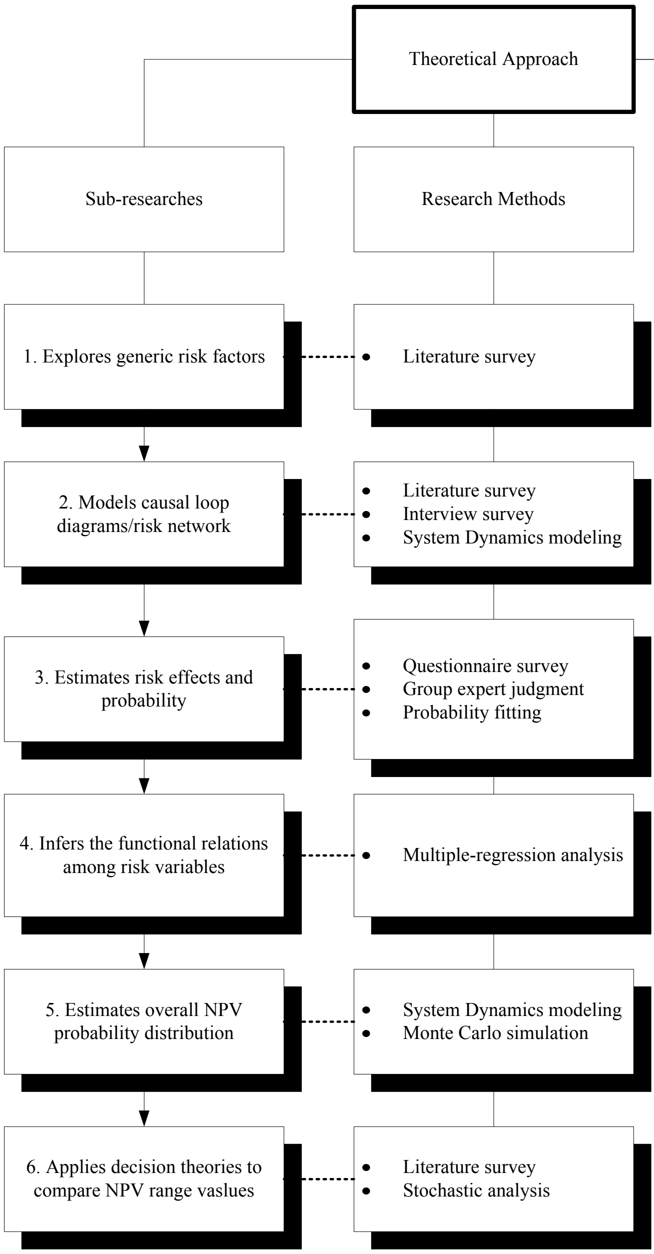


Figure 3.3.1 The Theoretical Approach and Presumption for PPP Project Concessionaire Selection

3.4 The State-of-the-Art

The major risk analysis techniques used in the research were System Dynamics modelling, risk rating matrix, multiple-regression analysis, and probability fitting. As shown in Figure 3.4.1, the researcher used System Dynamics to model project NPV and various risk cost networks that link to the

NPV model. Second, the risk rating matrix attached to the questionnaire was used to rate the risk degree. Third, the probability fitting was applied to estimate the probability distribution for the input variables in a risk cost network. Fourth, the multiple regression analysis was used to quantify and formulate the risk relationships in a risk network. Fifth, the project NPV probability distribution was predicted through Monte Carlo simulation. All of these techniques used in the theoretical approach, with an application example, are described in the following sections.

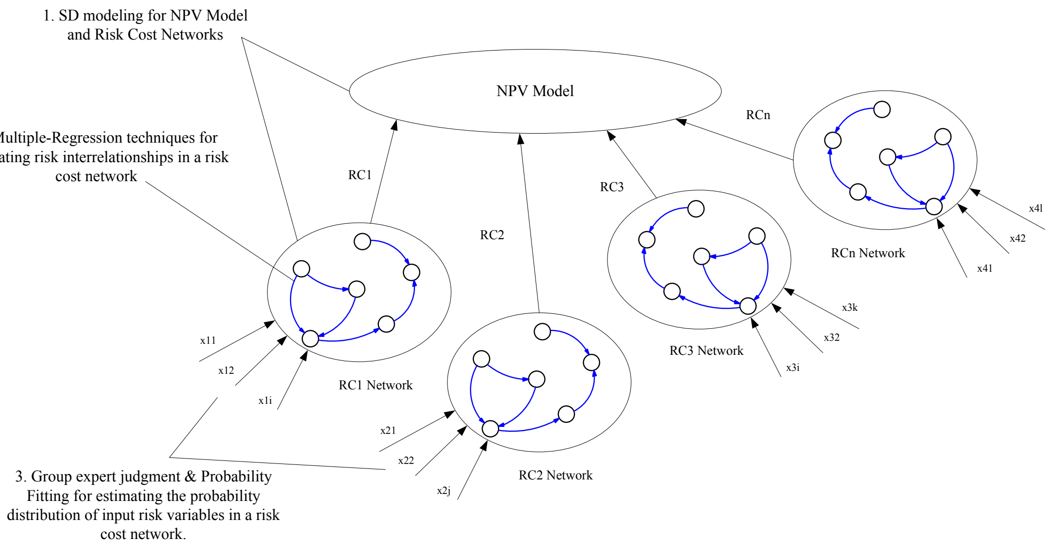


Figure 3.4.1 The Major Risk Analysis Techniques

3.4.1 System Dynamics

In a large-scale project, applying a causal-effect modelling technique to model risk inter-dependencies may be more appropriate than the spreadsheet used in current practices for risk cost estimates. Systematic dynamic (SD) is a both qualitative and quantitative tool with feedback and causal loop diagrams, appropriate for modelling the inter-relationships such as non-linear behaviour, time-delay effects and causal feedback for a complex project over time (Williams, 2002).

As shown in Figure 3.4.2 (left), Sterman (2000) demonstrated that SD uses multiple feedback loops to describe dynamic behaviour for understanding certain kinds of complex problems that involve changes over time. Multiple feedback loops are closed chains of cause and effect links in which information is fed back to generate further action. A causality link is considered positive or negative, and is represented by plus and minus signs. A positive link between two variables implies that the variables tend to move in the same direction of change. For example, if an increase (decrease) in a variable (D) leads to increase (decrease) in another variable (A), then the type of causality is positive. Otherwise, it is negative.

Similarly, there are two types of feedback loops: negative feedback loops and positive feedback loops. A negative feedback loop is an equilibrium seeking or stability-seeking loop. The negative feedback loop movement directs a system back to the starting or equilibrium point, tending to stabilize the system. The positive feedback loop generates growth rather than equilibrium, tending to destabilize a given system. System dynamics can model desires, expectations, perceptions, and goals. As shown in Figure 3.4.2 (right) (Sterman, 2000), when the difference between *real state* and *desired state* becomes greater, this will cause a greater correct *action* to feedback real state to approach the desired state. This shows a negative feedback loop which stabilizes the system.

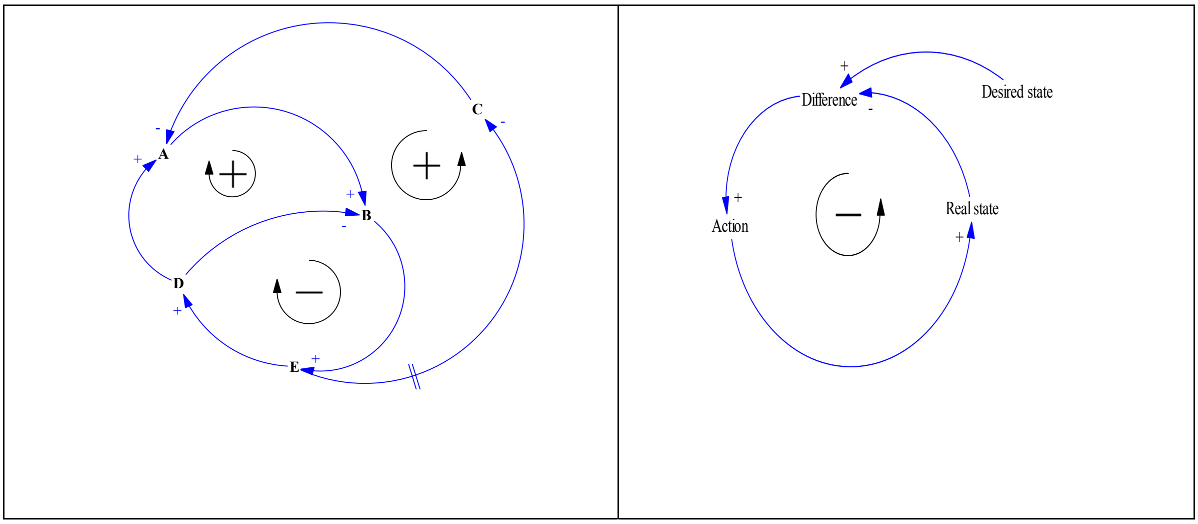


Figure 3.4.2 System Dynamics Feedback Loops (Left) and Go-seeking Feedback Loop (Right) (Sterman, 2000)

Kirkwood (1998) wrote that a system compounds specific events which will often cause four basic problematic patterns of behaviour over time. As shown in Figure 3.4.3 (Kirkwood), these patterns of behaviour are called exponential growth (generally caused by positive feedback loop) , goal seeking (generally caused by negative feedback loop), S-shape growth (generally caused by combination of positive and negative feedback loops), and oscillation (generally caused by negative feedback loop with delay). Sterman (1992) stated, "It is important to note that the large-scale projects are extremely complex, highly dynamic, have multiple feedback and non-linear relationships, and require both hard and soft data. That explains why SD can fulfill certain modelling requirements, especially for large-scale construction models"

System Dynamics modelling is widely applied to project management (Lyneis & Ford, 2007; Rodrigues & Bowers, 1996) which includes research and development (R&D), software development, product development, and construction management. The current studies included the impact of client behaviour on project development (Rodrigues & Williams, 1998), the product development process (Ford & Sterman, 1998), design error-induced construction remedies(Love et al., 2002), design and build for construction project (Chritamara et al., 2002), project disruption and delay (Howick, 2003; Williams, 2003; Williams et al., 2003), project performance management (Ogunlana et al., 2003), change management for construction project (Lee et al., 2005; Lee et al., 2007; Love et al., 2002; Park & Pena-Mora, 2004; Motawa et al., 2007), the potential of total cycle time compression and development phase for a construction project (Barker & Childerhouse, 2003), the influential factors to drive construction innovations (Park & Pena-Mora), product development resources allocation (Joglekar & Ford, 2005), and operation management for construction project (Lee et al., 2008).

From the literature, the researcher found that SD is a sustainability tool for modelling project performance. However, Williams (2002) criticized the use of SD simulation based on its deviation from discrete event simulation in focusing on the state of the system and rates of change for pseudo-continuous modelling rather than the details of discrete events. It is difficult to distinguish operational detail within the SD models. Furthermore, the problems concerning stochastic value instead of deterministic value for risk variables (Williams) and quantifying qualitative data makes SD modelling challenging (Coyle, 2000; Luis & Deborah, 2003). Concerning the modelling of detailed discrete-event for project operational network; this is not the purpose of the SD model. The SD model is not a real-time prediction and detection tool that is generally used to improve short-term operation efficiency. On the contrary, it is a useful tool for analyzing project performance policies based on the overall trends that the SD model generates (Garcia, 2005). Therefore, as bid-evaluation is based on the long-term NPV trends, the SD model can be used for this purpose. Concerning parameter inference for a SD model, applying correct hybrid tools at the right time for project modelling may be necessary

(Williams). The research combines various techniques and tools to infer the risk consequence and likelihood for risk variables.

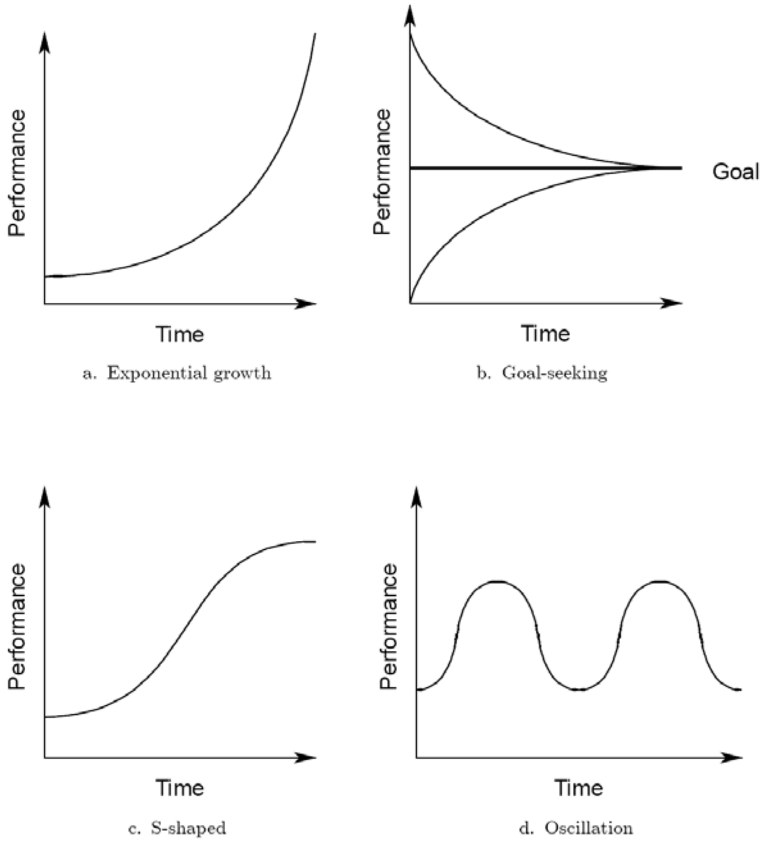


Figure 3.4.3 Patterns of System Behaviour (Kirkwood, 1998)

3.4.2 The Hybrid Techniques

As previously discussed, imperfect information and qualitative data concerning risk events in a PPP project may be included. Therefore, the challenge was how to assess the probability distribution for the risk effects in term of qualitative and non-monetary data. The risk matrix, which incorporates expert judgment and statistic techniques, can be applied to probability distribution for the expected risk effect in a risk network.

3.4.2.1 Risk Rating Matrix

A risk matrix is used to plot the project's risk for an immediate view of the risk profile of a project based on each the likelihood and impact rating of each risk event. Mapping risks in a matrix over a specific phase of a project will illustrate different consequences of cost and time (Akintoye et al., 2001; DAU, 2003; Dey, 2002; Kindinger, 2002). Table 3.4.1 (modified from Australia Government, 2005; Cooper et al., 2005) is an example of risk matrix with risk effect scale numbering from 1 to 25. A higher rating indicates a greater level of risk effetc. The researcher designed a questionnaire survey based on the 1 to 25 scale in form of the risk matrix shown in Table 3.4.1. The researcher sent this questionnaire survey to participants asking them to rate the risk effect for all of the risk events over the project life cycle using expert judgment. The purpose was to provide a consistent scale of magnitude to rate and quantify the expected risk effect for each risk event.

3.4.2.2 Expert Judgment

In Chapter 2, the researcher discussed the fact that the PPP projects are usually unique and lack historical data, especially for software data, and thus it may be necessary to gain information gained from the project expert who has project expertise and knowledge. Expert judgment is said to encounter cognitive limitations due to the potential biases associated with the individual subjective views (Akintoye et al., 2001). However in the research, the researcher incorporated group expert judgment and statistic techniques to assess subjective data in a systematic way, thus reducing subjective bias. To reduce the potential bias arising from an individual judgment to make a consistent decision, the questionnaire was sent to participants who were a group of risk experts in order to obtain sufficient sample size of data for statistic analysis. A group of participants might be the project managers, project engineers, contractors, subcontractors, *core* service operational managers and stakeholders, departmental stakeholders, technical consultants, issuance companies, financial and legal advisers and others who are experienced in many facets of a large-scale transport project.

Table 3.4.1 The Reference Matrix for Rating Risk Effect

IMPACT (I) \ LIKELIHOOD (L)	Very Low (VL)	Low (L)	Medium (M)	High (H)	Very High (VH)
Very High (VH)	17	19	22	24	25
High (H)	15	18	20	21	23
Medium (M)	9	12	13	14	16
Low (L)	3	6	8	10	11
Very Low (VL)	1	2	4	5	7

3.4.2.3 Multiple Regression Analysis

The regression modelling technique has been extensively recommended in the construction engineering and management field to predict the project performance (Liou & Huang, 2008; Molenaar & Songer, 2001; Russell, 1992). The regression modelling technique is used by professionals when it is hypothesized that one variable (*X*, the independent variable) statistically causes another variable (*Y*, the dependent variable) to change. The researcher will apply the quadratic multiple regression model including interaction terms and quadratic terms to quantify the functional relations for a dependent risk variable and its independent variables in a risk cost network, which is expressed as:

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \beta_3 X_{i3} + \ldots + \beta_n X_{in} + \beta_{n+1} X_{i1} X_{i2} + \beta_{n+2} X_{i1} X_{i3} + \beta_{n+3} X_{i2} X_{i3} + \ldots \beta_m X_{in-1} X_{in} + \beta_{m+1} X_{i1}^2 + \beta_{m+2} X_{i2}^2 + \beta_{m+3} X_{i3}^2 + \ldots + \beta_j X_{ij}^2 + \varepsilon_i$$

, where Y_i = the value of the dependent variable in risk network *i*; β_0 to β_j = constant or regression coefficients; X_{i1} to X_{ij} = the value of the independent variables in risk network *i*; *i* = the ith risk cost network; *j* = number of relatively independent variables; ε_i = the *RANDOM NORMAL(0, σ)* for the error term of Y_i that is a normal distribution with mean of *0* and standard deviation *σ*, where *σ* = square root of mean square error (MSE). This is a random variation that was incorporated into the regression models. Especially, the interaction terms $X_{n-1}X_n$ will be modeled to examine the statistical interaction effects of risk variables X_{n-1} and X_n in a risk network. An example is shown in section 6.3.1.

3.4.2.4 Probability Fitting

A series of theoretical distribution functions were applied to fit the data collected from a questionnaire survey. The process of identifying and confirming the distribution was called fitting a distribution (Molenaar & Songer, 2001; Park & Sharp-Bette, 1990; Springer, 1997). Park and Sharp-Bette stated that this process can provide several benefits when fitting a distribution to data applied in risk simulation: (a) the empirical distribution for the same variable might be different when obtaining different sets of observations at different times. By fitting a theoretical distribution to the data, the specified distributions should be less sensitive to random fluctuations between different observations; (b) if empirical distributions are defined for observed data, then their use in the simulation implied that no random variables falling outside the range of the observed data would be generated. On the other hand, with a fitted theoretical distribution, random variables outside the range of the observed data can be generated. "This is a much desired feature in risk simulation, since many project outcomes depend heavily on the probability that an 'extreme' event may occur.(Park & Sharp-Bette, 1990)"

In probability fitting, a fitted probability distribution for the input risk variables in a risk cost network can be inferred. Since each risk cost network links to the NPV model, the researcher could thus predict the probability distribution of NPV values by Monte Carlo simulation.

3.4.2.5 Monte Carlo Simulation

Monte Carlo simulation is used to study outcome variability. Each risk event can be triggered by one or more causes and can result in one or more consequences. Once the probability for each main event and any sub-events is estimated and determined, the likelihood for these causal sub-events is combined to calculate the occurrence likelihood for the main event. Monte Carlo simulation is currently regarded as the most powerful technique for cash-flow analysis. It is useful when there are many variables with significant uncertainties (Reilly, 2005). The more complex the project and the more risks and uncertainty that are associated, the more valuable Monte Carlo simulation analysis will be (Dey & Ogunlana, 2004; Stahr, 2006; Watson, 2005).

3.4.3 Ranking Decision Rules

As discussed in chapter 2, mean-variance/mean-semi-variance, stochastic dominance and expected-loss ratio were applied to compare and rank the NPV range values for bidding proposals. The details are described in chapter 2 and section 7.3.

3.5 Research Reliability and Validity

Research reliability and validity are two important concepts. Reliability is concerned with the accuracy of the actual measuring instrument or procedure, while validity is concerned with the success of measuring *what the researchers set out to measure* (Mitchell & Jolley, 2006). To ensure research quality, there are four widely used criteria for research: reliability, measurement validity, internal validity, external validity. Table 3.5 summarizes the relevant actions that will be taken for each criterion test when doing the research.

3.5.1 Reliability

Reliability reflects the confidence of whether study operations such as data collection procedures can be repeated with the consistent results (Bryman, 2001; Payne & Payne, 2004; Yin, 2003). If a later investigator follows the same procedures as described by an earlier investigator, they should yield the same findings and conclusions (Yin). This represents one aspect of creditability by minimizing the errors and bias in a study (Mitchell & Jolley, 2006). Yin contended that former research work cannot be repeated without documenting the studying procedures and having a database available for independent inspection. To ensure reliability, the procedures and every step of the research process a described in detail (Mitchell & Jolley); all collected data and evidences, including copies of archives, the secondary data, interview records and questionnaires should be well-documented and organized and stored in a database for easy access (Yin). All data and evidence sources should be sufficiently cited in the relevant database to maintain a chain of evidence (Yin), ranging from initial research questions to ultimate research conclusions, for the external observer to trace.

3.5.2 Construct validity

Yin (2003) defined construct validity as "establishing correct operational measures for the concepts being studied" . It is also referred to as measurement validity (Bryman, 2001). It concerns the question of whether the operational set of measures used to measure the concepts accurately reflects the concepts of interest (Bryman; Yin).

To ensure construct validity, the researcher will take three actions as recommended by Yin (2003). First, triangulate multiple data sources. Bryman (2001) referred to triangulation as using more than one method or source of data in the study of social phenomena. Deacon, Bryman, and Fenton (1998) stated that triangulation is being increasingly used to refer to a process of cross-checking findings from both qualitative and qualitative research. Yin recommended collecting information from multiple sources and triangulating them to encourage convergence lines of inquiry. He wrote that "with data triangulation, the potential problems of construct validity also can be addressed because the multiple sources of evidence essentially provide multiple measures of the same phenomenon" The researcher used multiple sources of evidence, including preliminary studies, governments officials' report archives, interviews and questionnaire survey forms collected from those participants who were from both public and private sectors and were experienced or expert in the selected case project. Furthermore, the multiple sources of evidence were compared and cross-checked for data triangulation. Secondly, a chain of evidence was conducted which was mentioned in the reliability function. Lastly, the draft for research reports was reviewed by key participants who are experienced or expert in the field related to the PPP projects.

3.5.3 Internal validity

Mitchell and Jolley (2006) defined internal validity as referring to (a) the rigor with which the study was conducted (e.g., the research design, the care taken to conduct measurements, and decisions concerning what was and wasn't measured); and (b) the extent to which the research designers had accounted alternative explanations for any causal relationships they explore. As for the studies that do not explore causal relationships, only the first of these definitions should be considered when assessing internal validity. The researcher focused on building a cause-effect model to predict project NPV trend for PPP project bid-selection, which involves the above two definitions.

Table 3.5 Criteria and Actions to Ensure Research Quality

Criteria	Actions	Phase of research process to take actions
Reliability	• The research procedure will be described in detail (Mitchell & Jolley, 2006). • Well documented data (Yin, 2003; Tellis, 1997). • Makes citations for data sources (Yin, 2003; Tellis, 1997). • Establishes a database (Yin, 2003; Tellis, 1997). • Makes a chain of evidence (Yin, 2003; Tellis, 1997).	• Data collection
Construct validity	• Collects multiple sources of evidence (Yin, 2003; Tellis, 1997). • Conducts data triangulation (Yin, 2003; Tellis, 1997). • Makes a chain of evidence (Yin, 2003; Tellis, 1997). • Let key informants review the draft for the case study report (Yin, 2003; Tellis, 1997).	• Data collection • Composition
Internal validity	• Applies cause-effect modelling (Yin, 2003) • Does pattern-matching with analytic analyses such as descriptive statistics, probability distribution analysis. scenario & sensitivity analysis and discrepancy comparison (Kazell & Keravnou, 2003; Mitchell & Jolley, 2006; Yin, 2003).	• Data analysis
External validity	Formulate theory and prepositions (Yin, 2003). Use falsification to test generalization (Flyvbjerg, 2006).	• Research design

As for the first definition, the researcher has designed the research in terms of formulating research questions and theory propositions, and setting up methods for data collection and analysis and research reliability and validity by following a series logic process from top to bottom. This introduced the research philosophies, developed overall research strategies for the whole research as well as individual research strategies for each research question based on the research strategies in order to set up research methods for data collection and analysis. This ensured the rigor and quality of the research.

As for the second definition, Yin (2003) stated that when an event cannot be directly observed, the internal validity for case study research concerns the problem of making inferences by questions such as: “Is the inference correct?” “Have the rival explanations and possibilities been considered?” “Is the evidence convergent?” “Does it appear to be airtight?” As described above, the researcher used multiple sources of evidence with triangulation (Yin) which were based on literature survey, questionnaire survey and interviews, and causal relationships that could not be directly observed by the researcher. Furthermore, Yin pointed out that a logic model which deliberately stipulates a complex chain of events over time has become increasingly useful in recent years, especially in doing case study evaluation. This type of evaluation uses logic models as an analytic technique matching, empirically observed events to theoretically predicted events. The researcher applied cause-effect modelling technique to model the cause-effect interrelationship network for negative events and positive effects to predict the NPV trend pattern for the PPP case project. This was then tested for precision of pattern matching by discrepancy comparison between predicted and real values (Kazell & Keravnou, 2003; Mitchell & Jolley, 2006; Yin).

3.5.4 External validity

A major inquiry is “how can a single case possible be representative so that it might yield findings that can applied more generally to other cases?” (Bryman, 2001) Yin (2003) stated analogizing a case study to survey research, in which a sample can be readily generalized with a larger population or universe was not correct. He asserted that survey research relies on statistical generalization (enumerate frequencies) of populations or universes, whereas case studies rely on analytical generalization (generalize theories) to a broader theory. Yin took an example of how a case study can be generalized to theory. This was illustrated in Jacobs (1961) book, *The Death and Life of Great American Cities.* In this book, Jacobs covered broad theoretical issues in urban planning, such as the role of sidewalks, the role of neighborhood parks, the need for primary mixed uses, the need for small blocks, and the processes of slumming and un-slumming, rather than reflect the single experiences of New York. In practice, aggregating these issues represents building a theory of urban planning, which is still a significant contribution to the field on urban planning. Flyvbjerg (2006) similarly stated that a single case with small-N research to study related phenomena is more often at the front of theoretical development. The objective of the thesis research is to develop a theoretical approach that is able to solve the common issues of the current PPP project concessionaire selection methods. The researcher needed to investigate different aspects of issues and phenomena by the small-N research as stated by Flyvbjerg (2006), which included the need to explore both positive and negative factors that will affect PPP project NPV, the need to model and interpret the interrelationships between these factor variables over project life cycle, and the need to measure the overall effects of these factors on project NPV. An analogy to build a theory for urban planning was developed by Jacobs (1961) that aggregates these issues and explores these phenomena by N-research to build a theory for PPP project concessionaire selection.

Chapter 4 Risk Factors and Causal Loop Diagrams

The purpose of the research was to evaluate and compare the long-term project NPV trends with risk impact between the bidding proposals against base case from a public perspective. Therefore, the researcher investigated and identified the generic risks which would impact PPP project performance in the first instance. The risk interdependencies (cause-effect interrelationships) were addressed based on the case scenarios by causal loop diagrams. These risk causal loop diagrams were then be converted to the quantitative SD models to evaluate risk effects on the project NPV by interview and questionnaire survey.

As discussed in Chapter 3, the generic risk factors for PPP projects were collected from the secondary data including two major sources: empirical studies and official publications. The collected secondary data were then summarized into a set of generic PPP risk factors with explanations of how the risk factors would physically interact in the construction and operation stages.

4.1 Literature Reviews for Risk Factors

The researcher used a survey reviewing the current literature on PPP project risk factors published from 2000 to 2006. The sources for empirical studies included journal articles and conference papers, research reports, textbooks, commercial or organizational documents, and so on. The sources for official publications included the practice guidance, records, reports or other documents published by the governmental organizations. Table 4.1.1 and Table 4.1.2 summarize several empirical studies and official publications respectively by outlining the author names, research methods to collect risk factors, the project types to which the risk factors apply, and the project phases on which the risk factors focus. All of the risk factors collected from the secondary data are listed in Appendix I.

Table 4.1.1 Risk Data Sources from the Empirical Studies

Authors	Research methods	Types of Project	Risk Focuses
Li (2005)	Literature survey	Generic PPP projects	The whole project life cycle
Hodge (2004)	Literature survey	Generic PPP projects	The whole project life cycle
Ghosh & Jintanapakanont (2004)	Literature survey	Generic PPP projects	The whole project life cycle
Thomas (2003)	Literature survey/ case study	BOT road projects	The whole project life cycle
Dey (2002)	Literature survey	Large-scale construction projects	Construction
Mott MacDonald (2002)	Not available	Large-scale public projects	Construction
Akintoye et al (2001)	Literature survey/ case study	Generic PPP projects	The whole project life cycle
Shen et al.(2001)	Interview survey	Sino-foreign joint ventures of construction projects	The whole project life cycle
Wang (2000)	Literature survey/ case study	Generic BOT infrastructure projects	The whole project life cycle
Moody (2006)	Not available	Generic PPP projects	Construction
Cooper et al (2005)	Not available	Generic PPP projects	The whole project life cycle
Nguyen and Ogunlana (2005)	Literature survey/ field observations/ structured interviews	Road tunnel infrastructure projects	Construction
Mills (2001)	Not available	Generic PPP projects	Construction

Table 4.1.2 Risk Data Sources from the Official Publications

Authors	Research Methods	Types of Project	Risk Focuses
HM Treasury (2003)	No available	Generic PPP projects	The whole project life cycle
Partnership Victoria (2001)	No available	Generic PPP projects	The whole project life cycle
South Africa (2001)	No available	Generic PPP projects	The whole project life cycle
United Nations (2000)	No available	Generic PPP projects	The whole project life cycle
European Commission (2003)	No available	Generic PPP projects	The whole project life cycle

However, the current data sources for risk factors have the following issues:

1. No clear data sources: Most of the authors in the literature mentioned that risk factors were collected from literature surveys, interview surveys or case studies, but the authors did not give references for this data. It is problematic that the researcher cannot demonstrate research reliability described previously in Chapter 3 in which outcomes are predictable and coherent.

Therefore, to achieve research reliability, the researcher clearly displayed the data sources for each of the identified risks, as shown in Table 4.1.3.

2. Ambiguous terminologies for risk factors: Most of the empirical studies lacked descriptions or definitions of listed risk factors, and it was difficult to accurately and consistently establish the causal relationships for risk factors. Furthermore, some empirical studies used ambiguous terminologies to describe risk factors, which lead to misunderstandings of the meanings and properties of risks. These issues will incorrectly and inconsistently describe and measure risks. As a result, the research could not meet the requirements for internal validity described previously in Chapter 3. Therefore, to achieve internal validity, the researcher defined and described the generic risk factors before structuring causal loop diagrams.
3. No clear logic to choose and classify risk events: Choosing and classifying risk events seemed to differ among studies. Most researchers did not clearly explain the logic of how to choose and classify the risk events. Unclear logic to choose and classify risks would incorrectly and inconsistently address, measure and generalize the physical risk interrelationships for PPP projects, which would lead to failure in both internal and external validity as described in Chapter 4. Therefore, in order to achieve internal and external validity with a clear boundary to model the physical risk interrelationships, the researcher uniformly classified all risk events into project-related risk events (internal risks) and non project-related events (external risks) for respective construction and operation phases.
4. Incomplete and unrepresentative risk factors: The risk lists developed and concluded by most of the authors of reviewed literature might be incomplete and unrepresentative risks for PPP/PFI projects. The result was that the research cannot meet the requirements for construct validity and external validity described in Chapter 3. To achieve both construct and external validity, the researcher maximized the completeness and coverage to summarize risk factors by cross-checking and triangulating the risk events derived from different data sources, including the empirical studies shown in Table 4.1.1, the official publications shown in Table 4.1.2, and the reviewed literature and cases. A list of generic risk factors that have been developed drawn from the secondary data is outlined in Table 4.1.3. They are categorized as availability, design, construction, operation, cost, technology, organization, finance, contract,

third party, asset ownership, economy, market, politics, regulation, industrial relation, and Force Majeure.

Table 4.1.3 The Generic Risk Factors

Risk Factors	Internal/ External to Project	Project Phases	Evidence
Availability risks			
(1) Land unavailable	Internal	Construction	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the Melbourne City Link (Hodge, 2004), the Yangtze Three Gorges Project (Lu, 2004), the Bangkok Second Stage Expressway (The Work Bank, 1999).
(2) Resources unavailable	Internal	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the London Underground (NAO, 2004a), the Bangkok Elevated Road and Track System (The Work Bank, 1999), the Labin B Power Plant (Lu, 2004), the STEPS Deal (PAC, 2005b), the BBC's White City 2 Development (PAC, 2006b).
(3) Performance unavailability	Internal	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the London Underground (EC, 2002; PAC, 2005a), the Melbourne City Link (Hodge, 2004).
Design risks			
(4) Scope changes	Internal	Construction/operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the Channel Tunnel Rail Link(PAC, 2006a), the Thailand Underground Rail Project (Ghosh & Jintanapakanont, 2004)
(5) Defective design	Internal	Construction	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the Melbourne City Link (Hodge, 2004).
(6) Design changes	Internal	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the BBC's White City 2 Development (PAC, 2006b), the Melbourne City Link (Hodge, 2004), the Thailand Underground Rail Project (Ghosh & Jintanapakanont, 2004).

Construction risks			
(7) Construction cost overrun	Internal	Construction	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the Boston's Artery/tunnel, the Great Belt Rail Tunnel, the Shinkansen Joetsu Rail Line, and the Channel Tunnel (Flyvbjerg et al., 2003; Reilly, 2005).
(8) Construction delay	Internal	Construction	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the Melbourne City Link (Hodge, 2004), the Thailand Underground Rail Project (Ghosh & Jintanapakanont, 2004).
(9) Defective construction	Internal	Construction	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the Melbourne City Link (Hodge, 2004).
(10) Construction changes	Internal	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the Melbourne City Link (Hodge, 2004).
(11) Complex system interface/ integration	Internal	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: Airwave(PAC, 2002a), London Underground(PAC, 2005a).
(12) Failed commissioning tests	Internal	Construction	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the Melbourne City Link (Hodge, 2004).
Operation risks			
(13) Low operating productivity	Internal	Operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the Karvina Sewerage (EC, 2004b), the Thailand Underground Rail Project (Ghosh & Jintanapakanont, 2004).
(14) Mis-pricing	Internal	Operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the ASA and Rethmann and the RWE Entsorgung (EC, 2004b).
(15) Revenue loss	Internal	Operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the Channel Tunnel Rail Link (PAC, 2006a), the Melbourne City Link (Hodge, 2004), the ASA and Rethmann (EC, 2004b).
(16) System breakdown	Internal	Operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the Melbourne City Link (Hodge, 2004), the Thailand Underground Rail Project (Ghosh & Jintanapakanont, 2004).
(17) High maintenance frequency	Internal	Operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the Thailand Underground Rail Project (Ghosh & Jintanapakanont, 2004).

(18) Accidents and safety issues	Internal	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the London Underground (EC, 2002; NAO, 2004a), the Thailand Underground Rail Project (Ghosh & Jintanapakanont, 2004).
Cost risks			
(19) Price escalation	Internal	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the London Underground (EC, 2002), China case (Lu, 2004).
Technology risks			
(20) Complex/non-innovation technology	Internal	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the London Underground (PAC, 2002a; PAC, 2005a), National Physical Laboratory (NAO, 2006).
Organization risks			
(21) Poor cooperation/ coordination	Internal	Construction/ Operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the London Underground (EC, 2002), the Yangtz River Three Gorges (Lu, 2004).
Finance risks			
(22) Finance unavailable	Internal	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the Channel Tunnel Rail Link(PAC, 2006a), the National Air Traffic Services(PAC, 2003c).
(23) Refinancing liabilities	Internal	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the Channel Tunnel Rail Link (BBC NEWS, 2007), the National Air Traffic Services (NAO, 2004b; PAC, 2003c), the Norfolk and Norwich Hospital (PAC, 2006c), the BBC's White City 2 Development (PAC, 2006b), the Darent Valley Hospital (NAO, 2005).
(24) Insolvency of contractor	Internal	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the Thailand Underground Rail Project (Ghosh & Jintanapakanont, 2004), the Royal Armouries Museums in Leeds (PAC, 2001).
(25) Ownership change	Internal	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the Channel Tunnel Rail Link (PAC, 2006a)
(26) Tax increases	External	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the Xiaolangdi Project on Yellow River (Lu, 2004).
(27) Insurance increases	Internal/ External	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the Laibin B Power Plant (Lu, 2004).

Contract risks			
(28) Contractual disputes	Internal	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the Melbourne City Link (Hodge, 2004), the Thailand Underground Rail Project (Ghosh & Jintanapakanont, 2004).
(29) Inflexible contract arrangements	Internal	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the National Air Traffic Services (NAO, 2004b; PAC, 2003c), the Redevelopment of MOD Main Building (PAC, 2003b), the Nessebar "Golden Bug" Landfill (EC, 2004b).
(30) Delay in contract change negotiation	Internal	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the London Underground (NAO, 2004a), National Airport Traffic Services (PAC, 2003c), the Thailand Underground Rail Project (Ghosh & Jintanapakanont, 2004)
(31) Contract breach	Internal	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the North-South Expressway (NSE) and the Kuala Lumpur-Karak Highway (The Work Bank, 1999), the New IT Systems for Magistrates' Courts: the Libra Project (PAC, 2003a), the Melbourne City Link (Hodge, 2004).
(32) Contract remedies/ penalties	Internal	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the London Underground (EC, 2002), the Melbourne City Link (Hodge, 2004), the Thailand Underground Rail Project (Ghosh & Jintanapakanont, 2004).
Third party risks			
(33) Default of subcontractor	Internal	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the London Underground (EC, 2002), the Melbourne City Link (Hodge, 2004), the National Physical Laboratory (NAO, 2006), the Thailand Underground Rail Project (Ghosh & Jintanapakanont, 2004).
(34) Inspection and testing delay	Internal	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the Thailand Underground Rail Project (Ghosh & Jintanapakanont, 2004).
Asset ownership risks			
(35) Latent defect	Internal	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the London Underground (EC, 2002).

(36) Shorter asset life	Internal	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the London Underground (EC, 2002; NAO, 2004a).
(37) Less residual values	Internal	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the London Underground (EC, 2002; NAO, 2004a) .
(38) Termination liabilities	Internal	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the North-South Expressway (NSE) and the Kuala Lumpur-Karak Highway (The Work Bank, 1999), the National Physical Laboratory (NAO, 2006)
Economy risks			
(39) Higher level of inflation rate	External	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the Channel Tunnel Rail Link (PAC, 2006a), the Thailand Underground Rail Project (Ghosh & Jintanapakanont, 2004)
(40) Volatility of exchange rate	External	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the North-South Expressway (NSE) and the Kuala Lumpur-Karak Highway(The Work Bank, 1999), the Water Conservancy and Hydropower Project in Southern China (Lu, 2004), the Thailand Underground Rail Project (Ghosh & Jintanapakanont, 2004).
(41) Higher level of interest rate	External	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the North-South Expressway (NSE) and the Kuala Lumpur-Karak Highway(The Work Bank, 1999), the Harnaschpolder Wastewater Treatment Project (Smith, 2006).
Market risks			
(42) Less demand	Internal/ external	Operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the Channel Tunnel Rail Link (PAC, 2006a), the National Air Traffic Services (PAC, 2003c).
(43) Higher competition	External	Operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: Channel Tunnel Rail Link (PAC, 2002b), the Melbourne City Link (Hodge, 2004), the Zhuhai International Airport(Lu, 2004).
(44) Downside economic events	External	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the Asia Toll Road Projects (The Work Bank, 1999), the Thailand Underground Rail Project (Ghosh & Jintanapakanont, 2004).

Politics risks			
(45) Political interference	External	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the Bangkok Elevated Road and Track System (The Work Bank, 1999), the Constanta Water and Wastewater Project (EC, 2004b), the Prescom in Targoviste. (EC, 2004b).
Regulatory risks			
(46) Unsuitable regulatory policy	Internal/ external	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: National Air Traffic Services (NAO, 2004b; PAC, 2003c), the Melbourne City Link (Hodge, 2004), the Liaoning Wastewater Treatment Plant (Lu, 2004).
(47) Approval delays	Internal/ external	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: National Air Traffic Services (NAO, 2004b; PAC, 2003c), the Water and Wastewater Infrastructure in Southern China (Lu, 2004).
(48) Law/policy changes	External	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the London Underground (EC, 2002), the Melbourne City Link (Hodge, 2004).
Environment risks			
(49) Unforeseen site conditions	Internal	Construction	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the Thailand Underground Rail Project (Ghosh & Jintanapakanont, 2004).
(50) Environmental pollutions	Internal	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the Great Belt and Oresund Links/Demark (Flyvbjerg et al., 2003).
Industrial relation risks			
(51) Industrial disputes	External	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the Vasco da Gama Bridge (EC, 2003), the Thailand Underground Rail Project (Ghosh & Jintanapakanont, 2004).
Force Majeure risks			
(52) Force Majeure	External	Construction/ operation	• Data sources: Table 4.1.1 & Table 4.1.2 • Case: the London Underground (EC, 2002), the Channel Tunnel Rail Link (PAC, 2002b), the Melbourne City Link (Hodge, 2004), the Labin B Power Plant (Lu, 2004), the Thailand Underground Rail Project (Ghosh & Jintanapakanont, 2004).

4.2 Risk Causal Loop Diagrams

One of the core mechanisms of PPP procurement is risk allocation so that the public and private parties work together to properly and efficiently deal with the risks for better performance in the long-term life of the project. In this chapter, the researcher explores the downside effects of a PPP project in giving the public sector a clear picture to start risk allocation and which risks would be suitable for transfer to the private sector. Once risks are allocated between the public sector and private sector, Chapter 7 will describe the balance effects (beneficial effects) with their costs arising from the risk management actions that might be addressed in later bidding proposals.

A framework for risk causal loop diagrams (CLD) used to investigate the downside effects is based on the following principles and methods:

1. In Chapter 4, the causal loop diagrams (CLDs) were built to address risk interrelationships, which were based on the case scenarios described current literature. They were empirically confirmed by interviews to examine whether the CLDs could fit the applied case of the Taiwan high speed rail.
2. All of the risk factors, including their direct variables and intermediate variables were described by the causal loop diagrams with evidence to explain the consequences during the construction and operation phases of the project.
3. Since the research analyzed NPV cash flow for PPP bidding proposals, all of the direct risk consequences or intermediate risk consequences were converged into construction cost overrun at construction phase and revenue loss at operate phase respectively, so that NPV values could be estimated by linking both construction cost overrun and revenue loss into the NPV cash flow model.
4. The researcher explored the downside effects giving the public sector an idea of where to start risk allocation for a PPP project. Thus, the risk causal loop diagrams were based on the following objectives:
    a. Only model the risk variables that have completely different effects when implemented in private and public parties respectively, so that a judgment can be easily made for risk allocation between two parties for a PPP project. The researcher did not model those *soft* risk effects arisen from human factors because there is no

obvious difference between the private and public party. For example, the human factors like de-motivation and exhaustion would happen in a person naturally whether the person was affiliated with the private or the public sector. Therefore, modelling such soft risks as human factors would be beyond the scope of the research.

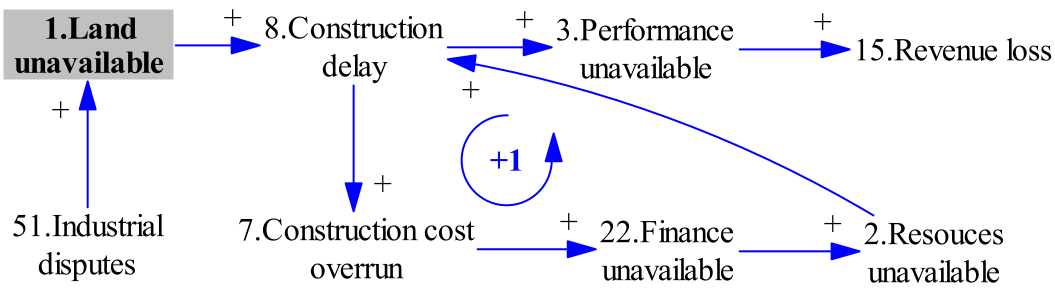
b. Risk allocation is made through PPP contract management, so the risk management should be able to be converted to the commercial contract terms and conditions. Therefore, the risk causal loop diagrams were modeled based on the major risk variables that can be allocated through commercial contract terms and conditions.

Based on the principles and methods presented, 52 risk casual loop diagrams were completely analyzed and addressed in Appendix V. Some indicative causal loop diagrams were extracted from Appendix V and discussed in the following sections.

4.2.1 Land unavailable

The term, *land unavailable*, refers to the risk costs and delays arising from acquiring lands for infrastructure construction. As shown in Figure 4.2 (1), the land unavailable risk event would cause construction delay due to the fact that there is no land available on which to start building an infrastructure (Hodge, 2004; Lu, 2004; The Work Bank, 1999). The construction delay would be likely to further cause the construction cost overrun risk event since the extra costs were incurred during maintenance of the purchased materials and equipment and paying for manpower during the construction time delay. Furthermore, the construction cost overrun risk event could possibly lead to finance unavailable risk event due to the risk of running out of money and having to borrow more money from other financial institutes. Consequentially, the unavailability of land would create a vicious circle (the positive loop 1) of more resources unavailable, more construction delays and more cost overruns. The construction delay also leads to the performance unavailable risk that the infrastructure will not be available for operation, thus resulting in revenue loss. In general, land unavailable risk would cause dynamic feedback effects on construction cost overruns during the construction phase and also on revenue loss during the operation phase respectively.

The land unavailable risk would likely be triggered by the industrial disputes risk event that would result should residents protest against the unsatisfied land acquisition costs or the environment and ecology impact (Hodge, 2004; Lu, 2004; The Work Bank, 1999).



<u>Figure 4.2 (1) Causal Loop Diagram for 'Land Unavailable' Risk Event</u>

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. as a BOOT contract for the City Link road infrastructure project in Melbourne. It was one of the Australia's largest public BOOT infrastructure projects, costing AUD$2.1 billion. Due to delays for land available by the agreed date, the government authority was liable for costs associated with those delays incurred by project contractor, Transurban, (Hodge, 2004). In addition, Lu (2004) in the Yangtze Three Gorges Project (China) indicated that this lead to delays in project progress due to expensive land acquisition and difficult resident relocation. The Work Bank's report (Work Bank, 1999) also reflected that the PPP contract for the Bangkok Second Stage Expressway had the same problem in that the government authority transferred the land too late to the project contractor, Bangkok Expressway Company Limited (BECL) due to the land acquisition difficulties.

4.2.2 Resources unavailable

The term*, resources unavailable*, refers to the possibility that the quantity or quality of the material resources of equipment, facilities or materials, and the like, the manpower resources such as manager, engineers, and the like, and the energy resources such as water, power, gas, and the like cannot meet contract requirements, and therefore are unavailable for construction and/or operation.

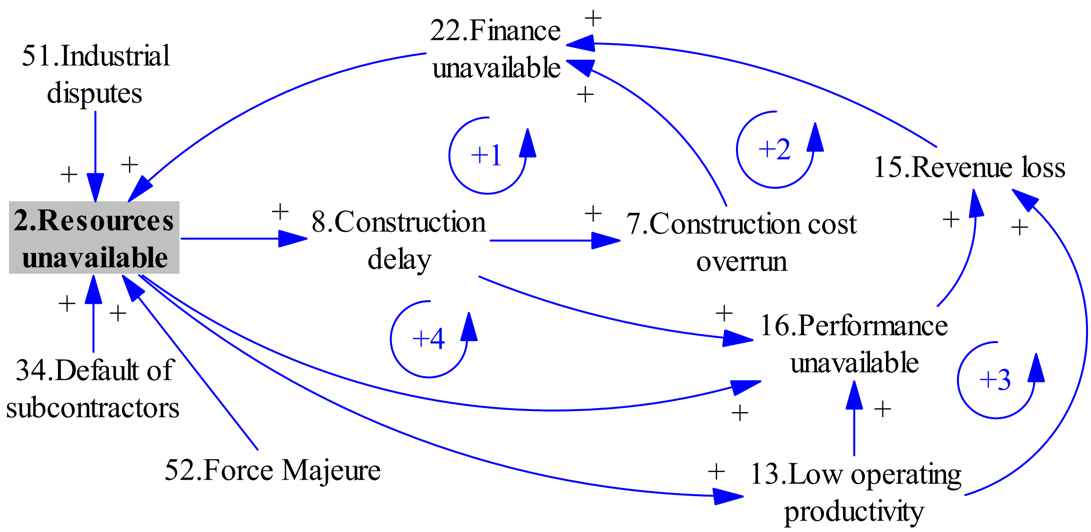


Figure 4.2 (2) Causal Loop Diagram for 'Resources Unavailable' Risk Event

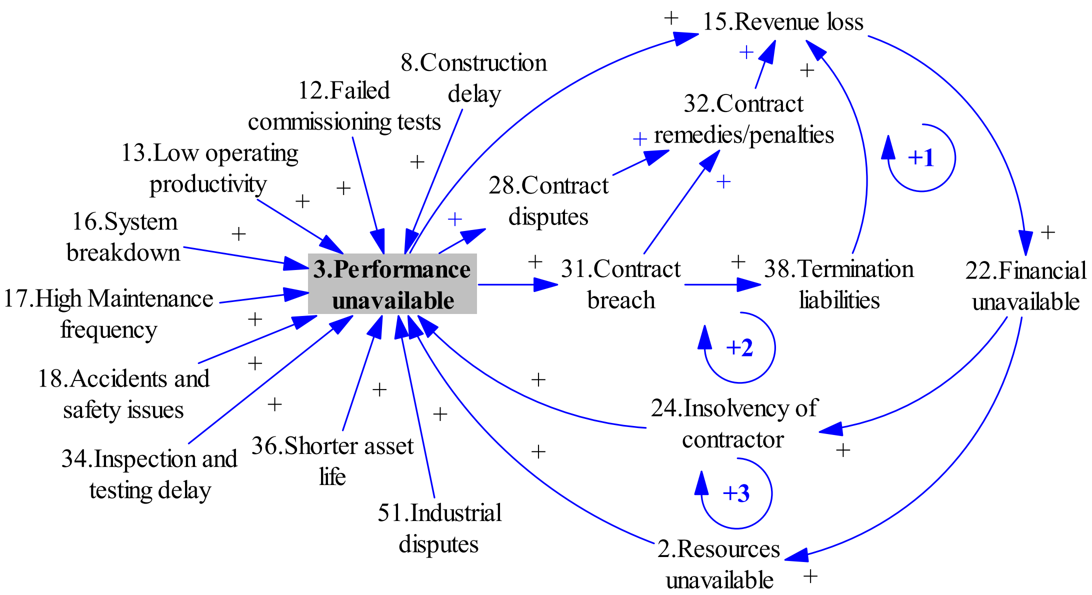
As shown in Figure 4.2 (2), the resources unavailable risk event would cause construction delays due to inadequate quantity and quality of manpower, materials and equipment for building infrastructure (NAO, 2004a; Work Bank, 1999a). The construction delays would likely cause construction cost overruns risk event since the extra costs were incurred while maintaining the purchased materials, equipment and paying for the recruited manpower during the construction time delay. Furthermore, the construction cost overrun risk would possibly result in the finance unavailable risk due to expenditure of money borrowed from the financial institutes. This would likely cause the event of resources unavailable due to insufficient funds for manpower, materials and equipment required to build infrastructure. Consequently, it would create a vicious circle (the positive loop 1) to cause more risk in construction delay and construction cost overrun. The construction delay would also result in performance unavailable because the infrastructure would not be ready to deliver its services. This would lead to revenue loss, with not enough credit to repay the debt, which will result in financial unavailable. Consequently, it would create a vicious circle (the positive loop 2) to cause yet again more risk in resources unavailable so that performance unavailable resulting in more revenue loss. At the operation stage, the resources unavailable risk event would directly cause low operating productivity event due to inadequate quantity and quality of manpower, materials and equipment which are required to deliver its services efficiently (NAO, 2004a; PAC, 2005b). It would lead to revenue loss which would cause financial unavailable again, which will create a vicious circle (the positive loop 3) to cause more risk in resource unavailable which leads to more low operating productivity and then more revenue loss. The low operating productivity would also directly cause performance unavailable since the adequate quantity and quality of manpower, materials and equipment is not available to operate the whole infrastructure. It would create a vicious circle (the positive loop 4) to cause revenue loss which leads to financial unavailable and more risk in resource unavailable. Finally, the resources unavailable risk event would result in dynamic feedback effects on construction cost overrun during construction phase and revenue losses during operation phase respectively.

The resources unavailable risk event would be likely to be triggered by the default of subcontractors risk events that the subcontractors are incapable of supplying materials, equipment, and manpower to build or operate the infrastructure (Hodge, 2004; NAO, 2006). The financial unavailable risk event is when the project contractor has insufficient capital to purchase materials, equipment or manpower required to build infrastructure (PAC, 2006). The industrial disputes risk events include strikes, industrial action, civil commotion, or public protests, which would cause materials, equipment, and manpower that cannot be supplied in time (EC, 2003). The Force Majeure risk events like earthquake, storm, flood, war, and fire, etc. make supply for materials, equipment or manpower unavailable (EC, 2002; Grey, 2004).

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for the cases, the UK National Audio Office's report (NAO, 2004a) on the London Underground indicated that they are unclear for both of the PPP project operation contractor, LUL, and infrastructure construction contractors, Infracos, to sustain and develop staff skilled to run PPP contract for the Tube network. In a report, the members of the UK Public Account Committee (PAC) for PFI criticized the fact that the professional skills for PFI contract management were not sustained for the operational phase due to unnecessary staff changes (PAC, 2005b). In addition, the Work Bank officials reported that staff changes were problematic in that there was not enough skilled personnel to deal with the PPP contract for the Bangkok Elevated Road and Track System (Work Bank, 1999). Lu (2004) indicated in a case study on BOT contract for the Labin B Power Plant (China) that the government officials took the materials unavailable risk to guarantee the fuel supply. Furthermore, the PFI contract for the BBC's White City 2 Development indicated that the space and technical capacity at White City 2 were under-utilized because experienced staff with professional skills were not utilized (PAC, 2006b).

4.2.3 Performance unavailable

The term performance unavailable refers to the possibility that asset performance is delayed or disrupted to deliver services outlined in the output specifications. As shown in Figure 4.2 (3), the performance unavailable risk event would delay or disrupt the services so that the operating contractor cannot meet the contract performance requirements, resulting in a contract breach (Hodge, 2004; PAC, 2005a). This would cause a contract remedies/penalties risk event in which the operating contractor must pay for the penalties and problems fixing costs according to contract terms and conditions (PAC, 2005a). The greater the cost for fixing a problem, the greater the loss for services. In addition, performance unavailable event would likely cause the contract disputes risk event that would cause contracting parties to argue over who should be held accountable for defective issues (Hodge, 2004). The more contract disputes exist between parties, the more contract remedies/penalties are incurred to settle the disputes. Therefore, the contract remedies/penalties risk event arising from contract break or contract disputes would lead to revenue loss risk event. Moreover, the performance unavailable would directly cause revenue loss because the infrastructure cannot deliver its services (Hodge, 2004). The cumulative revenue loss would likely cause the financial unavailable risk resulting in the lack of adequate credits by the contractor to pay debt. This would likely cause the insolvency of contractor risk event so that the contractor was unable to provide the services. Consequently, this would lead to a performance unavailable event again. This would create a vicious circle (the positive loop 1.)



<u>Figure 4.2 (3) Cause Loop Diagram for 'Performance Unavailable' Risk Event</u>

Furthermore, the performance unavailable event would cause a contract breach risk event when the operating parties could not provide services to meet the contract requirements. This event would lead to termination liability for which the operating parties pay according to the contract terms and conditions (Work Bank, 1999). This would result in revenue loss risk event and then financial unavailable. Consequently, these events create a vicious cycle (the positive loop 2) at performance unavailable risk again. As stated above, the financial unavailable risk event would likely result in resources unavailable because the project contractor would not have enough capital to purchase materials, equipment or manpower that are required to operate the infrastructure. This would also create a vicious circle (the positive loop 3) at performance unavailable risk. In general, the resources unavailable risk event would result in dynamic risk feedback effects on revenue loss during the operation phase.

The performance unavailable risk event would be likely to be triggered by several risk events such as the resource unavailable event (NAO, 2004a; PAC, 2005b; Work Bank, 1999) that the materials, equipment, and manpower of the contractor cannot meet the operation requirements for infrastructure; the construction delay event (Ghosh & Jintanapakanont, 2004; Hodge, 2004; Work Bank); failed commissioning tests, and inspection and testing delay events (Ghosh & Jintanapakanont) in which infrastructure is inoperable; and low operating productivity (EC, 2004c). System breakdown (Hodge), high maintenance frequency (Ghosh & Jintanapakanont) and accidents and safety issues (EC, 2002; NAO, 2004a) lead to the infrastructure that cannot be operated under normal conditions so that the contractor performance cannot meet the contract requirements; insolvency of contractor events occur (Ghosh & Jintanapakanont) which result in bankruptcy and the incapability to operate the infrastructure. Shorter asset life (EC, 2002; NAO, 2004a) occurs when the infrastructure is disposed of and thereby contracts can no longer deliver services. Industrial disputes (EC, 2003; Ghosh & Jintanapakanont) occur when strikes, industrial action, civil commotion, or public protests result in the inability to supply materials, equipment, and manpower to operate the infrastructure.

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. The members of the European Commission reported (EC, 2002) on the London Underground and indicated both the PPP project operation contractor, LUL, and infrastructure construction contractors, Infracos, should assume the responsibility to make the railway infrastructure available and in working condition. The members of the UK Public Accounts Committee criticized the government authority for not terminating the contract with the PFI project service contractor, LUL, when the LUL officials failed to deliver the project and broke the contract with London Underground (PAC, 2005a). Moreover, Hodge (2004) indicated in the Melbourne City Link case study that the project contractor, Transurban, initiated an AUD$37 million claim against the government authority for less demand and subsequent financial loss due to contract breach.

4.2.4 Design changes

The term design changes refers to the possibility that the changes of originally agreed design or the correction of the defective design lead to additional costs and time delay.

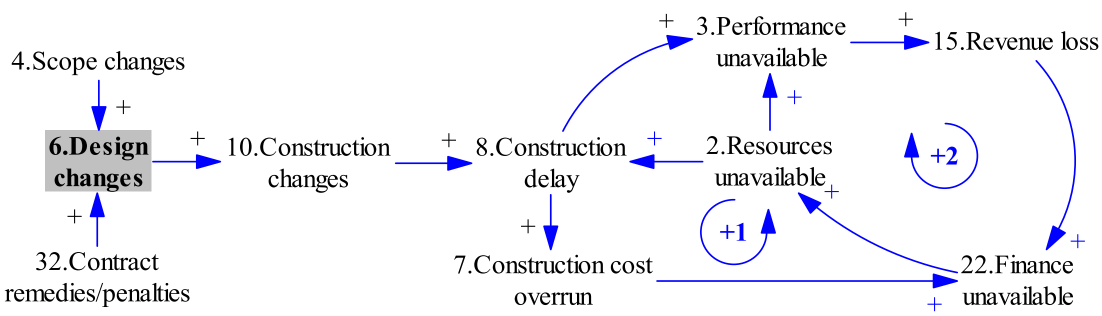


Figure 4.2 (4) Cause Loop Diagram for "Design Changes" Risk Event

As described above, the Figure 4.2 (4) shows that the design changes risk event would cause construction change events (PAC, 2006b) since the construction depends on the design. The more construction changes occur, the more construction delays would occur. The construction delays would lead to construction cost overruns at the construction stage, which would likely lead to finance unavailable events due to lack of money for construction. It would result in more risks in resources unavailable events and more risk in construction delays since the construction parties would not have adequate funds for employment. Again, this would create a vicious circle (the positive loop 1) and cause more risk in construction delay, and more construction cost overruns. This would also lead to performance unavailable event as the infrastructure would not be ready to deliver its services, resulting in revenue loss. Revenue loss would lead to financial unavailable events since there would not be enough credit to repay the debt. Furthermore, as previously described, the financial unavailable event would likely lead to a resources unavailable event because there would be inadequate amounts of money for the required tasks and resources. Consequently, it would create a vicious circle (the positive loop 2) and cause increased risk in performance unavailable events and more risk in revenue loss. In general, the design changes would cause dynamic feedback effects on construction cost overruns during construction phase and revenue losses during operation phase, respectively.

The design changes risk event would possibly be triggered by the risk events such as: (a) scope changes (PAC, 2006a) which result when design or construction parameters need to be changed to meet the new scope requirements; and (b) contract remedies/penalties (Hodge, 2004; PAC, 2006b) because the remedies for poor performance failed to meet output specifications.

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As in the PFI contract for the BBCs White City 2 Development, the members of the UK Public Account Committee (PAC) criticized the fact that £60 million was needed for additional costs (an increase of 29%) due to the design changes. Introducing variations after contracting inevitably increase risk costs (PAC, 2006b). In addition, Hodge (2004) indicated that the tunnel in the Melbourne City Link project needed to be redesigned after experts discovered it had defective construction; this led to delays in the tunnel opening. Furthermore, the Ghosh and Jintanapakanont (2004) reflected in their case study of the Thailand Underground Rail Project that design change is one of the most important factors regarding project delivery.

4.2.5 Construction cost overrun

The term *construction cost overrun* refers to the possibility that the infrastructure is incapable of delivering within the budget. As shown in Figure 4.2 (5), the construction cost overrun risk event would possibly lead to finance unavailable events due to inadequate capital availability for construction (Flyvbjerg et al., 2003; Reilly, 2005). This would likely lead to resources unavailable events in which there was not enough money to purchase materials and equipment, or to recruit skilful manpower for infrastructure. These events would result in construction delays in the construction phase and then construction cost overruns due to the need for purchasing new materials and equipment and paying for recruited manpower during the construction time delay. This creates a vicious circle (the positive loop 1) causing more risk in resources unavailable events, and more construction delays and cost overruns.

On the other hand, the construction delays would also cause performance unavailable events because the infrastructure might not be ready to deliver services. It would also lead to revenue loss since there would be insufficient credit to repay the debt, resulting in financial unavailable events. Consequently, this would create a vicious cycle (the positive loop 2) causing more risk in resources unavailable events resulting in more construction delays and performance unavailable events which would lead to more revenue loss.

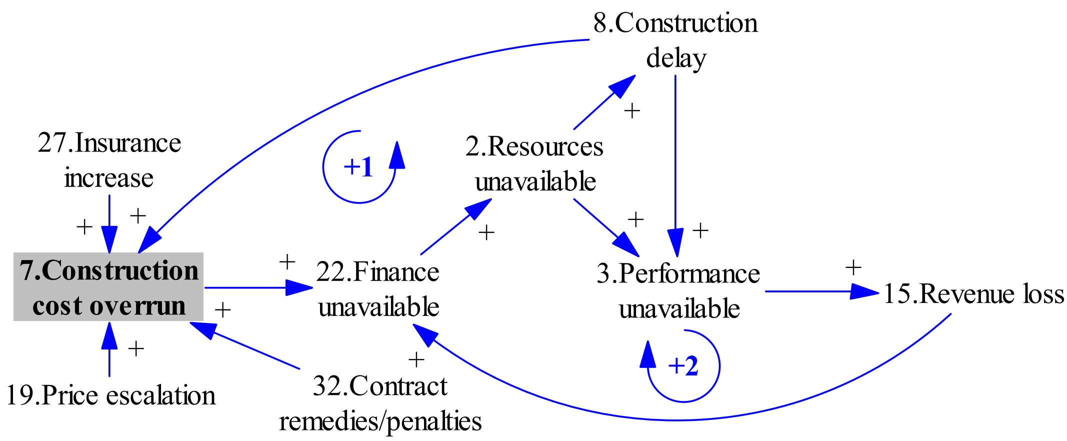


Figure 4.2 (5) Cause Loop Diagram for 'Construction Cost Overrun' Risk Event

The construction cost overrun event is often triggered by risk events such as: (a) construction delays resulting in extra costs incurred during the construction time delay; and (b) price escalation which is the unexpected increase in the labor costs, materials and equipments used for infrastructure construction (Hodge, 2004). Contract remedies/penalties is defined as the extra costs for remedies for defective construction which had failed to meet contract requirements (Hodge). Insurance increase occurs when the agreed project insurances substantially increases during the construction stage (Lu, 2004).

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. Many researchers have found (Flyvbjerg et al., 2003; Reilly, 2005) that in 9 out of 10 transport infrastructure projects, costs are underestimated resulting in cost overruns. For rail projects, actual costs are on average 45% higher than estimated costs (standard deviation =38). For all project types, the actual costs are 28% higher than the estimated costs (standard deviation = 39). Cost underestimation and cost overruns across 20 nations and 5 continents appear to be a global phenomenon that has not decreased over the past 70 years. For example, in the Boston, Massachusetts artery/tunnel project in the US, there is 196% of cost overruns; 110% of cost overruns exist for Great Belt rail tunnel in Denmark, 100% of cost overruns exist for Shinkansen Joetsu rail line in Japan; and 80% cost overruns exist for Channel tunnel in the UK and France, respectively.

4.2.6 Construction delay

The term *construction delay* refers to the possibility that the officials of the facility are incapable of delivering on time. As discussed, Figure 4.2 (6) shows that the construction delay risk events would likely cause construction cost overrun risk events because of the extra costs incurred during the construction time delay. Then, the construction cost overrun risk event would lead to a finance unavailable event due to lack of capital. This event then leads to resources unavailable events because of inadequate funds for materials and manpower for infrastructure construction. A construction delay would result. Again, the vicious circle would occur (the positive loop 1) and cause more risk in construction delay and more risk in construction cost overruns.

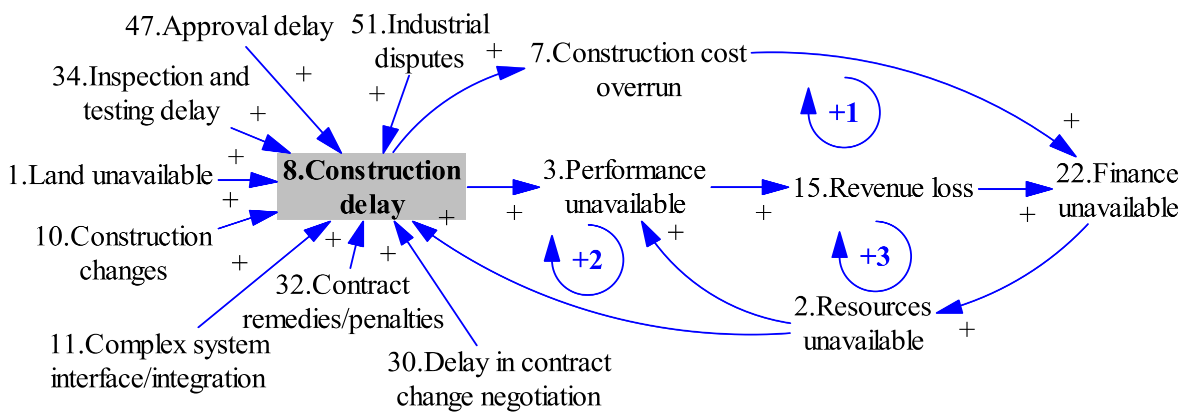


Figure 4.2 (6) Cause Loop Diagram for 'Construction Delay' Risk Event

On the other hand, the construction delay events would also cause performance unavailable events since the infrastructure would not be ready to deliver its services. This would lead to revenue loss based on bad credit issues which will result in financial unavailable events. Consequently, the positive loop 2 would cause yet again more risk in construction delays so that more performance unavailable events would result in more revenue loss. Furthermore, at the operating stage, the resources unavailable event would directly cause performance unavailable events due to the lack of materials or manpower for infrastructure performance. Positive loop 3 would cause increased risk in revenue loss. In general, the construction delay risk event would result in dynamic feedback effects on construction cost overruns during construction phase and revenue losses during the operation phase.

The construction delay would be likely to be triggered by the risk events such as: (a) land unavailable events (Hodge, 2004; Lu, 2004; Work Bank, 1999) which is when the land cannot be acquired on time for infrastructure construction; (b) resources unavailable events (NAO, 2004a; Work Bank) created when the required materials, equipments and manpower are not ready for construction; (c) construction changes (Hodge) which occur when additional time is needed to complete construction; (d) complex system interface/integration(PAC, 2005a) which is a likely delay in design and construction work since the designed and constructed infrastructure is incompatible with other public systems; (e) delays in contract change negotiation (Hodge; NAO, 2004b; PAC, 2003c) which is the additional time needed to reach an agreement between parties for construction changes; (f) contract remedies/penalties (EC, 2002; Ghosh & Jintanapakanont, 2004; Hodge) when time is needed to remedy construction problems in order to meet contract requirements; (g) inspection/testing delays (Ghosh & Jintanapakanont) when there is a delay in project commissioning because of additional time needed to passing inspection and testing; (h) approval delay occurs when the permits or licenses needed to proceed with construction as scheduled are delayed in processing; (i) industrial disputes (EC, 2003; Hodge) cause the time delay due to strikes, industrial action, civil commotion or public protests.

These risks have been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. Hodge (2004) indicated the government authority was to pay for construction delays due to delays arising from land acquisition and industrial disputes in the Melbourne City Link project. Moreover, Ghosh and Jintanapakanont (2004) reflected on the Thailand Underground Rail Project that construction delay was one of the most important factors leading to project delivery delay.

4.2.7 Defective construction

The term *defective construction* refers to the situation in which the equipment, system or facility cannot meet the construction standards and requirements. As shown in Figure 4.2 (7), the defective construction would cause failed commission tests (Hodge, 2004) at the end of construction stage that the facilities cannot pass the operating tests. This results in a contract remedies/penalties risk to fix defect issues which would result in design changes and construction changes. The more construction changes, the more construction delays would occur. As described above, the extra costs incurred in maintaining the existing materials and equipment, purchasing new materials and equipment and paying for recruited manpower during the construction time delay would lead to construction cost overruns.

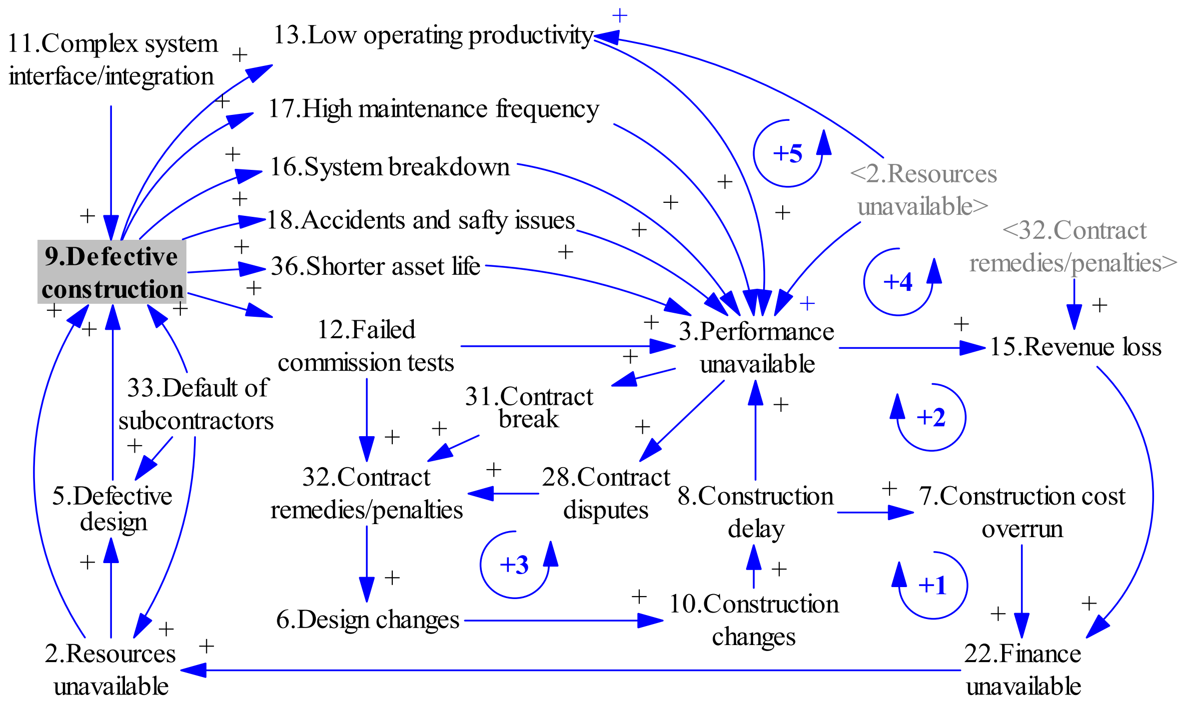


Figure 4.2 (7) Cause Loop Diagram for "Defective Construction" Risk Event

This fact would likely cause finance unavailable events due to lack of money for construction. This would further result in more risk in resources unavailable events which would likely cause more risk in defective design and more risk in defective construction since the construction parties may lack money. Consequently, this would create a vicious circle (the positive loop 1) causing more risk in defective construction, more risk in construction delay and construction cost overruns.

On the other hand, the defective construction would possibly cause a series of risk events at the operation stage such as: (a) low operating productivity (EC, 2004a; Ghosh & Jintanapakanont, 2004) which exists when system operating productivity is lower than the output specification that was setup in the contract requirements; (b) high maintenance frequency (Ghosh & Jintanapakanont) which occurs when the maintenance frequency is higher than expected so that the system cannot deliver service as required; (c) system breakdown (Hodge, 2004) when that system would completely fail to deliver services; (d) accidents and safety issues (Hodge) which occur when the system cannot be operated as safely as the contract required; (d) shorter asset life (EC, 2002; NAO, 2004a) occurs when the system has a shorter life than the expected time set up in the contract output specifications. All of these would lead to performance unavailable events in which the infrastructure is not able to deliver services as required in the contract output specifications. The more performance unavailable events occur, the more revenue loss occurs as well. This fact would be likely to cause financial unavailable events which would result in more risk in resources unavailable events in which the contract parties do not have adequate money to employ the required materials, equipment and manpower from suppliers to deliver services. Consequently, this creates a vicious circle (the positive loop 2) causing more risk in defective construction. In addition, performance unavailable events would lead to contract breaches that result in infrastructure performance inability to meet contract requirements. This would necessitate construction remedies/penalties risk events to fix defect issues. This would likely cause contract disputes risk events in which contract parties argue with each other relative to who should be responsible for defect issues. The more contract disputes occur, the more contract remedies/penalties costs would incur to settle the disputes. The contract remedies/penalties would result in design changes and construction changes yet again thus causing more risk in construction delay. Consequently, this again creates the vicious circle (the positive loop 3) causing more risk in performance unavailable events and more risk in revenue loss.

Furthermore, the resources unavailable events would create two vicious circles (the positive loop 4 and loop 5) causing more risk in performance unavailable events and low operating productivity respectively since there would not be adequate money to secure the required materials, equipment and manpower from suppliers to deliver service. In general, the defective construction risk event would result in dynamic feedback effects on construction cost overrun during construction phase and revenue losses during operation phase respectively.

The defective construction events would be likely to be triggered by the following situations: (a) the defective design event (Hodge, 2004) in which the design created cannot meet output specifications; (b) default of subcontractors (EC, 2002; Hodge, 2004; NAO, 2006; PAC, 2002a) so that the construction provider cannot meet contract requirements because the subcontractors are incapable or insolvent; (c) resources unavailable event (Lu, 2004; NAO, 2004a; PAC, 2002a, 2006b; Work Bank,

1999) such that the quantity and quality of the materials, equipment, and manpower required for construction are inadequate; (d) complex system interface/integration (PAC, 2002a; PAC, 2005a) in which the constructed system is difficult to interface with or incompatible with other public systems.

This type of risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. Hodge (2004) indicated relative to the Melbourne City Link project that a major consortium subcontractor, TOVJ, needed to pay the project contractor, Transurban AUD$153.6 millions to settle a dispute over delays and traffic problems caused by faulty construction.

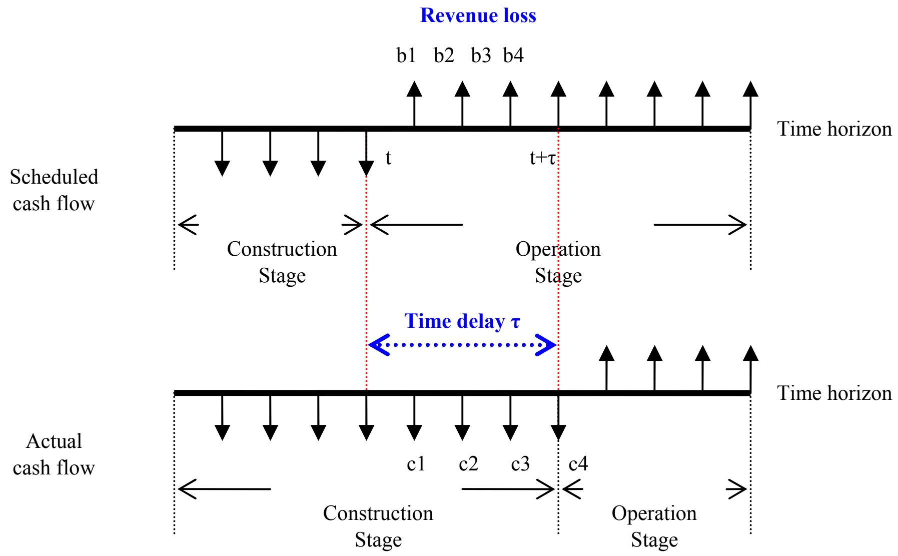
4.2.8 Notes on the Time Delay

In the Causal Loop Diagrams, the **TIME DELAY** would lead to 'revenue loss' in the following situations. This will be explained by cash flow diagrams.

Case 1: Construction time delay at construction stage would lead to revenue loss at construction stage. *A*s shown in the Case 1 cash flow diagram, the upper one that is the scheduled cash flow is compared with the lower one that is the actual cash flow. In the scheduled cash flow, the construction is scheduled to complete and start to operate at time t. But in the actual cash flow, the construction cannot be completed until time $t+\tau$. Therefore, the construction delay τ at CONSTRUCTION STAGE would lead to revenue loss (the scheduled income: $b1+b2+b3+b4$ from time t to time $t+\tau$) at CONSTRUCTION STAGE since the project cannot be operated to earn money from time t to time $t+\tau$. During construction delay τ, the new construction costs $c1+c2+c3+c4$ are born. Thus, the actual loss is $b1+b2+b3+b4+c1+c2+c3+c4$.

The more time delay τ in completing construction, the more delay in earning money. In other words, the more construction delays, the more revenue loss due to the increased performance unavailable (the project cannot start to service). This would lead to a serious financial problem because there is no revenues in the expected timeline to repay the debt (principle and interest) borrowed from the financing institutions for investment at the construction stage. Furthermore, the financial unavailable would lead to resources unavailable due to a lack of capital to recruit manpower, and purchase materials and equipment for construction, therefore causing construction delays. Consequently, this would create a vicious cycle that increases risk in construction delay which leads to performance unavailable which leads to revenue losses which lead to financial unavailable which leads to resource unavailable which leads to more risk in construction delay.

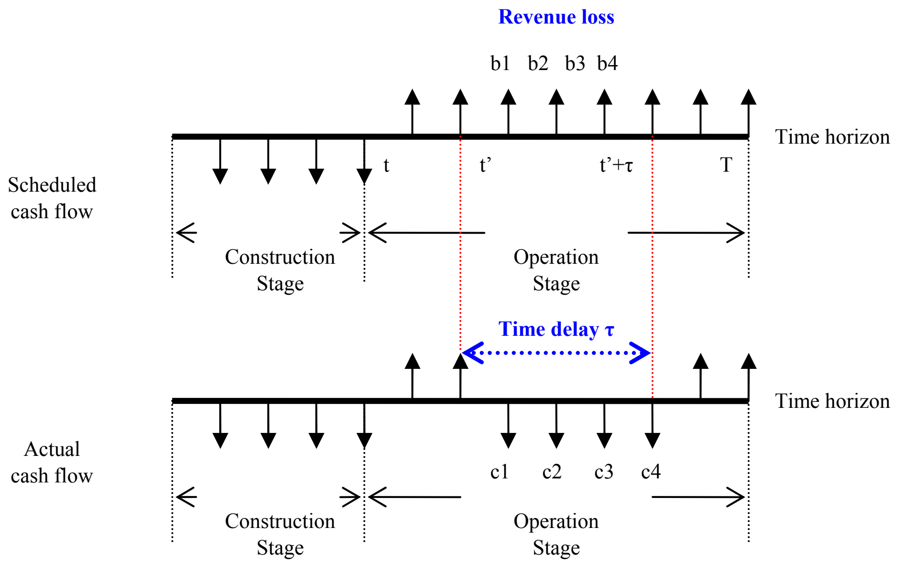
Therefore, in such a case, the PPP projects ***don't generate income until completing construction but revenue loss during construction delay at construction stage*** due to performance unavailable (project cannot be started for services) which would lead to financial unavailable which in turn would ***generate effect on resource unavailable*** which would lead to more construction delay at ***construction stage***. The loop 2 in the Figure 4.2.(2) is such a case.



Case 1: Construction time delay at construction stage would lead to revenue loss at construction stage

Case 2: Operation time delay at operation stage would lead to revenue loss at operation stage

As shown in the Case 2 cash flow diagram, the THSR project is scheduled to operate from time *t* to time *T*. But in the actual cash flow, the project cannot be operated to earn money from time *t'* to time *t'+τ* due to performance unavailable (services are stopped ***to repair system breakdown or solve the accidents & safety issues***). Therefore, the operation delay *τ* at OPERATION STAGE would lead to revenue loss (the scheduled income: *b1+b2+b3+b4* from time *t'* to time *t'+τ*) at OPERATION STAGE since the project cannot be operated to earn money from time *t'* to time *t'+τ*. During operation delay *τ*, the new costs *c1+c2+c3+c4* to repair system breakdown are born. Thus, the actual loss is *b1+b2+b3+b4+c1+c2+c3+c4*.



Case 2: Operation time delay at operation stage would lead to revenue loss at operation stage

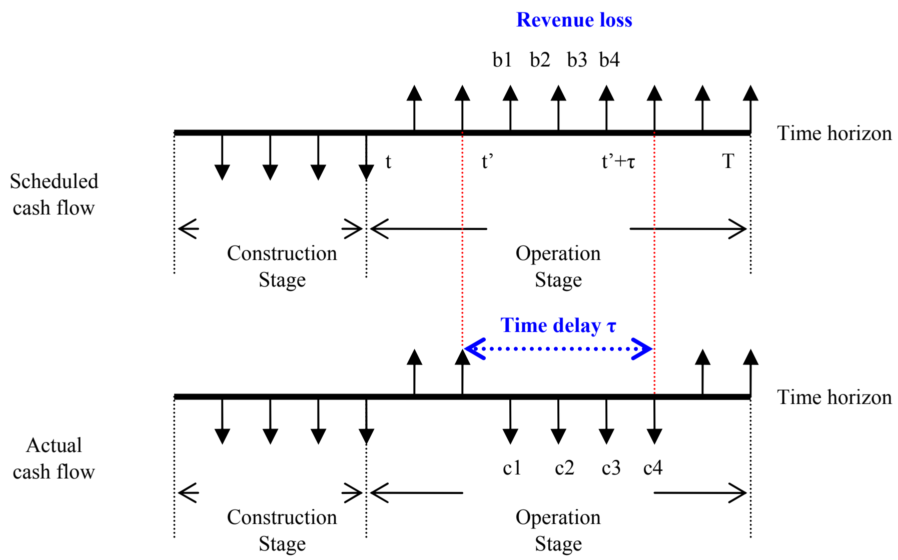
At operation stage, project services are stopped or delayed (performance unavailable) due to some events such as system breakdown, accidents and safety issues. This would create a vicious circle of increased risk in revenue loss (no income) during OPERATION STAGE which would lead to financial unavailable which would lead to resource unavailable (there will be not enough capital to purchase materials, equipment or to recruit manpower required to operate the project.) which would lead to more risk in performance unavailable. The loop 3 in the Figure 4.2.(3) is such a case. (Note: performance unavailable (variable 3) is caused by some events such as system breakdown (variable 16). Thus, the dependent variable 3 is the function of the independent variable 16.)

Case 3: Construction time delay at operation stage would lead to revenue loss at operation stage

As shown in the Case 3 cash flow diagram, the THSR project is scheduled to operate from time t to time T. But in the actual cash flow, the project cannot be operated to earn money from time t' to time $t'+\tau$ due to performance unavailable (services are stopped ***to remedy defective construction***). Therefore, the construction delay τ at OPERATION STAGE would lead to revenue loss (the scheduled income: $b1+b2+b3+b4$ from time t' to time $t'+\tau$) at OPERATION STAGE since the project cannot be operated to earn money from time t' to time $t'+\tau$. During construction delay τ, the new costs $c1+c2+c3+c4$ to remedy defective construction are born. Thus, the actual loss is $b1+b2+b3+b4+c1+c2+c3+c4$.

The defective construction that refers to civic work cannot meet the construction standards and contract requirements will need to be remedied or reworked. At operation stage, the remedy or rework (construction changes) for defective construction would lead to construction delay at OPERATION STAGE, because the extra time is needed to remedy construction defects. This would lead to performance unavailable that the project cannot be operated for services during remedy or rework. Consequently, it would create a vicious circle that increases risk in revenue loss during OPERATION STAGE which would lead to financial unavailable which in turn would lead to resources unavailable which leads to more risk in performance unavailable. The loop 2 in Figure V4 and the Loop 2 in Figure V5 of the Appendix V are examples of such a case. A real case is the Melbourne City Link (Hodge, 2004) addressed in Appendix V5. The defective construction was found out in two tunnels of the Melbourne City Link, which led to revenue loss due to the need to seal tunnels for construction rework at operation stage.

From this description, only revenue loss during CONSTRUCTION STAGE leads to construction delay during CONSTRUCTION STAGE and revenue loss during OPERATION STAGE leads to operation delay or construction delay during OPERATION STAGE. There is no such case that revenue loss during OPERATION STAGE leads to construction delay during CONSTRUCTION STAGE.



Case 3: Construction time delay at operation stage would lead to revenue loss at operation stage

Chapter 5 Taiwan High Speed Rail Project Risks

5.1 The Background of THSR

The network for Taiwan high speed rail (THSR) is shown in Figure 5.1.1. The THSR consists of a 345km (220 miles) route from northern Taiwan to southern Taiwan. The THSR is designed for express trains capable of traveling at up to 350 km/h. The THSR allows travelers to make the trip in roughly 90 minutes as opposed to the current 4 to 6 hours travel time by conventional rail or auto highway system. The total cost for this project is currently estimated to be USD $16.5 billion; it would be one of the largest privately funded transport schemes to date in the world (Mott MacDonald, 2007).

This project is delivered in build-operate-transfer (BOT) mode. The project consortium, the Taiwan High Speed Rail Corporation (THSRC), won the bid and signed the Taiwan High Speed Rail Construction and Operation Contract and Station Area Development Contract with the project authority, the Bureau of High Speed Rail (BHSR), Ministry of Transportation and Communications (MOTC) on July 23, 1998. The THSRC was officially authorized with a 35-year concession for THSR construction and operation, and a 50-year concession for station specific zone developments. Private investment companies committed to civil works, stations, track work, electrical and mechanical systems, maintenance bases and financial costs of approximately $13.1 billion in U. S. dollars.

Actual construction began in March 2000 and running tests started in January 2005. With time overruns of one and half years, the operation began on January 5, 2007. Initially THSRC officials expected the ridership to be 163,000 passengers per line daily, but projected that eventually ridership will be 336,000 passengers per day by the year 2033. This will see the high-speed line account for 5.5% of the transportation market in Taiwan (BHSR, 2009).

To avoid conflicts with other forms of transportation where ever possible, there are 10 new stations, along with large number of new bridges, tunnels and viaducts. As illustrated in Figure 5.1.2, no less than 300km of the lines totaling 345km in length have been built either in tunnels or on viaducts. The route includes steep gradients to cross the terrain. Initially, THSPC looked at German and French high-speed technology to form the core system for THSR which uses German ICE power cars and

French TGV Duplex intermediate trailers. However, Japanese technology was ultimately chosen, with Kawasakis 700 series Shinkansen trains used as models. The finished product has been classified as 700T and the first train was completed in January 2004 (Railway-technology.com, 2007).

Figure 5.1.1 The THSR Network, 700T Train and Shingchu Station(BHSR, 2009)

Figure 5.1.2 Tunnels and Viaducts on The THSR Network(BHSR, 2009)

The project had been plagued by repeated controversy, including allegations of poor quality construction, claims of unresolved safety concerns based on three derailments during tests in early November 2006, and the 1-year delay. Supporters of the project believed THSR would help relieve traffic congestion along the heavily traveled western corridor while providing the advantages of greater safety, higher transit volume, low land occupancy, energy economy and low pollution. It had also been stated that the THSR will help to promote balanced development for western Taiwan (Shan, 2006).

5.2 Risk Scenarios of THSR Project

The interview survey was conducted to explore the risk scenarios of THSR project. The purposes of the interview survey were: (a) to modify the causal loop diagrams created in Chapter 4 to ensure that the physical risk causal relationships fit the likely risk scenarios for the applied case of the THSR project; (b) to gather parameter information for risk variables to model risk cost network for the THSR project. The timeline and method for interviewing are referenced in Appendix II. The interview statements for 52 risk scenarios of THSR project were completely addressed in Appendix VI. Some indicative risk scenarios were extracted from Appendix VI and discussed in the following section.

5.2.1 'Land Unavailable' on THSR

As discussed in the Section V1 and the CLD illustrated in Figure V1, failure to acquire the lands on schedule would be possibly be a result of industrial disputes risk events, and would likely cause construction delay risks. Relative to the THSR project, the interview statements are:

> "The overall length of lands for the whole route of THSR runs through the west corridor of Taiwan is about 345 kilometers. Among of them, the private lands occupy about 789 hectares, which were acquired by expropriation, whereas the public lands occupy about 101 hectares, which were acquired by appropriation. These include lands for routes and five station zones that include Taoyuan Station, Hsinchu Station, Taichung Station, Chaiyi Station and Tainan Station. In addition, the lands for constructing and operating six maintenance depots and bases from north Taiwan to south Taiwan are required, which includes Hsichih Depot, Liuchia Depot, Wujhi Depot, Taibao Base, Main Workshop and Tsoying Depot. The private and public lands occupy about 221 hectares. ***Most of the scheduled land acquisition can be completed to support the start of other work packages, but a delay in land acquisition on schedule would seriously delay the completion of other work packages including track work,***

civic work, station construction, depot construction and signal & communication systems of the M/E core system."

"All of land acquisition requires a negotiation with the land owners, a setup of property rights of superficies and an approval request from the related government authority for lands. However, you know there are 1,607 houses, 225 factories, 1,095 graves, and 70 stables on the lands. Thus negotiation for acquiring these lands is very complicated. ***The major delay was still caused by several disputes and strikes from the land owners*** from Taipei to Kaohsiung due to various reasons like that the land owners were usually unhappy with the acquisition prices, or they cannot find another places for settle, or the Green groups wanted to stop this project because they thought it would have a great impact on the environment. In addition, ***the minor delay was caused by obtaining an approval from the government authorities to change property right for industrial purpose***. This project has been approved by central government, but property right change is still under control of local governments. Some of local governments did not completely support land acquisition, so most of the approval delays for land acquisition are caused by local government."

"According to the past experiences, there were about 5% -11% of land owners would argue against land acquisition, and about ***3%-13% of processing time for land acquisition would be delayed for the public transport projects; the larger projects, the more delay.***"

"The land acquisition is a preliminary job before starting other work packages. Our job is to remove obstacles and ensure land acquisition can be completion as requested by the Fourth Division (which is responsible for Engineering Management and Contract Performance Supervision). The Fourth Division estimated that ***one year behind construction would incur additional construction administration cost about NT$5.5 b***, which includes manpower costs, material and equipment maintenance costs and interests for purchasing material and equipment, etc."

From the above interview statements, the general risk causal loop diagram for land unavailable shown in Figure V1 fits the likely scenarios for the THSR project. But, from the statements such as, "The major delay was still caused by several disputes and strikes from the land owners…", and "the minor delay was caused by obtaining an approval from the government authorities to change property right for industrial purpose," the direct causes of land unavailable were industrial disputes and approval delays. Therefore, the direct cause and consequences of land unavailable risk events shown in Figure V1 are modified in Figure 5.2.1 to fit the THSR project.

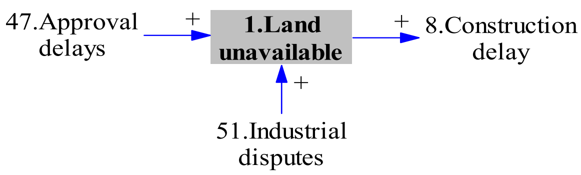


Figure 5.2.1 The Direct Cause and Consequence for 'Land Unavailable'

5.2.2 'Resources Unavailable' on THSR

As discussed in the Section V2 and the CLD shown in Figure V2, resources including manpower, material, and energy could not meet the contract requirements for construction and operation which had possibly been triggered by financial unavailable issues of default by subcontractors, industrial disputes and Force Majeure, and would likely cause construction delay. As for the THSR project, the interview statements are:

> "***No doubt the subcontractors are the most important resource for supplies.*** There are 12 subcontracts for civic works: C210 and C215 were carried by joint venture of subcontractors, Obayashi Corp. of Japan and Fu Tsu Construction Co. Ltd of ROC; C220 was carried by joint venture of Daiho Corp. of Japan and Chiu Tai General Contractor Co. Ltd of ROC and Kou Kai Construction Co. Ltd of ROC; C230 by joint venture of Hyundai Engineering & Corp. of Korea, Chung Lin General Contractor Co. Ltd of ROC and Zen Pacific Civil Contractor Co. Ltd of Hong Kong; C240 by joint venture of Hyundai Engineering & Corp. of Korea and Chung Lin General Contractor Co. Ltd of ROC; C250 by joint venture of Hochtief AG of German, Pan Asia Corp. of ROC and Ballast Nedam international of Holland; C260 and C270 by joint venture of Bilfinger and Berger Bauaktiengesellachaft of German, and Continental Engineering Corp. of ROC; C280 by joint venture of Samsung Corp. of Korea, Korea Heavy Industries & Construction Co. Ltd. of Korea and International Engineering & Construction Corp. of ROC; C291 and C296 by joint venture of Shimizu Corp. of Japan and Evergreen Construction Corp. of ROC; C295 by joint venture of Italian Thai Development Public

Company Limited of Thailand, Evergreen Construction Corp. of ROC, and Pacific Electric Wire & Cable Company of ROC. As for station construction, there are 6 subcontracts: S215 was carried by subcontractor Futsu/Obayashi JV; S220 by Daiho; S250 by Taisei/CEC/CTCI/Taian JV; S280 by Teco/Takenaka JV; S290 by Evergreen/Shimizu JV; S395 by SECI. The Core System for Electrical and Mechanical Equipment is supplied by joint venture of TSC which includes Japan Shinkansen System and other 6 Japanese companies for train units, signaling system, electric power and electric train system, telecommunication system, general electrical and mechanical equipment along the rail, training simulator and personnel training, etc. Tract work contract was carried by subcontractors TSC and TSIEC. As for maintenance depot construction, the detailed design contract D370 was carried by subcontractor, Po-Chen International (USA); D220 was carried by Shi-Ya Construction; D290 and D250 by joint venture of Chung-Ding Construction, Do-Yuan Engineering, and Chung-Lu Construction; D295 by joint venture of Do-Yuan Engineering and TVBJ (Australia); D502 by Safop (Italy); D503 by Vector Systems Pte. Ltd (Australia), etc."

"Apparently, ***a subcontractor's skill and coordination capability*** are the most important factors to ensure subcontractors resources ***can be used to properly build, integrate, and perform heterogeneous systems to meet the contract requirements.*** The Taiwan high speed rail is a high-technology project. All of the civic work, track work, mechanical systems and electrical systems were types of innovative technologies. Of special importance was the fact that Taiwan has complicated geographical features and natural conditions such as soil condition, underground water, mountain tunneling, typhoon, flood, and earthquakes, and the like which need high-technology solutions to overcome. The subcontractor selection should ensure it ***has enough skilled technicians and equipment to implement high-technology***. Moreover, there are about 50 major engineering items for all work packages including civic engineering, track work, power system, telecommunication system, and signaling system, etc., which need to be properly ***integrated to ensure the whole system can work well***. If any subcontractor for an item failed, the whole THSR project would risk failure. Most of these outsourcing contracts (subcontracts) were contracted by international tendering and carried out by joint venture of local and international companies. ***The differences on language, culture, technique between subcontractors would challenge whether the subcontractors and***

concessionaire can coordinate well to ensure the whole system can be built and performed to conform contract requirements."

"Natural calamity is another threat to disrupt resource supplies. Like Taipei Mass Transit, the service was stopped before due to flooding caused by a typhoon. The THSR has suffered from the 921 (September 21, 1999) earthquake that led to serious equipment and facility damage. We required the concessionaire and their subcontractors who have the Standard of Procedure to deal with the risk from the typhoon and earthquake often happens in Taiwan, which would likely to cause equipment breakdown and power unavailable so that the construction or operation is forced to disrupt."

"The residents along the THSR line who suffered from ***the noise of THSR*** often protested against the THSR project construction and operation. Some of the project performance would therefore be stopped. ***The acceptable level is less than 75 decibels to continue for 8 minutes.*** The point test indicated that it often reaches ***76 to 94 decibels*** which would often cause the arguments and protects from the residents to stop project services."

"Another problem is ***the financial capability of contractor*** which is a potential risk to delay resource supplies and would lead to serious construction and service delay. The concessionaire would be easy to suffer financial difficulties before complete construction, especially when there was a great delay. That is because the project is only expanding with no revenue at construction phase. At operation phase, especially at the beginning of services, like Taipei Mass Transit, the demand is usually less than expected. This would lead to financial difficulties, too. I would say that the financial difficulties for concessionaire would cause significant impact on resource supplies that are required for THSR construction and operation."

"According to the past experience of the similar transport projects like Taipei Mass Transit, the minimum average delay for construction due to the lack of resource supplies is about ***45 days***. According to the contract mechanism, the Fourth Division of BHSR, which is responsible for Engineering Management and Contract Performance Supervision will step in when the lack of resources would delay each work package behind the schedule until ***120 days***."

From the above interview statements, the researcher determined that the direct cause and consequence for land unavailable events shown in Figure V2 fit the likely scenarios for the THSR project.

5.2.3 'Performance Unavailable' on THSR

As discussed in the Section V3 and based on the CLD shown in Figure V3, the project performance were delayed or disrupted in delivery of services which lead to revenue losses, which were possibly triggered by construction delays, resource unavailable, failed commissioning tests, inspection and testing delay, low operating productivity, system breakdown, high maintenance frequency, accidents and safety issues, insolvency of contractors, shorter asset life, and industrial disputes. Relative to the THSR project, the interview statements are below:

"There would be lots of challenges to start running this state-of-the-art project. The preliminary condition is that ***all of work package should be completed and passed the inspection & commissioning tests on schedule*** for operation. ***Annual delay to start operation would be likely to cost about NT$19.3 billion including NT$13.8 billion for interest and NT$5.5 billion for operating cost***. Moreover, the basic requirement is that we need high quality engineering work to build and operate this high-technology system which should ***dynamically integrate*** trains, signaling and communication systems, and power systems to meet the commissioning test requirement that the THSR is able to efficiently and safely operate under high-speed running in 350 km/hr. The train and track are Japanese specifications, but the signaling and communication systems are Germany specifications. They need to be ***integrated very well*** to ensure ***the whole THSR system*** can be operated without any defect during ***its expected service life***."

"For example, if the Turn Out system that is used to guide the trains on the right track is ***out of order***, then the regular trains would be canceled or delayed for services, which would cause that ***the whole system broke down*** or even lead to the ***rail crash***. The unreliable integration between train, track signaling and communication system will then ***need frequent modification and maintenance***. All of these ***would reduce operation efficiency***."

"Another major challenge is the ***skilled manpower and communication issue***. For example, a central control room has been built to monitor and operate THSR for the entire 345km line. It is similar to the brain controlling the body to work properly. It needs to control access to and from depots. It controls the in-cab APT and interlocking that allow route-setting and locking functions to be performed at the stations and depots along the route. Any problem on the controlling system would cause improper operation and even accident and safety issues. However, we require ***the skilled and practical manpower with good communication and coordination*** to use this state-of-the-art artificial intelligence. Originating from different countries, the current staff in the central control room may be skilled to use the central control system but speak different languages. There would be potential risk to reduce the operation quality and efficiency due to ***communication and coordination problems*** between the train drivers, maintenance staff and the staff in the central control room."

"When the THSR stops or there is a delay in service, the direct consequence is revenue loss. Being unable to meet service requirements will be ***penalized***. We estimate that the maximum number of trains that would delay service on time for ***more than 30 minutes in a month is about 45 trains***, and there would be ***no train delay*** if the operation company can monitor and control whole system well. According to the contract terms and conditions, ***the half of ticket fare*** should be refunded to every rider if the train behind the schedule ***more than 30 minutes***; ***the whole ticket fare*** should be refunded if delay ***more than one hour***. Furthermore, the cumulative delay service on time would likely to cause ***20% of trains*** that are unable to provide service as scheduled. We estimate that the ***break-even daily capacity is about 60 trains***. If the number of daily in-service train is less than the break-even daily capacity, then it would lead to revenue losses."

From statement that "all of work package should be completed and passed the inspection and commissioning tests on schedule for operation," the inspection and testing delay and failed commissioning tests risk events are included in construction delay. Therefore, they are removed from CLD shown in Figure 4.2.3. From the above statements, the researcher indicated that resources unavailable (the required for skilled and practical manpower), system breakdown, accidents and safety issues, high maintenance frequency, and poor cooperation/coordination (communication and coordination problem) would cause low operating productivity (reduce operation efficiency) and then lead to performance unavailable events which cannot meet contract service requirements (contract breach). Thus, the Figure V3 is modified as Figure 5.2.3 to fit the THSR project.

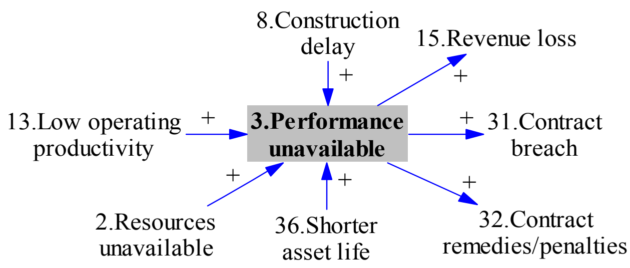


Figure 5.2.3 The Modified Direct Cause and Consequence for 'Performance Unavailable'

5.2.4 'Scope Changes' on THSR

As discussed in the Section V4 and the CLD shown in Figure V4, the project scope changed after contracting which lead to time delay and extra costs, possibly triggered by law/policy changes political interference and Force Majeure. Relative to the THSR project, the interview statements are below:

"The scope change would be a major source to cause construction cost overrun. The ***politics*** were one of the typical reasons to make the output specifications radically changed. Initially, there were 3 stops sited in the cities of Taoyuan, Taichung and Kaohsiung along the whole 345 km route from the north to south of Taiwan planned for THSR project. The purpose is to make the THSR a real high-speed train with minimum stops. However, the citizens of cities that had no stops worried that it would be bad news to their metropolitan development in the future. These cities officials strongly expected that if they were on the route of THSR that it would help to boost economic development. Later on, these cities started to lobby the central government to influence policy and plan with the assistant of legislators. ***Eventually the stops were changed from three to six.***"

"During construction the 9/21 earthquake happen in 1999 which caused the most serious damage in the late 20th century' this changed lots of rules for the THSR. ***The policy-maker therefore changed rule that requires earthquake-proof technology.***"

"Furthermore, the THSR route passes the South Taiwan Science Park, one of the major manufacturer pools of electronics and semiconductor in the world. When the trains pass, it will cause unendurable vibration that would significantly influence the products that are manufactured on the delicate instruments. ***The semiconductor industry officials strongly argued*** that the public and private sector should sort it out together. Similarly, ***the residents*** who live near the whole THSR route often **protested the enormous noise** produced by the THSR. Thus, ***the rules were changed to request the system design for the higher level of earthquake-proof, vibration-proof and noise-proof technology for THSR project.***"

From these statements, it is apparent that scope changes are usually caused by law/policy changes that arise from political interference (political reasons), Force Majeure (the earthquake), industrial disputes (the industrial argument and protest), and thus lead to design changes. Thus, the direct causes and consequences for scope change shown in Figure V4 were modified as Figure 5.2.4 to fit the THSR project.

Figure 5.2.4 The Modified Direct Cause and Consequence for 'Scope Changes'

5.2.5 'Defective Design' on THSR

As discussed in the Section V5 and the CLD shown in Figure V5, the defective design would lead to a defective system that would potentially cause defective construction and performance unavailable events, possibly catalyzed by defaults of subcontractors and resources unavailable events. Relative to the THSR project, the interview statements are below:

> "It would be very awful that the THSR is the state-of-art in high-speed rail system, but employs an old ticketing system. The ticketing system is one of cases on ***defective design that would make a defective facility***. For example, the online booking system is very unfriendly. Numerous customers have complained that it takes at least 40 minutes to finish processing a transaction because the system must simultaneously handle the seat arrangements and confirm that the banks can successfully collect the money. Overbooking also continues to occur. Moreover, the malfunction rate for ticket-checking at the gate is still higher than 5%. Frankly speaking, it seems that the THSR was doing flight business. Why do the customers need to go to the platform 20 minutes before train starts? It seems like boarding time to take a flight. That is a train, rather than a plane! This case told us that ***the subcontractors*** are very important and that they need to be familiar with the THSR operations, and ***have skilled design staff*** to design and build the ticketing system for the THSR, rather than copying the current flight ticketing system. Obviously their performance cannot meet contract requirements, so our supervising team has asked them ***to change design and modify ticketing system*** to meet THSR output service requirements."

> "Another serious issue is that the defective design would cause problem on ***defective construction about system interface and integration***. The core power system, train vehicle, electrical and mechanical system, and signaling system are a mix of European and Japanese systems. The Japanese train vehicle only fits a one-way and one direction signaling system, but the European signaling system is one-way & two directions system. Apparently, they are not compatible. The benefit for one-way and one direction is that two trains will not crash into each other. The drawback is that once the accident happens, the whole line should be closed. On the contrary, the benefit for the one-way and two directions system is that the route will not need to be closed. However, its drawback is the whole signaling system becomes very

complex so that its difficult to integrate with other systems. Any problem about ***unskilled technicians***, ***human ignorance***, ***poor communication***, and even ***system disorder*** would lead to ***serious rail crash***. Our supervising team has also asked them ***to modify information control systems*** for signaling and communication systems to meet the THSR output service requirements."

Based on these statements, the defective design would normally be caused by default of subcontractors, and resource unavailable (unskilled design staff), and could easily lead to defective construction (defective facilities) and complex system interface/integration. Thus, the direct causes and consequences for defective design shown in Figure V5 were modified as Figure 5.2.5 to fit the THSR project.

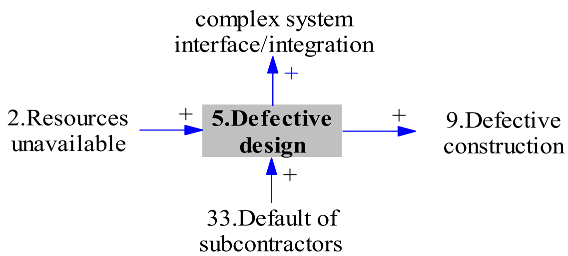


Figure 5.2.5 The Modified Direct Cause and Consequence for 'Defective Design'

Chapter 6 Risk Network Modelling and Simulation

As discussed in Chapter 2, the base case public sector comparator (PSC) will be a benchmark for different project bidding proposals when choosing the preferred bidder to provide the best value for money, and the NPV is proposed to measure the long-term value for money for a PPP project. In section 6.1, the project NPV cash flow model was constructed to describe risk-free cash flow which does not include any valuation of risks. The risk network addressed in section 6.2 will be modeled to link with the NPV cash flow model, which will be able to produce time-profiles of NPV for the base case (PSC).

According to an accounting principle, the project cash flow can be calculated as: *Net Cash Flow F = [sum of revenue (operation revenues) – sum of expense (construction costs + operation costs + interest + depreciation))*[1-tax rate] + annual raising capital - annual principal repayment + depreciation*, which will be further converted to be net present values discounted over time. The details are described in Section 6.1.7.

Based on the major components of a project NPV cash flow as stated, the researcher divided the structure of risk-free cash flow model (Figure 6.1) into one major model linked with six sub-models. The project cash flow model is used to calculate NPV values and the six sub-models are: (a) operating revenue sub-model which is used to calculate operation costs; (b) construction cost sub-model which is used to calculate construction costs; (c) operating cost sub-model which is used to calculate operation costs; (d) project financing sub-model which is used to calculate principal repayment and interest; Depreciation sub-model is used to calculate depreciation; (e) discount rate sub-model which is used to calculate discount rate.

In Section 6.2, a risk cost network for the expected risk effects was modeled and linked to the related sub-models to address its impact on project cash flow. All of the sub-models linked with the risk cost network were linked to the project cash flow model in order to calculate NPV values by compounding all risk effects. This way, the model structure was clear for ease of management, especially when observing the NPV value changes by changing a risk variable.

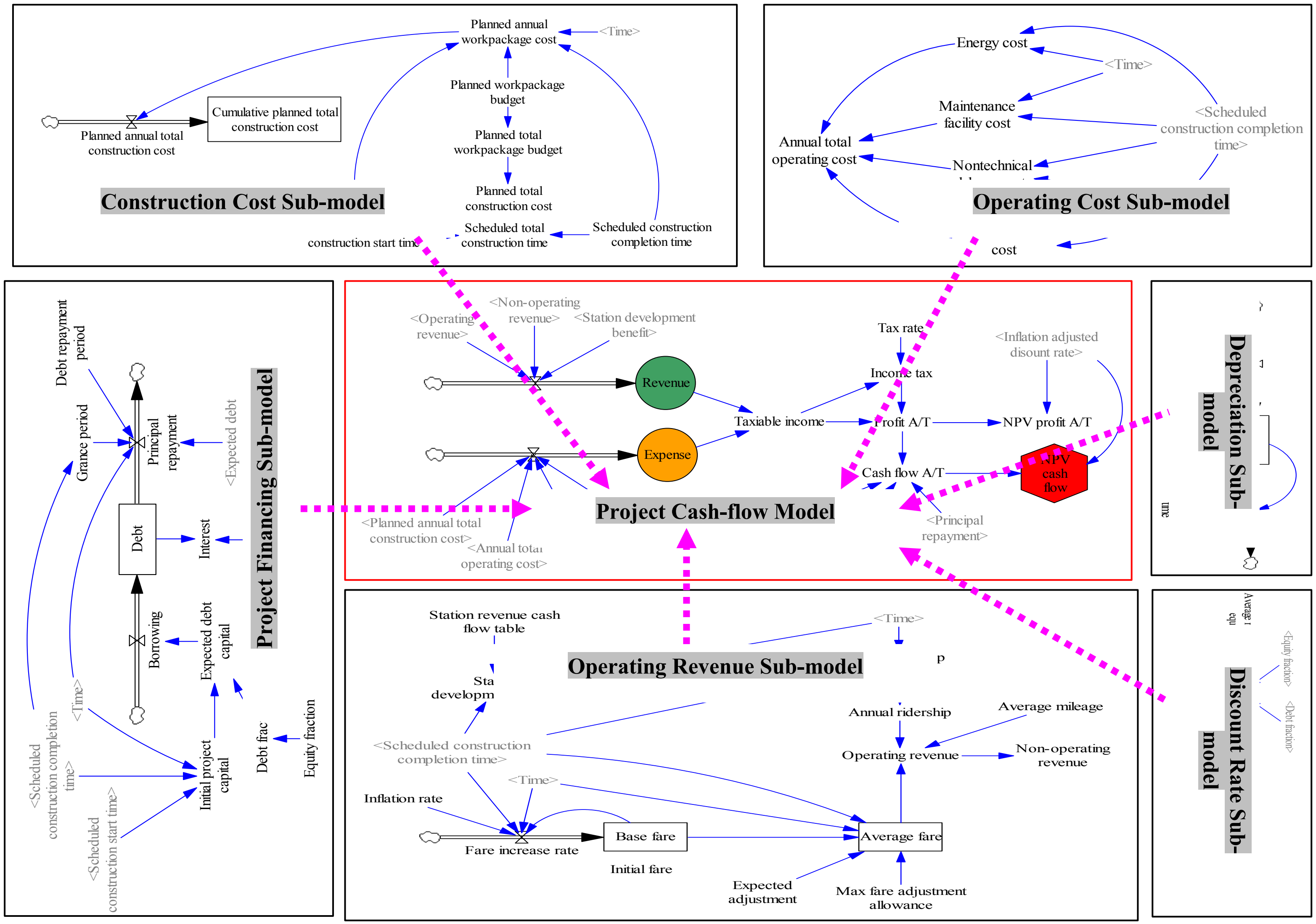


Figure 6.1 The NPV Cash flow Model with Its Six Sub-models

6.1 Project NPV Cash Flow Modelling

The model illustrated in Figure 6.1 was used to model the planned spending profile, which includes contingency plan budget, NT$54.2 billion to form the public sectors (BHSRs) budgeted model (project NPV cash flow: the budgeted). In Section 6.2, all risk cost networks built by SD modelling are linked to Figure 6.1 to form risk estimated project cash flow model (project NPV cash flow: the estimated) that was proposed in the research methodology. There are two types of data used for comparison after the whole risk models were developed: (a) the budgeted by BHSR, and (b) the risk-adjusted by SD modelling. These two cost profiles were compared with each other to determine whether the approach proposed by the research was better than the BHSRs approach. The variables for Figure 6.1 are described as the following subsections.

6.1.1 Construction Cost Sub-model

The planned total construction budget, excluding contingency cost,(the risk cost is budgeted as NT$54.2 billion by BHSR) for the THSR project is about NT$377.4 billion (exchange ratio: 1US$ = 33 NT$ in 1998) which is budgeted for the eight work packages consisting of: civil work (NT$138.2 billion), track work (NT$21.5 billion), station construction (NT$18.7 billion), depot construction (NT$14 billion), Mechanical/Electrical (M/E) core system (NT$79.3 billion), land acquisition (NT$55.8 billion), Taipei underground rail (NT$28.9 billion), design and supervision (NT$21 billion) (Hsu, 2000). Therefore, the planned total construction costs are the sum of construction cost of all work packages:

$$PTCC = \sum PWB_i$$

Where

PTCC: planned total construction cost;
PWB_i: planned work package budget;
i: Work package index

As for construction time, the civil work was scheduled to start in March 2000 and was completed by November 2004; the track work was from January 2002 to April 2005; station construction was from January 2002 to April 2005; the depot construction was from January 2001 to

April 2005; the M/E core system was from September. 2003 to September 2005; the land acquisition was from July 1998 to January 2002; the Taipei underground rail was from July 1998 to April 2005; the design and supervision was from July 1998 to September 2005 (Hsu, 2000). Therefore, the scheduled start time for construction was the earliest start time for all work packages:

$$SCST = Min\ (SST_i)$$

where

SCST: scheduled construction start time;
SST_i *= scheduled start time of work package;*
i: Work package index

The scheduled completion time for construction was the latest completion time for all work packages:

$$SCCT = Max\ (SCT_i)$$

Where

SCCT: scheduled construction completion time;
SCT_i *= scheduled completion time of work package;*
i: Work package index

Thus, the scheduled total construction duration was:

$$STCD = SCCT - SCST = Max\ (SCT_i) - Min\ (SST_i)$$

Where

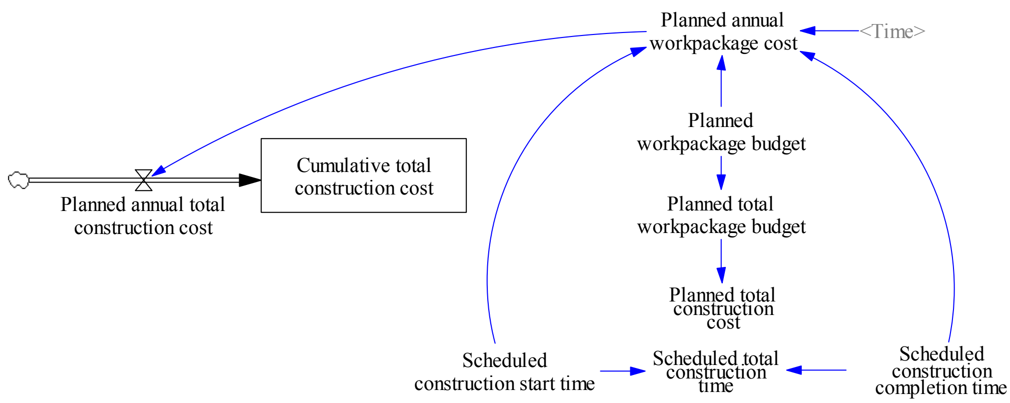
STCD: scheduled total construction duration;
SCCT: scheduled construction completion time;
SCST: scheduled construction start time;
SCT_i *= scheduled completion time for work package;*
SST_i *= scheduled start time for work package;*
i: Work package index

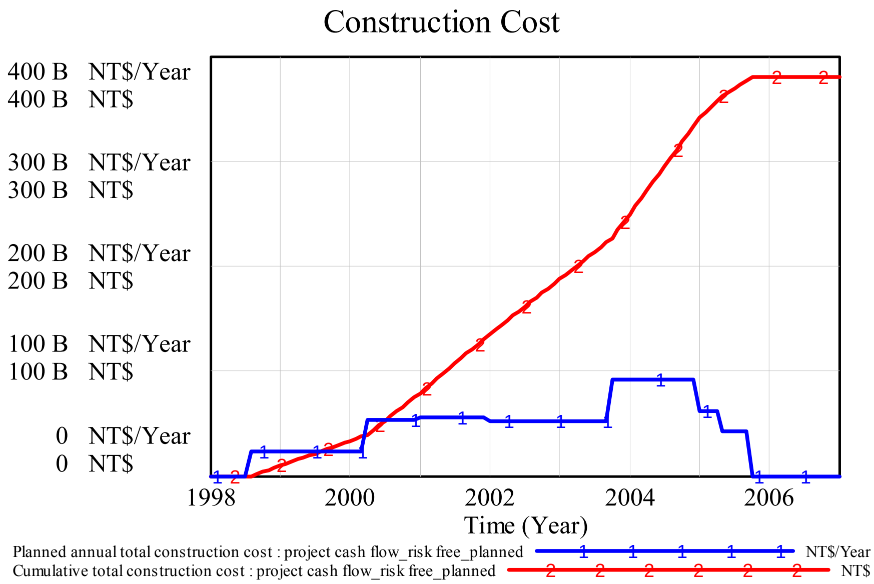
The planned average annual construction cost for each work package was:

$$PAWC_i = PWB_i / (SCT_i - SST_i)$$

Where

PAWC: planned annual work package cost;
PWB_i*: planned work package budget;*
SCT_i *= scheduled completion time for work package;*
SST_i *= scheduled start time for work package;*
i: Work package index





<u>Figure 6.1.1 The SD Model for Total Construction Cost and Its Outputs</u>

The planned annual total construction cost was:

$$PATCC = \sum PAWC_i$$

Where

PATCC: planned annual total construction cost;
PAWC: planned annual work package cost;
i: Work package index

The cumulative total construction cost from the construction start time to construction completion time was:

$$CTCC = \int_{SCST}^{SCCT} PATCC \cdot dt$$

Where

CTCC: cumulative total construction cost;
PATCC: planned annual total construction cost;
SCST: scheduled construction start time;
SCCT: scheduled construction completion time;

The related SD variables and parameters shown in Figure 6.1.1 are listed in Appendix III.

6.1.2 Project Financing Sub-model

The total investment capital for the THSR project was about NT$440.5 billion which was increased during the construction phase. The average for annual raising capital during construction phase was:

$$APC = PTCC/STCD = PTCC/(Max\ (SCT_i) - Min\ (SST_i))$$

Where

APC: annual project capital;
PTCC: planned total construction cost;
STCD: scheduled total construction duration;
SCT_i *= scheduled completion time for work package;*
SST_i *= scheduled start time for work package;*
i: Work package index

The basic fiscal requirement of the public sector for project capital structure was 30% of total capital investment for equity, and the rest was for debt, including the government long-term fund and bank loan. Therefore, the equity/dept ratio = 3 to 7 which meant that the equity fraction is 30% and debt fraction is 70%. The annual borrowing rate was:

$$B = APC * W_d$$

Where

APC: annual project capital;
W_d*: debt fraction*

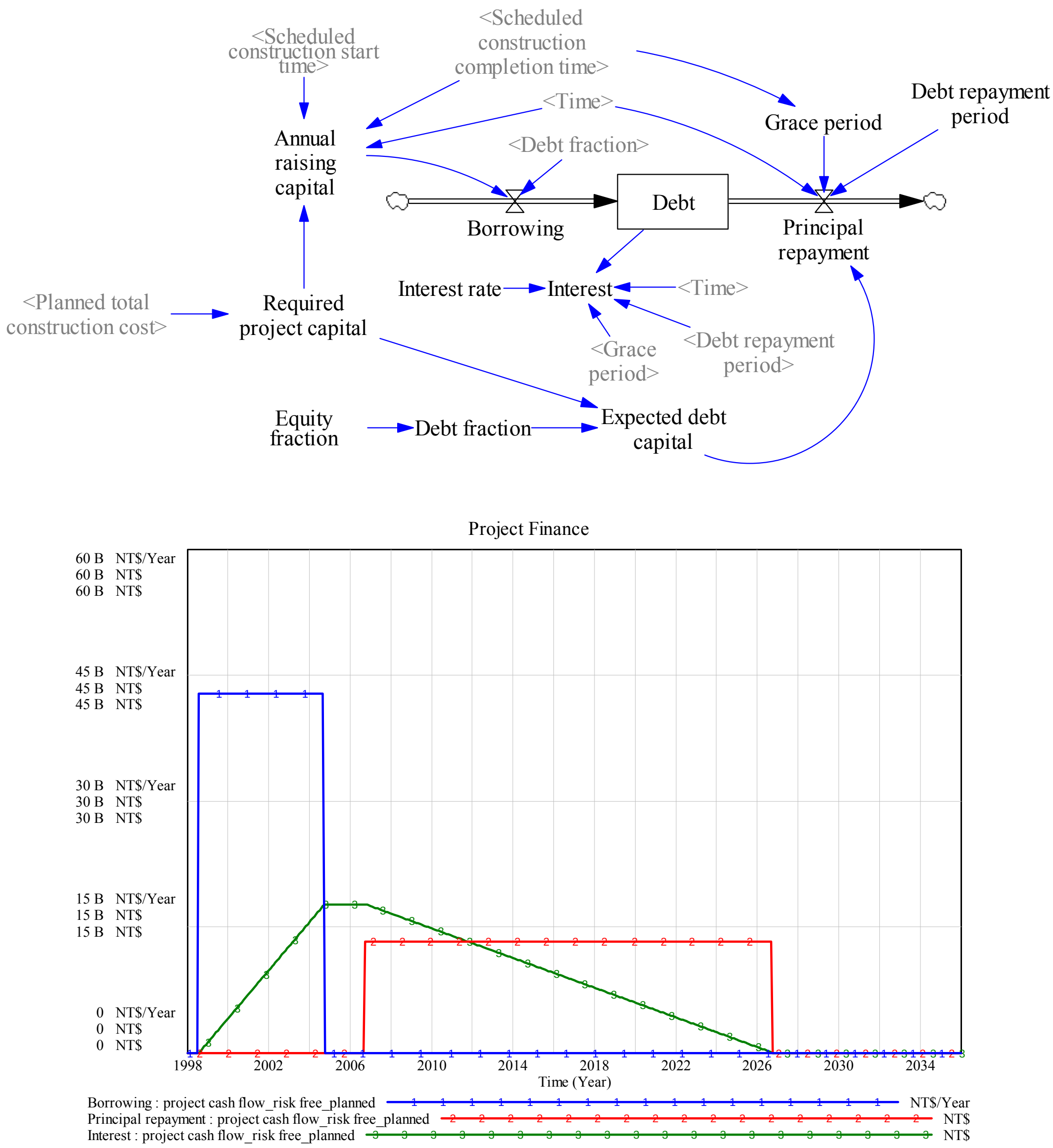


Figure 6.1.2 The SD Model for Project Finance and Its Outputs

The debt repayment period for THSR project is 20 years. This repayment period should proportionately repay both the principal and the interest during loan period, but there is a grace period for debt principal that the project contractor did not need to pay during construction. The principal repayment rate was:

$$P=DC/DRP=PTCC*d/DRP$$

Where

DC: debt capital

PTCC: planned total construction cost;

W_d*: debt fraction;*

DRP: debt repayment period = 20 years

Therefore, the cumulative debt was:

$$Debt = \int_{0}^{T} (B - P) \cdot dt$$

Where

B: annual borrowing rate;
P: annual principle repayment;
T: construction time + operation time.

The average interest rate for a bank loan to finance a large-scale public project in Taiwan is estimated to be 6.73% over 5 years (BHSR, 2007; Hsu, 2000). The annually incurred interest is equal to debt*interest rate.

6.1.3 Operating Revenue Sub-model

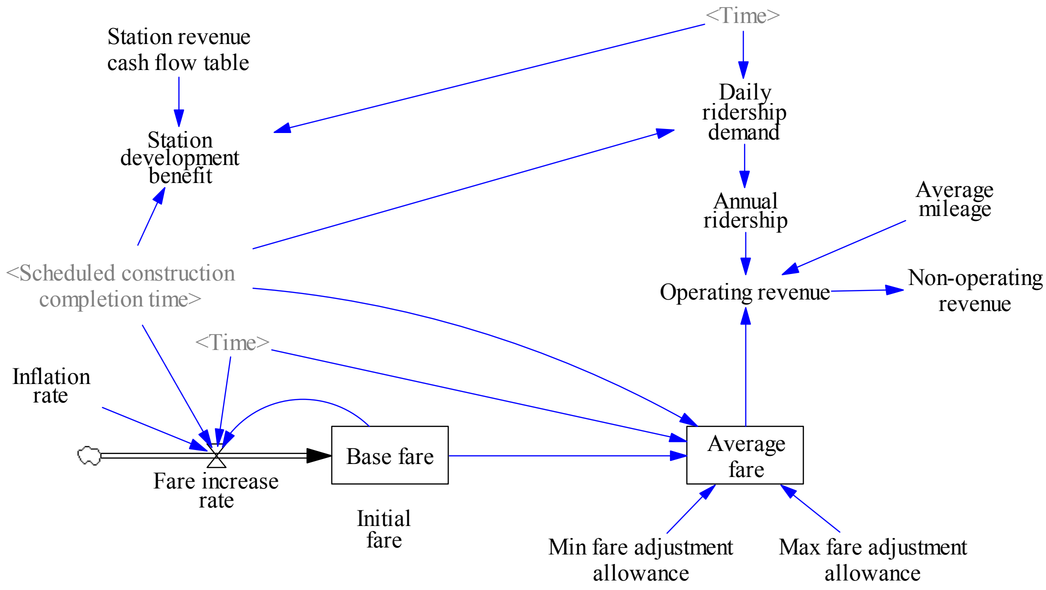
There were three income sources at project operation phase. The major one was ticket selling, and the rest included advertisement posting charges in the train, and station development benefits.

The base fare approved by the Ministry of Transportation and Communications (MOTC) were NT$3.459 per person*km, which can be annually adjusted by the inflation rate with maximum extra increase allowance for 20%, based on the factors like distance, peak time, and so on (BHSR, 2007; Hsu, 2000). Therefore, the annual base fare was:

$$F_b = F_o*(1+ r_{inf})^n$$

Where

F_b: *base fare;*
F_o: *initial approved fare;*
$\dot{f}$: *annual fare increase rate =* $F_b\, r_{inf}$;
r_{inf}: *inflation rate = 0.0369*
n = the nth year after starting operation.



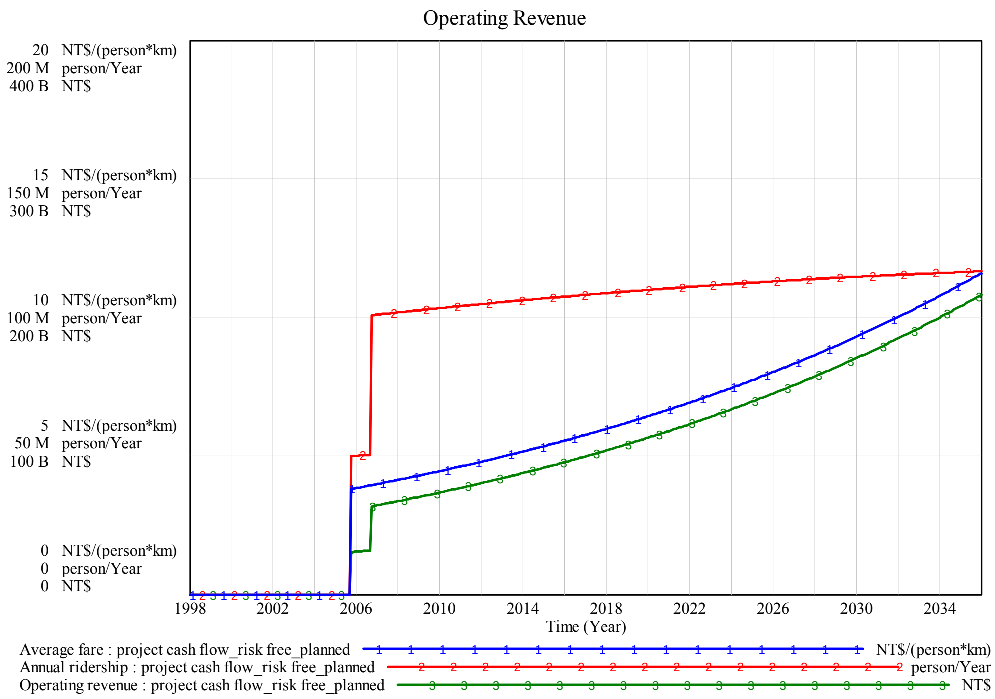


Figure 6.1.3 The SD Model for Operating Revenue and Its Outputs

Therefore, the average fare approved by BHSR was:

$$\hat{F} = F_b[1+(FA_{min} + FA_{max})/2]$$

Where

$\hat{F}$ *: Annual average fare;*

F_b*: base fare;*

FA_{min}*: Min fare adjustment allowance = 0;*

FA_{max}*: Max fare adjustment allowance=0.2.*

According to the research report for ridership forecast conducted by Hsu (2000), the data is plotted for the estimated average daily ridership (person/day) as shown in Figure 7.1.3.1. This figure showed that the daily ridership forecast can fit a quadratic regression model over time with a very low square root of MSE: s=0.0623, high R-sq: 99.8%, and low P value ≈ 0.00, which is below:

```
The regression equation is:
Ridership = - 10590 + 10.36 Year - 0.002526 Year**2

S = 0.0623880   R-Sq = 99.8%   R-Sq(adj) = 99.8%

Analysis of Variance

Source       DF       SS       MS        F      P
Regression    2  60.2816  30.1408  7743.78  0.000
Error        27   0.1051   0.0039
Total        29  60.3867
```

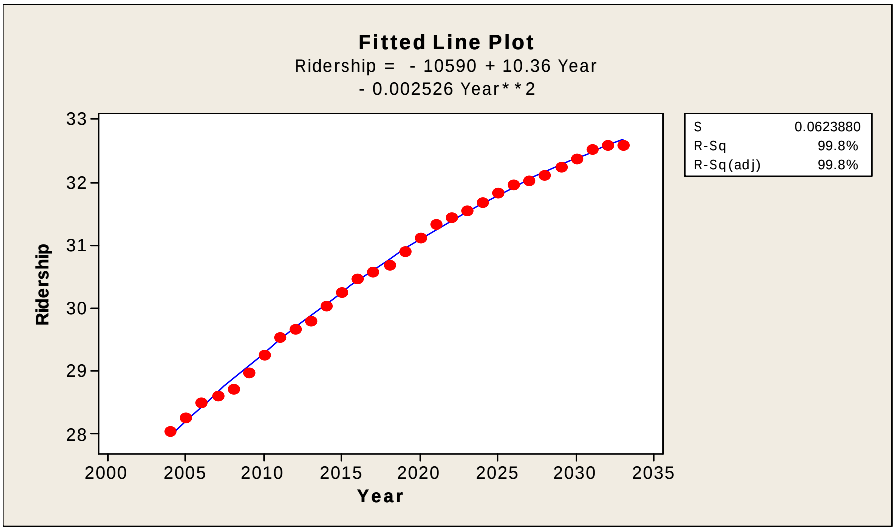


Figure 6.1.3.1 The Regression Model for the Estimated Daily Ridership

The daily ridership demand was:

*DRD = -10590+10.36*Time-0.002526*Time^2*

Therefore, the annual ridership was:

*AR=DRD*365*, where AR: the annual ridership

The annual operating revenue was:

*AOR = AAF*AM*AR*

Where

AOR: annual operating revenue;
AAF: annual average fare;
AM: average mileage = 160 km;
AR: the annual ridership

In addition to operating revenue, the non-operating revenue, like advertisement post, was estimated at 1% of operating revenue:

$$NOR = AOR*0.01$$

Where

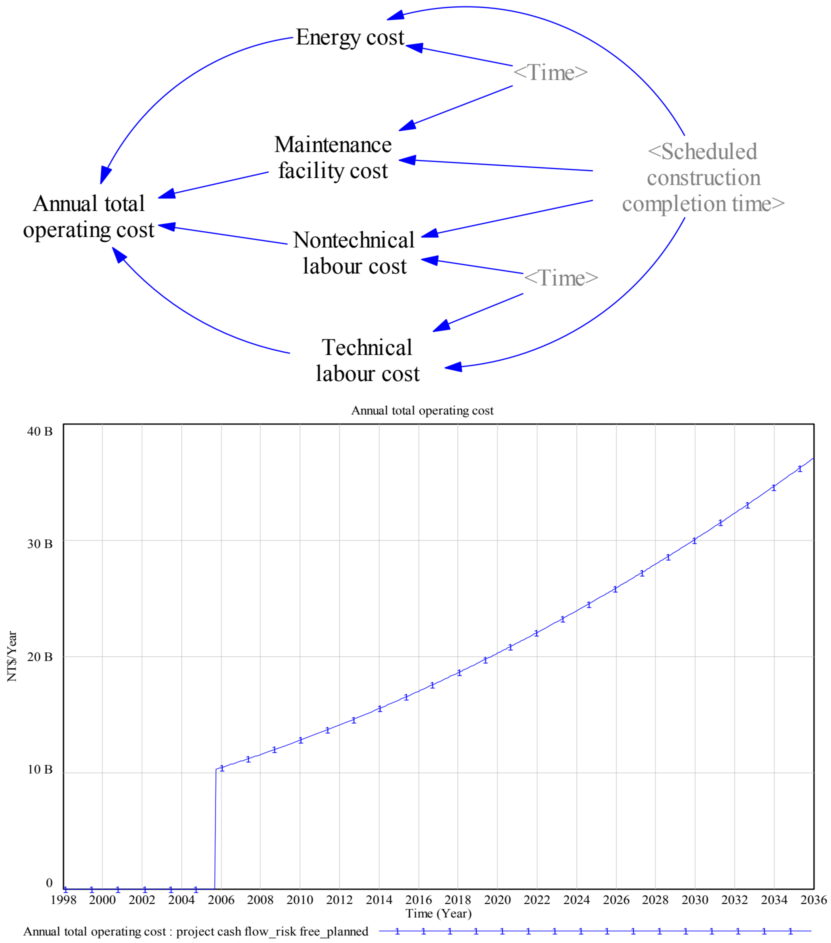
NOR: the non-operating revenue;
AOR: the annual operating revenue

The data for station development benefit obtained from (Hsu, 2000) cannot fit a specific regression model well, so the researcher input data as lookup variables in the SD model.

$$TOC = \sum OC_i$$

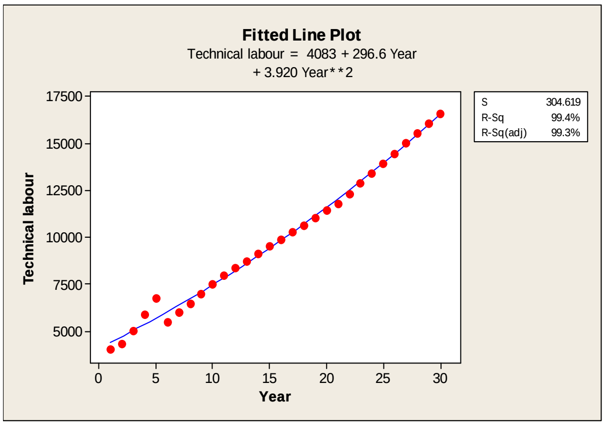
Where

TOC: annual total operating cost;
OC_i: operating cost elements;
i: operation cost element index



<u>Figure 6.1.4 The SD Model for Operating Cost and Its Outputs</u>

Table 6.1.4.1 The Regression Models for the Cost Elements of Operating Costs

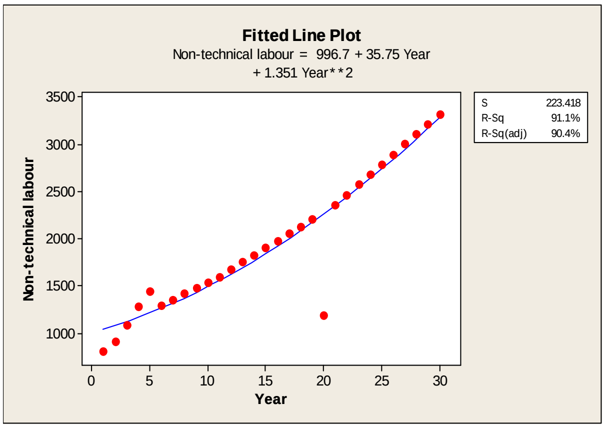


The regression equation is
Technical labour = 4083 + 296.6 Year + 3.920 Year**2

S = 304.619   R-Sq = 99.4%   R-Sq(adj) = 99.3%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	395019345	197509672	2128.50	0.000
Error	27	2505405	92793		
Total	29	397524750			

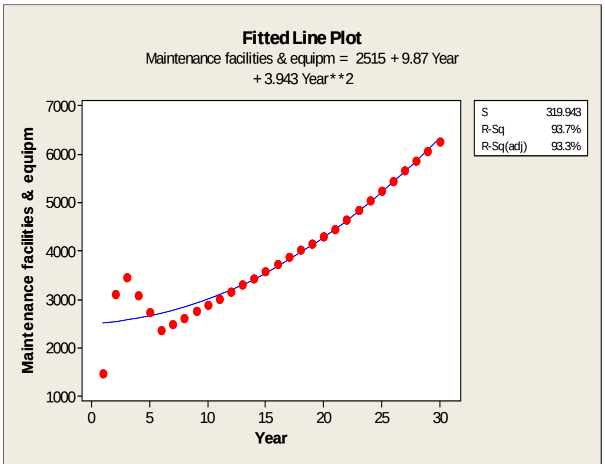


The regression equation is
Non-technical labour = 773.3 + 77.65 Year

S = 238.515   R-Sq = 89.5%   R-Sq(adj) = 89.1%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	13550207	13550207	238.19	0.000
Error	28	1592900	56889		
Total	29	15143107			

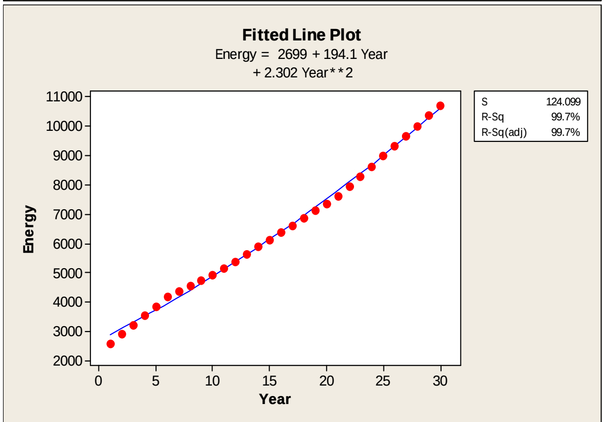


The regression equation is
Maintenance facilities & equipm = 2515 + 9.87 Year + 3.943 Year**2

S = 319.943   R-Sq = 93.7%   R-Sq(adj) = 93.3%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	41304532	20652266	201.75	0.000
Error	27	2763817	102364		
Total	29	44068349			



The regression equation is
Energy = 2366 + 313.3 Year - 7.161 Year**2 + 0.2035 Year**3

S = 61.1770   R-Sq = 99.9%   R-Sq(adj) = 99.9%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	159375238	53125079	14194.61	0.000
Error	26	97308	3743		
Total	29	159472546			

6.1.4 Operating Cost Sub-model

The total operating costs consisted of four cost elements: (a) energy costs, (b) technical labor costs, (c) non-technical labor costs, (d) maintenance facility costs. All of them, as estimated by BHSR(2007), can fit quadratic regression models with low S value (the square root of MSE), high R-sq, and low *p*-value, as shown in Table 6.1.4.1. The related SD variables and parameters shown in Figure 6.1.4 are listed in Appendix III.

6.1.5 Depreciation Sub-model

Hsu (2000) indicated that the depreciation for THSR asset was assumed as the declining balance method allocated each year with a given fraction of the book balance at the end of the previous year, over the depreciation lifetime of L years (Park & Sharp-Bette, 1990):

$$\alpha=\lambda(100\%/L)$$

$$D_n = \alpha BB_{n-1} = \alpha C_{asset}(1-\alpha)^{n-1}$$

$$BB_n = C_{asset}(1-\alpha)^n,\ n=1,...L$$

Where

α: *the fraction of the book balance;*
λ: *multiplier =1.5*
D_n: *the depreciation value at nth year;*
C_{asset}: *the estimated cost of asset;*
BBn: book balance or accounting value of asset after period n;
L: asset life time = 30 years

6.1.6 Discount Rate Sub-model

The weight average cost of capital (WACC) before it is risk-adjusted, is normally used as a discount rate for project financial analysis, which is (Park & Sharp-Bette, 1990):

$$r_{wacc} = w_e r_e + w_d r_d (1-t_m)$$

Where

r_{wacc}: *Weight Average Cost of Capital;*
w_e: *equity fraction;*
r_e: *return on equity;*
w_d: *debt fraction;*
r_d: *debt interest;*
t_m: *tax rate*

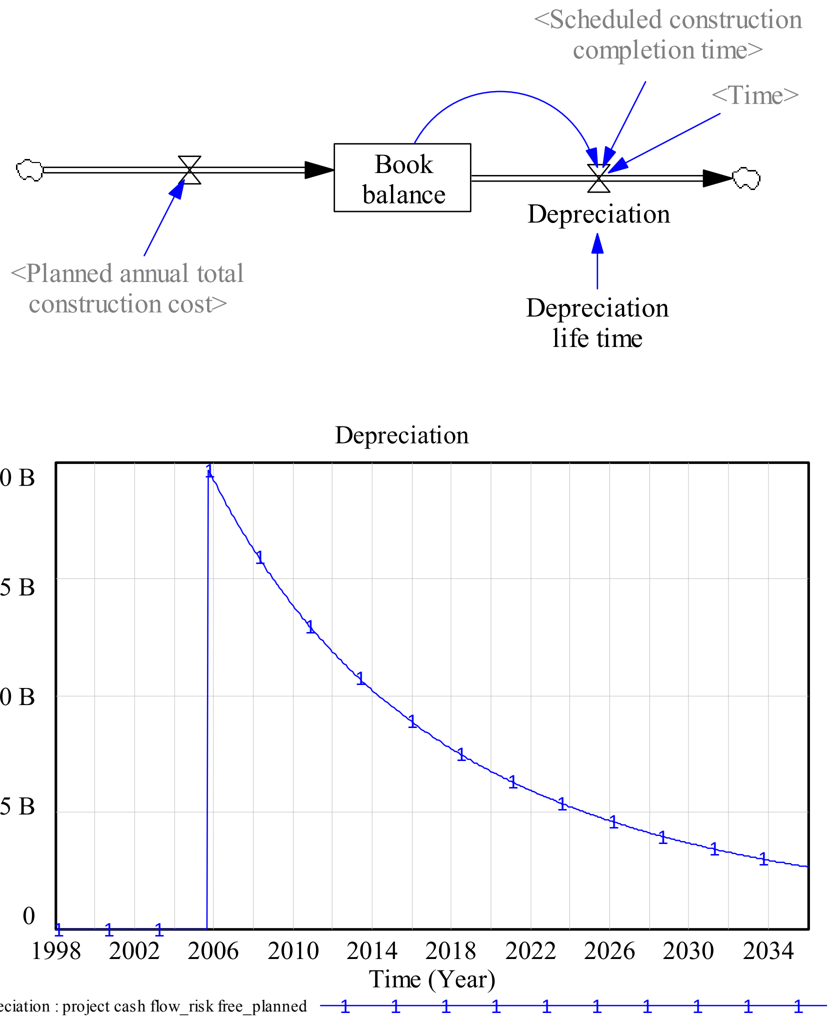


Figure 6.1.5 The SD Model for Depreciation and Its Outputs

It is adjusted by inflation effect as:

$$r'_{wacc} = r_{wacc} + r_{inf} + r_{wacc}\, r_{inf}$$

Where

r'_{wacc}: inflation adjusted discount rate;
r_{wacc}: Weight Average Cost of Capital;
r_{inf}: inflation rate

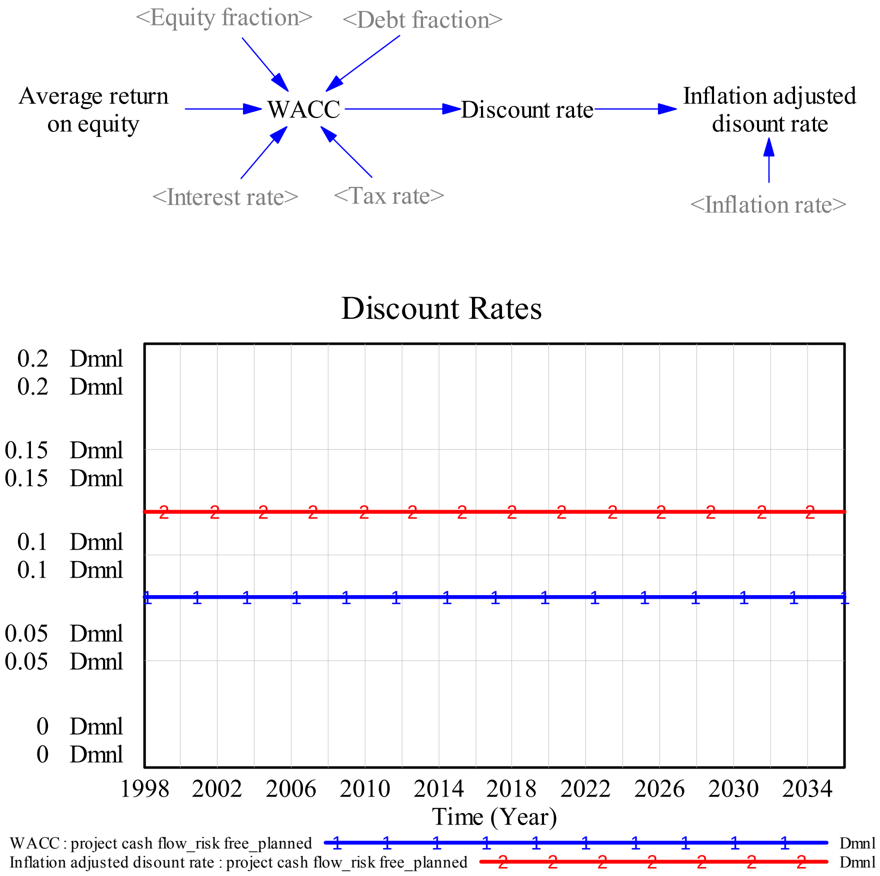


Figure 6.1.6 The Discount Rate SD Model and Outputs

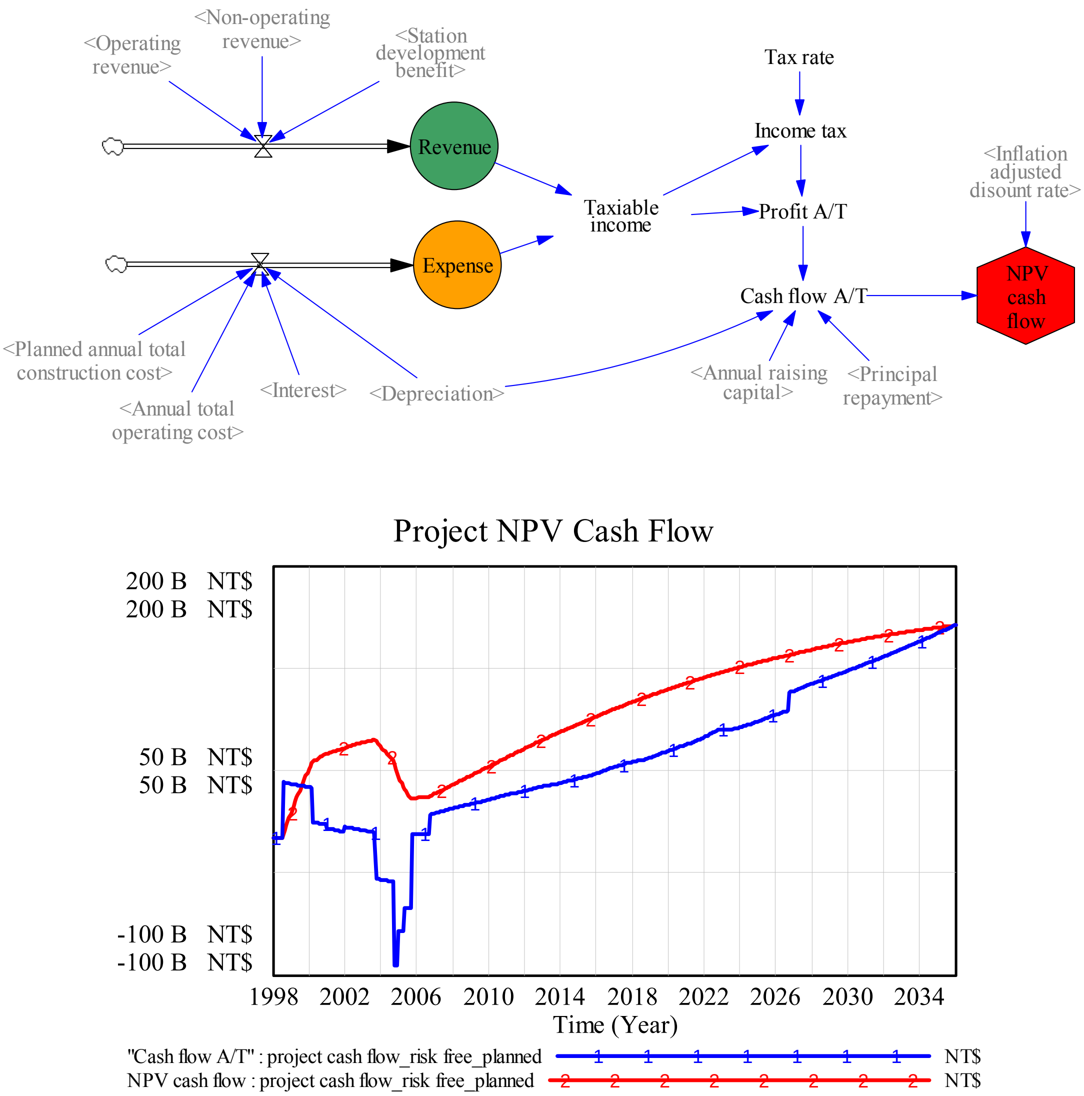
6.1.7 Project NPV Cash Flow Model

As shown in Figure 6.1.7, the project net cash flow = profit A/T (after tax) + annual raising capital - annual principal repayment + depreciation = (∑Revenue[i] - ∑Expense[j])*(1-tax rate) + annual raising capital - annual principal repayment + depreciation. The project NPV is (Park & Sharp-Bette, 1990):

$$NPV(r'_{wacc}) = \sum_{n=0}^{L} \frac{B_n - C_n}{(1+r'_{wacc})^n} = \sum_{n=0}^{L} \frac{F_n}{(1+r'_{wacc})^n}$$

Where

NPV: net present value;
B_n: the cash receipts at nth year;
C_n: the cash expenses at nth year;
F_n: cash flow at the nth year;
r'_{wacc}: inflation adjusted discount rate;
L: project life.



<u>Figure 6.1.7 The Project Cash Flow Model and Outputs</u>

There was a hump at the start of the graphs (see Figure 6.4.1). From the beginning of THSR project in 1988 until 2004, the THSRC (project contractor) continued borrowing money form financing institutions every year for construction. Since the income (the borrowed money) was more than outcome (the investment in construction), the NPV curve is gradually climbing until around 2004. In 2004, the THSRC stopped borrowing money so that there was no income but outcome (spending money in construction) after year 2004 during construction stage. Because the outcome is much more than income, the NPV curve started to sharply decline after 2004 during the latter half of construction stage until starting to operate THSR project. This is why there was a hump at the beginning of the graphs and why the project NPV cash flow is positive before the completion of the project.

The public sector BHSR had budgeted NT$54.2 billion for a contingency plan as risk premium (Hsu, 2000). Then, the required project capital = planned total construction cost + contingency plan budget. The project finance model should take contingency plan budget into account as shown in Figure 6.1.8, which compares the NPV project cash flow as risk-free (planned by BHSR) with risk-adjusted (budgeted by BHSR).

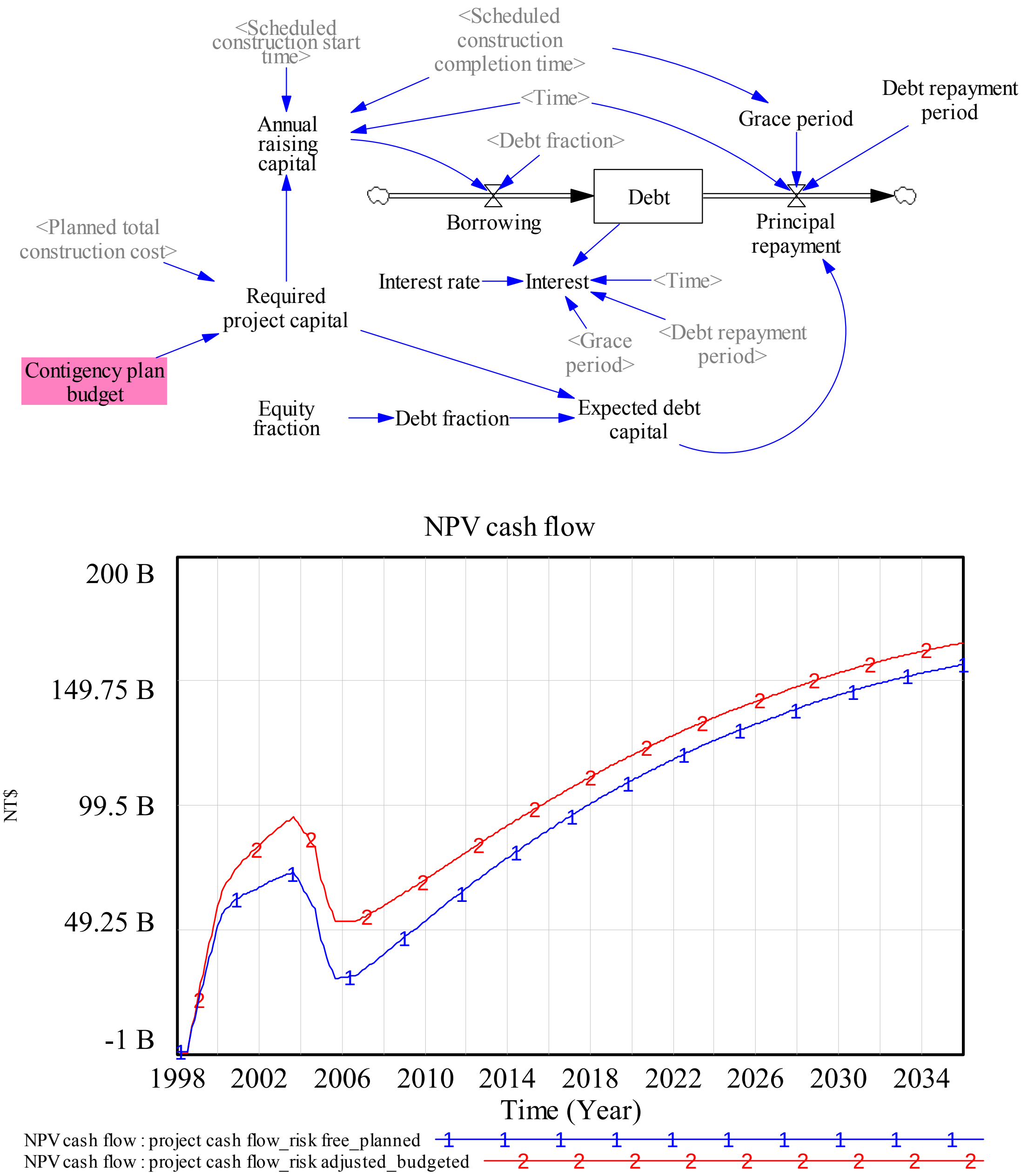


Figure 6.1.8 The Project Cash Flow Model Including Risk Budget

6.2 System Dynamics for Risk Network Modelling

The probability of occurrence of a risk event and its magnitude of impact are used in evaluating "risk exposure" or "risk effect". In a simplified form, if the probability of occurrence of a risk event is *P* and its magnitude of impact on a project criterion is *I*, then the expected value (EV) of this risk effect would be (Akintoye, et al., 2001; Cooper, 2005): EV = *(P)(I).*

The thesis research used 1 to 25 scale values to represent the expected values of the risk effect. As described in Chapter 3, Chapter 8.9 and Appendix IV, the questionnaire survey was conducted to investigate and estimate the qualitative risk effects through expert judgment. Then, the probability distribution for the expected risk effects of risk variables and the functional relations among risk variables were inferred and quantified by the probability fitting and the multiple-regression analysis. All of the risk network models are completely analyzed in Appendix VII. Some indicative risk network models were extracted from Appendix VII and discussed in the following sections.

6.2.1 RCN for 'Land Unavailable' on THSR

Based on the scenario statements described in Section VI1 and the Figure VI1, the direct causes for land unavailable events were approval delays and industrial disputes, and the direct consequence was construction delays. Therefore, the linear multiple-regression model was applied to address the relationship between land unavailable, approval delays and industrial disputes for the SD model as shown in Figure 6.2.1:

$$RD_k(lu) = \beta_{0k} + \beta_{1k} * RD_k(id) + \beta_{2k} * RD_k(ad) + \varepsilon_{k,}\ k = c$$

Where

RD_k: *random variable for the expected risk effect;*
k: time period, c (construction stage); o (operation stage);
lu: risk event for 'land unavailable';
id: risk event for 'industrial disputes';
ad: risk event for 'approval delay';
β_{0k}: *the constant term for the multiple regression model;*
$\beta_{1k,}\beta_{2k}$: *the relational coefficients for the independent risk variables;*
ε_k: *the random error for the multiple regression model;*

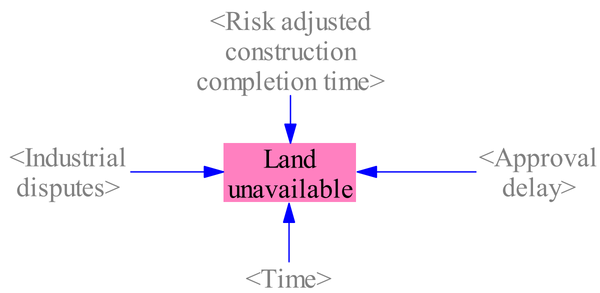


Figure 6.2.1 The SD Model for 'Land Unavailable' Risk Effect

6.2.2 RCN for 'Resource Unavailable' on THSR

Based on the scenario statements described in Section VI2 and the Figure VI2, the direct causes for resources unavailable events were default of subcontractors, Force Majeure, industrial disputes, and financial unavailable, and the direct consequence was construction delay. Therefore, the linear multiple-regression model was applied to address the relationship between resources unavailable events, default of subcontractor, Force Majeure, industrial disputes, and finance unavailable events for the SD model as illustrated in Figure 6.2.2.

$$RD_k\,(ru) = \beta_{0k} + \beta_{1k} * RD_k(ds) + \beta_{2k} * RD_k(fm) + \beta_{3k} * RD_k(id) + \beta_{4k} * RD_k(fu) + \varepsilon_k,\ k = c, o$$

Where

RD_k: random variable for the expected risk effect;
k: time period, c (construction stage); o (operation stage);
ru: risk event for 'resource unavailable';
ds: risk event for 'default of subcontractors';
fm: risk event for 'Force Majeure';
id: risk event for 'industrial disputes';
fu: risk event for 'financial unavailable';
β_{0k}: the constant term for the multiple regression model;
$\beta_{1k}, \beta_{2k}, \beta_{3k}, \beta_{4k}$: the relational coefficients for the independent risk variables;
ε_k: the random error for the multiple regression model;

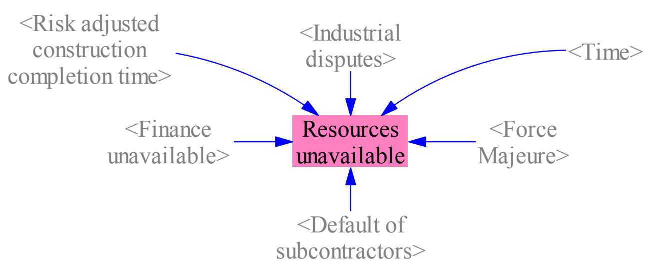


Figure 6.2.2 The SD Model for 'Resources Unavailable' Risk Effect

6.2.3 RCN for 'Performance Unavailable' on THSR

Based on the scenario statements described in Section VI3 and the Figure VI3, the direct cause for performance unavailable event was low operating productivity, and the direct consequences were revenue losses, contract remedies/penalties, and contract breaks. Therefore, the multiple-regression model was applied to address the functional relationship between performance unavailable and low operating productivity for the SD model illustrated in Figure 6.2.3:

$$RD_k\ (pu) = \beta_{0k} + \beta_{1k} * RD_k(lop) + \varepsilon_k,\ k = o$$

Where

RD_k: random variable for the expected risk effect;
k: time period, c (construction stage); o (operation stage);
pu: risk event for 'performance unavailable';
lop: risk event for 'low operating productivity';
β_{0k}: the constant term for the multiple regression model;
β_{1k}: the relational coefficients for the independent risk variables;
ε_k: the random error for the multiple regression model;

As for the direct consequence of contract remedies/penalties, according to the interview statements described in Section VI3, the researcher assumed that the number of trains that would likely delay on-time service was in linear proportion to the expected risk effect caused by risk event performance unavailable between the maximum consequence (the maximum number of delayed trains) and minimum consequence (the minimum number of delayed trains). Therefore, by using interpolation, the likely number of delayed trains was:

$$DeT = Int[(RD(pu) - RD_{min})/(RD_{max} - RD_{min}) * (DeT_{max} - DeT_{min}) + DeT_{min}]$$

Where

DeT: the number of trains that would likely delay on-time service;
Int[x]: integer function;
RD: random variable for the expected risk effect;
pu: risk event 'performance unavailable';
RD_{max}: 25;
RD_{min}: 1;
DeT_{max}: 45 trains;
DeT_{min}: 0 train;

Thus, the penalty (refund) for on-time delay that is the average of delay for more than 30 minutes and one hour was:

*Afr= (1+0.5)/2*AAF*

*ODR = DeT*Afr*Apt*AM*

where

Afr: the average fare refund;
ODR: on-time delay refund;
DeT: the number of trains that would likely delay on-time service;
AAF: the annual average fare, as shown in Section 6.1.3;
Apt: the average person per train = 350 person/train;
AM: average mileage = 160 km;

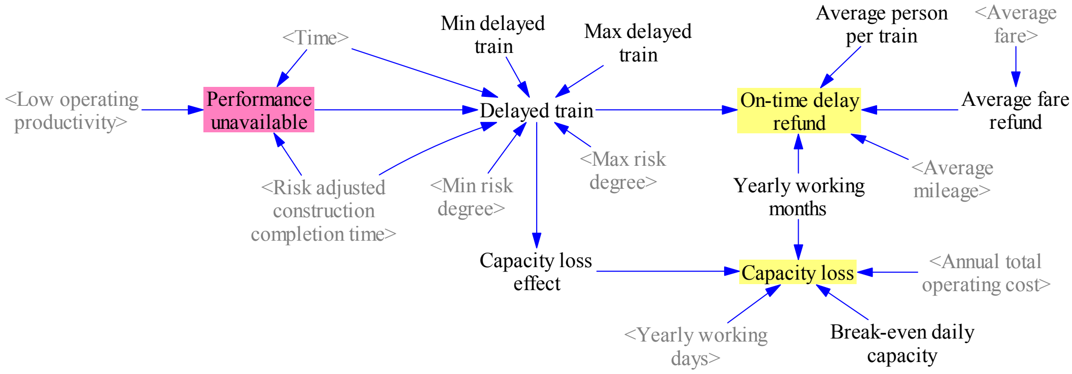
According to the interview statement in Appendix VI3, another consequence for capacity loss arising from less capacity than break-even daily capacity was:

*CLE =Int(DeT*0.2)*

*CL = CLE*12/(BEDC*2*365)*TOC*

Where

CLE: capacity loss effect;
Int[x]: Integer function;
DeT: the number of trains that would likely delay on-time service;
CL: capacity loss;
BEDC: break-even daily capacity for a single way =60;
TOC: annual total operating cost



<u>Figure 6.2.3 The SD Model for 'Performance Unavailable' Risk Effect</u>

6.2.4 RCN for 'Construction Cost Overrun' on THSR

Based on the scenario statements described in Section VI7 and the Figure VI7, the direct causes for construction cost overrun were construction delay, variability of interest rate, price escalation and insurance increases, and the direct consequence was finance unavailable. Therefore, the risk variable construction cost overrun for the SD model in Figure 6.2.4 is below:

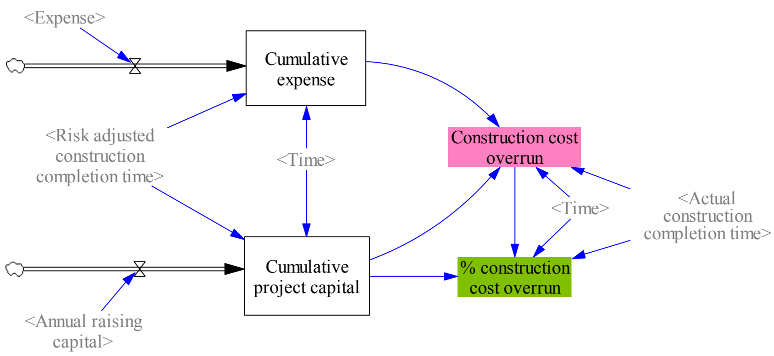


Figure 6.2.4 The SD Model for 'Construction Cost Overrun' Risk Effect

$$E = C_{radj} + C_{ins} + C_{int}$$

$$CE = \int_{RCST}^{RCCT} E$$

$$CPC = \int_{RCST}^{RCCT} AC$$

$$CCO = CE\text{-}CPC$$

where

E: the annual expense;
C_{radj}*: the risk adjusted annual construction cost;*
C_{ins}*: the annual insurance cost;*
C_{int}*: the annual interest;*
CE: the cumulative expense;
CPC: the cumulative project capital;
AC: the annual raising capital
RCCT: the risk adjusted construction completion time;
RCST: the risk adjusted construction start time
CCO: the construction cost overrun;

6.2.5 RCN for 'Construction Delay' on THSR

Based on statements made in Section VI8 and the Figure VI8, the direct causes for construction delay were land unavailable and resources unavailable, construction changes, delay in contracts, change negotiation, ownership changes, delays, and unforeseen site conditions. The direct consequences were construction delay and performance unavailable. As shown in Figure 6.2.5, the variable time delay effect on construction delay was assumed to be in linear proportion to the expected risk effect between the maximum time consequence (maximum time delay in each work package) and minimum consequence (maximum time delay in each work package). Therefore, the variable time delay effect in every work package is modeled below:

$$TD_{ij} = (RD_i - RD_{min})/(RD_{max} - RD_{min})*(TCMAX_{ij} - TCMIN_{ij}) + TCMIN_{ij}$$

where

TD_{ij}: time delay effect for a risk event on a work package (in percentage);
RD_i: random variable for the expected risk effect;
$TCMAX_{ij}$: maximum time delay effect for a risk event in a work package (in percentage);
$TCMIN_{ij}$: minimum time delay effect for a risk event in a work package (in percentage);
RD_{max}: 25;
RD_{min}: 1;
i: risk event index;
j: work package index

The variable increased completion time for work package was:

$$\Delta TD_{ik} = \sum TD_{ik} \cdot (SCT_k - SST_k) + \sum TD_{im} \cdot (SCT_m - SST_m)$$
$$\Delta TD_{im} = \sum TD_{im} \cdot (SCT_m - SST_m)$$

where

ΔTD_{ik}: increased completion time for a work package caused by a risk event;
TD_{ik}: time delay effect for a risk event in a work package (in percentage);
SCT_k: scheduled completion time for a work package;
SST_k: scheduled start time for a work package;
i: risk event index;
m: work package index for 'land acquisition';
k: work package index j≠ m (because when execution of workpackage k depends on execution of 'land acquisition' workpackage m)

Thus, the risk-adjusted construction completion time for a work package was:

$$RCCT_j = SCT_j + \Delta TD_{ij}$$

Where

$RCCT_j$: the risk-adjusted construction completion time for a work package;
SCT_j: scheduled completion time for a work package;
i: risk event index;
j: work package index

As the result, the risk variable construction delay was:

$$CD = Max(RCCT_j) - Max(SCT_j)$$

where

CD: construction time delay;
$Max(x_j)$: the maximum value of the elements in an array xj;
$RCCT_j$: the risk-adjusted construction completion time for a work package;
SCT_j: scheduled completion time for a work package;
i: risk event index;
j: work package index

As shown in Figure 6.2.5, the variable construction delay cost was:

$$CDC = CD*ACDC$$

where

CD: construction time delay;
ACDC: average administration cost due to construction time delay

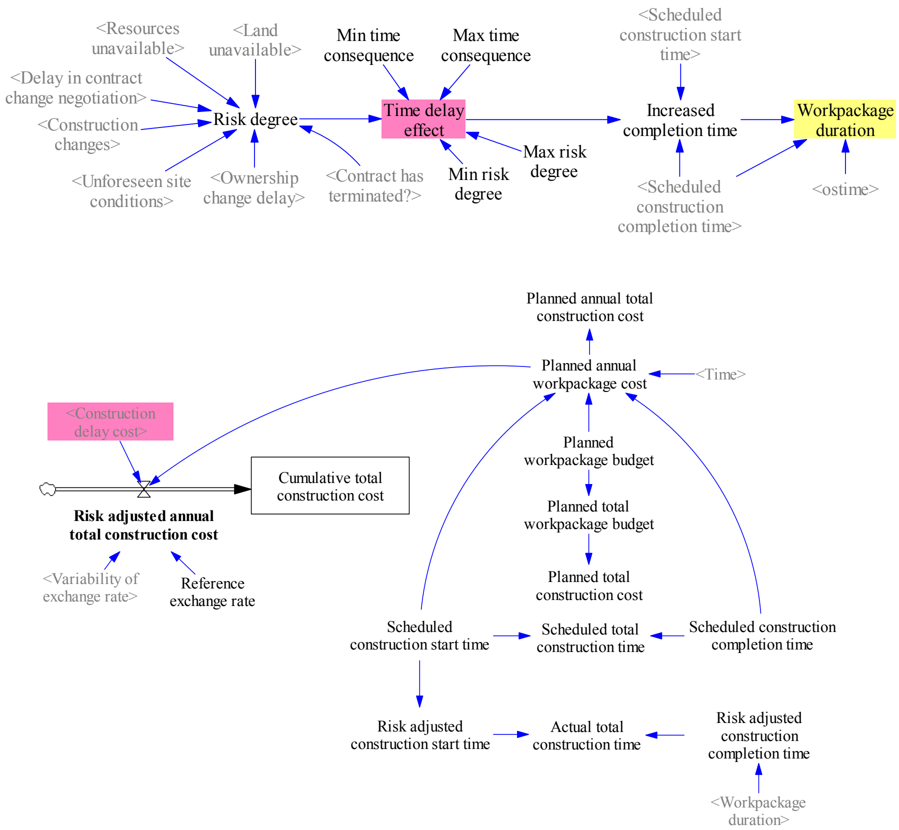


Figure 6.2.5 The SD Model for 'Construction Delay' and Construction Delay Cost

6.2.6 RCN for 'Mis-pricing' on THSR

The direct causes of mis-pricing and the inflexible contract arrangement influence policy on the fare adjustment rate for train ticket which would influence operating revenue are illustrated in the operating revenue sub-model. As shown in Figure 6.2.6, the expected fare adjustment rate is in linear reverse relationship with the expected risk effect caused by the risk event inflexible contract arrangement between the maximum consequence and minimum consequence. Therefore, by using interpolation, the expected fare adjustment rate was:

$$EFA = (RD(ica) - RD_{max})*(FA_{max}-FA_{min})/(RD_{min} - RD_{max})*+FAmin$$

where

EFA: the expected fare adjustment rate
FA_{max}: *maximum fare adjustment allowance = 0.2;*
FA_{min} : *minimum fare adjustment allowance = 0;*
RD: random variable for the expected risk effect;
Ica: risk event 'inflexible contract arrangement';
RD_{max}: *25;*
RDmin: 1

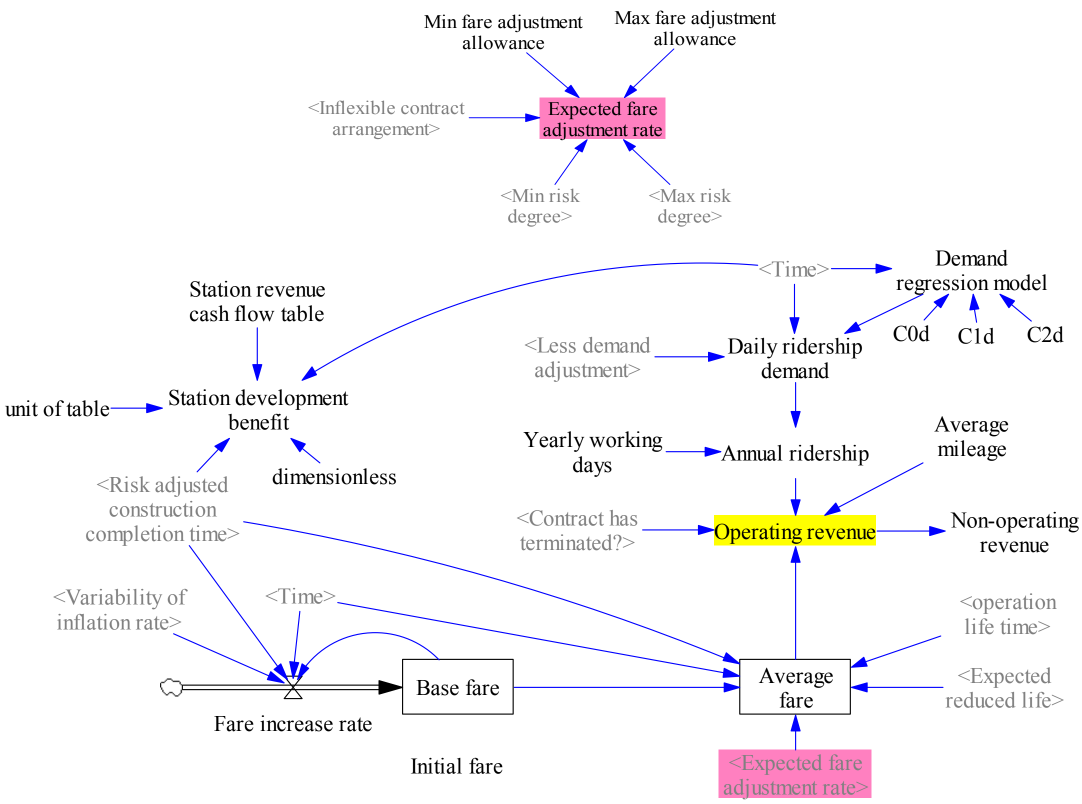


Figure 6.2.6 The SD Model for 'Mis-pricing' Risk Effect

6.2.7 RCN for 'Accidents and Safety Issues' on THSR

Based statements in Section VI18 and the Figure VI18, the direct causes of accidents and safety issues were resources unavailable, defective construction and complex system interface/integration, and Force Majeure, The direct consequences were low operating productivity, and contract remedies/penalties (the expected accident and safety loss). Therefore, the linear multiple-regression model was applied to address the direct cause relationships for the SD model as illustrated in Figure 6.2.7:

$$RD_k\,(asi) = \beta_{0k} + \beta_{1k} * RD_k(ru) + \beta_{2k} * RD_k(dc) + \beta_{3k} * RD_k(csi) + \beta_{4k} * RD_k(fm) + \varepsilon_k,\ k = o$$

where

RD_k: random variable for the expected risk effect;
k: time period, c (construction stage); o (operation stage);
asi: risk event 'accidents and safety issues';
ru: risk event 'resources unavailable';
dc: risk event 'defective construction';
csi: risk event 'complex system interface/integration';
fm: risk event 'Force Majeure'
β_{0k}: the constant term for the multiple regression model;
$\beta_{1k}, \beta_{2k}, \beta_{3k}, \beta_{4k}$: the relational coefficients for the independent risk variables;
ε_k: the random error for the multiple regression model;

As for the direct consequence of contract remedies/penalties, according to the interview statements, the maximum accident and safety loss for death penalty and system damage due to human factor and national disaster is NT$0.174 billion. The researcher assumes the expected accident and safety loss is in linear proportion to the expected risk effect caused by 'accidents and safety issues' between the maximum consequence (maximum accident and safety loss) and minimum consequence (minimum accident and safety loss). Therefore, by using interpolation, the expected accident and safety loss at operation stage was:

$$EASL = [RD(asi) - RD_{min}]/(RD_{max} - RD_{min})*(ASD_{max} - ASD_{min}) + ASD_{min}$$
$$ASD_{max} = Apt*Acdh$$

Where

EASL: expected accident and safety loss;
RD: random variable for the expected risk effect;
asi: risk event 'accidents and safety issues';
RD_{max}: 25;
RD_{min}: 1;
ASD_{max}: maximum accident damage, NT$1.3 millions;
ASD_{min}: minimum accident damage, NT$ 0.00 billions;
Apt: average person per train;
Acdh: average accident damage per head

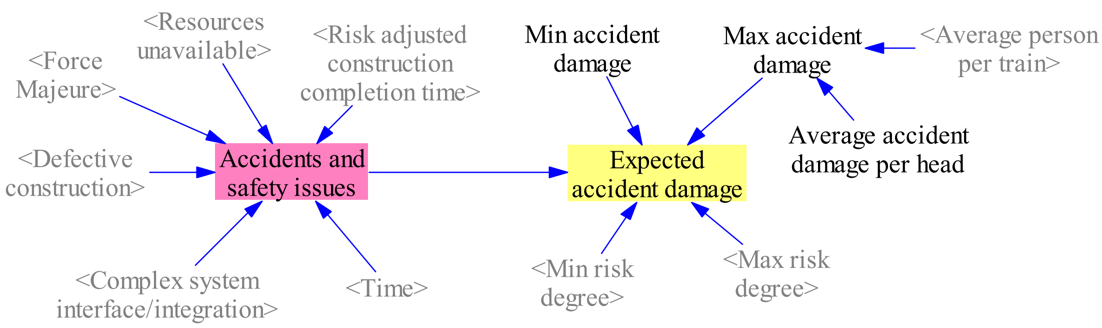


Figure 6.2.7 The SD Model for 'Accident and Safety Issues' Risk Effect

6.2.8 RCN for 'Price Escalation' on THSR

From the scenario statements described in Section VI19, Section VI39, Figure VI19, and Figure VII39, the variability of inflation rate would influence money for time, which is linked with the discount rate sub-model shown in Figure 6.1.6 to replace the inflation rate. Then, the new value for inflation adjusted discount rate would be linked with project cash flow model shown in Figure 6.1 to change NPV value. The new value for inflation adjusted discount rate illustrated in Figure 6.2.8 (a) was:

$$r'_{wacc} = r_{wacc} + r_{inf} + r_{wacc}\, r_{inf}$$

Where

r'_{wacc}: *inflation adjusted discount rate;*
r_{wacc}: *Weight Average Cost of Capital;*
r_{inf}: *variability of inflation rate*

In addition, the variability of inflation rate would be linked with the operation revenue sub-model to replace the inflation rate to change fare increase rate below:

$$AFIR' = F_b\, r_{inf}$$

where

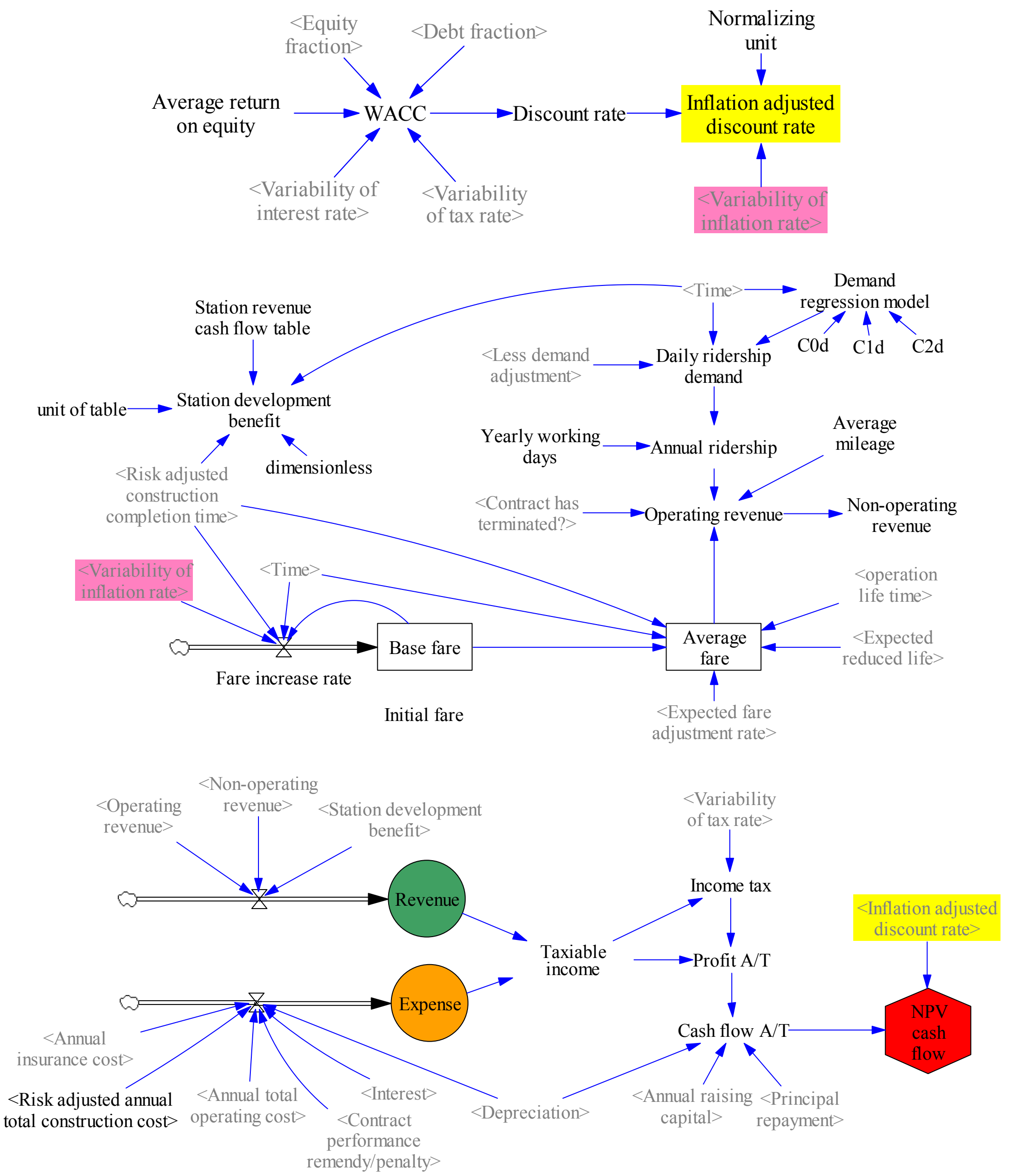
AFIR' = risk adjusted annual fare increase rate;
F_b: *base fare;*
r_{inf}: *variability of inflation rate*

Furthermore, based on the scenario statements described in Section VI19, Section VII40, Figure VI19, and Figure VII40, the variability of exchange rate would influence construction cost and operation cost which is linked with the construction cost sub-model shown in Figure 6.1.1 and operation cost sub-model shown in Figure 6.1.1. The new values for construction cost and operation cost illustrated in Figure 6.2.8 (b) were:

$$CC_{adj} = (PATCC + CDC) * r'_{ex} / r_{rex}$$

Where

CC_{adj}: *risk adjusted construction cost;*
PATCC: planned annual total construction cost;
CDC: construction delay cost
r'_{ex}: *risk adjusted exchange rate =* $MAX(r_{rex}, r_{ex})$
r_{rex}: *reference exchange rate = 33;*
MAX(A,B): maximum function of two alternatives A, B;
r_{ex}= *'variability of exchange rat' addressed in Appendix VII40*



<u>Figure 6.2.8 (a) Risk Variables ‘Variability of Inflation Rate’ and ‘Inflation Adjusted Discount Rate’ Are Linked with Discount Rate Sub-model, Operation Revenue Sub-model and Project Cash Flow Model Respectively</u>

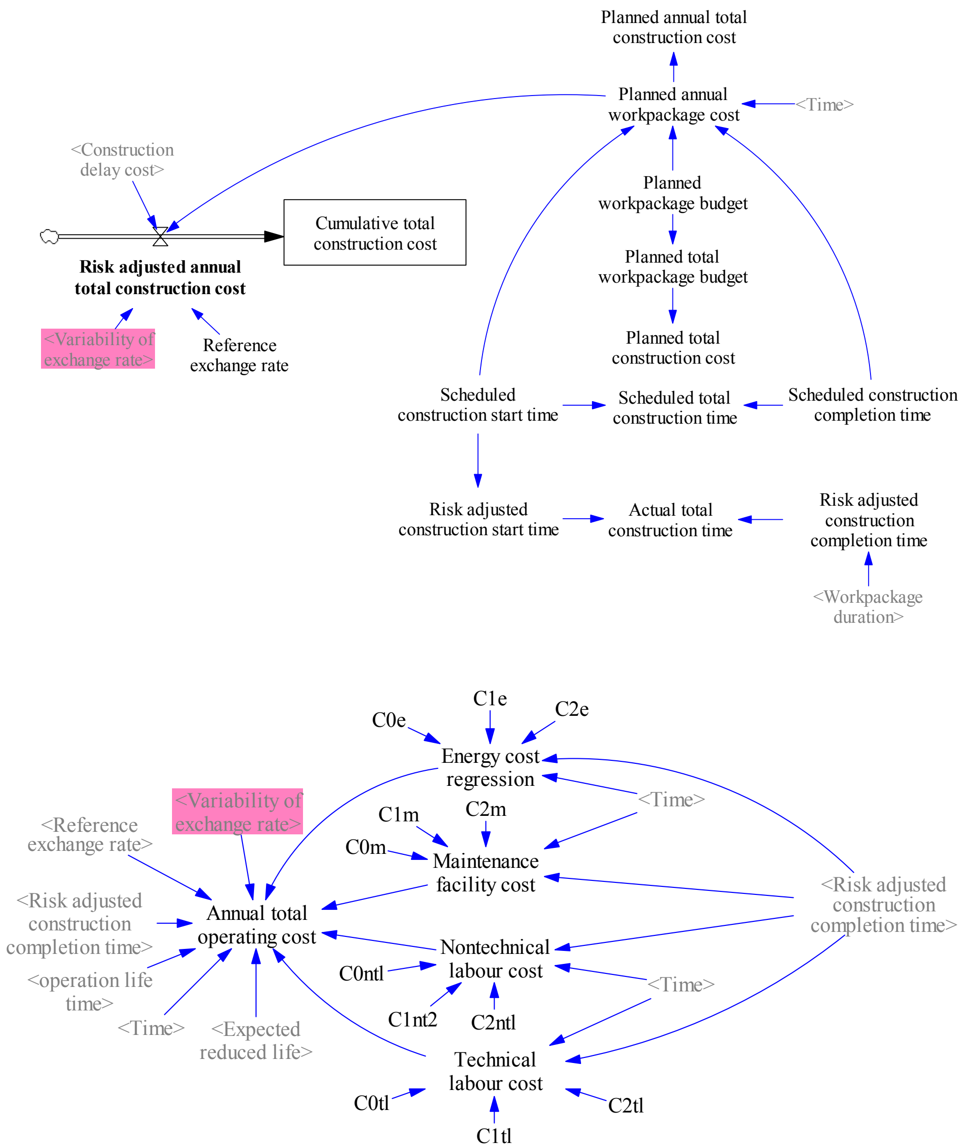


Figure 6.2.8 (b) Risk Variable 'Risk Adjusted Exchange Rate' and 'Reference Exchange Rate' Are Linked with Construction Cost Sub-model and Operation Cost Sub-model Respectively

6.2.9 RCN for 'Finance Unavailable' on THSR

Per statements in Section VI22 and the Figure VI22, the direct causes for finance unavailable were unsuitable regulatory policy, construction cost overruns, and revenue losses. The direct consequences were resources unavailable events, and insolvency of contractor.

As in Section VI22, The risk variable for 'finance unavailable' was the function of two independent variables: percentage of construction cost overrun for construction stage, and debt service coverage (Dsc) for operation stage, which was:

$$RD_k(fu) = \overline{\pi} + \varepsilon_k,\ k=c;$$
$$= \overline{D}_{sc} + \varepsilon_k,\ k=o;$$

Where

RD_k: *random variable for the expected risk effect;*
k: time period, c (construction stage); o (operation stage);
fu: risk event 'finance unavailable';
$\overline{\pi}$: *average percentage of construction cost overrun;*
$\overline{D}_{sc}$: *average Debt Service Coverage*

The percentage of construction cost overrun and the exponential smooth for average percentage of construction cost overrun were:

$$\pi = (EXP-APC)/APC*100\%$$
$$\overline{\pi} = \int_{tsc}^{t} \frac{\pi - \overline{\pi}}{t - t_{cs}}$$

where

EXP: annual total expense;
APC: annual project raising capital;
t: time at construction stage
t_{cs}: *construction start time*

According to the interview statement, the $RD_k(fu)$ during construction stage was assumed to be a linear reverse relationship with $\overline{\pi}$ when -100% < $\overline{\pi}$ < 0% :

$$RD_k(fu) = 1+\varepsilon_k,\ \overline{\pi} \le -100\%;$$
$$=(\overline{\pi}+1)(RD_{max} - RD_{min}) + 1+\varepsilon_k,\ -100\% < \overline{\pi} < 0\%;$$
$$=25+\varepsilon_k,\ \overline{\pi} \ge 0\%$$

Where

RD_{max}: *25;*
RD_{min}: *1;*
k: time period c (construction stage)

The debt service coverage (Chang & Chen, 2001) and the exponential smooth for average debt service coverage were:

$$D_{sc} = Eb/(I+(Pr/(1-Tm))$$
$$\overline{D}_{sc} = \int_{tos}^{t} \frac{D_{sc} - \overline{D}_{sc}}{t - t_{os}}$$

where

E_b: *Earnings before Interest, Tax and Depreciation*
I: Interest
Pr: Principal Repayment

Tm: Tax Rate

According to the interview statement, the $RD_k(fu)$ during operation stage was assumed to be a linear relationship with $\overline{D}_{sc}$ when $0 < \overline{D}_{sc} < D^*_{sc}$ (desired DSC level) :

$$RD_k(fu) = 1+\varepsilon_k, \quad \overline{D}_{sc} \geq D^*_{sc};$$

$$= RD_{max} - \overline{D}_{sc}\,(RD_{max} - RD_{min}) / D^*_{sc} + \varepsilon_k, \quad \overline{D}_{sc} < D^*_{sc}$$

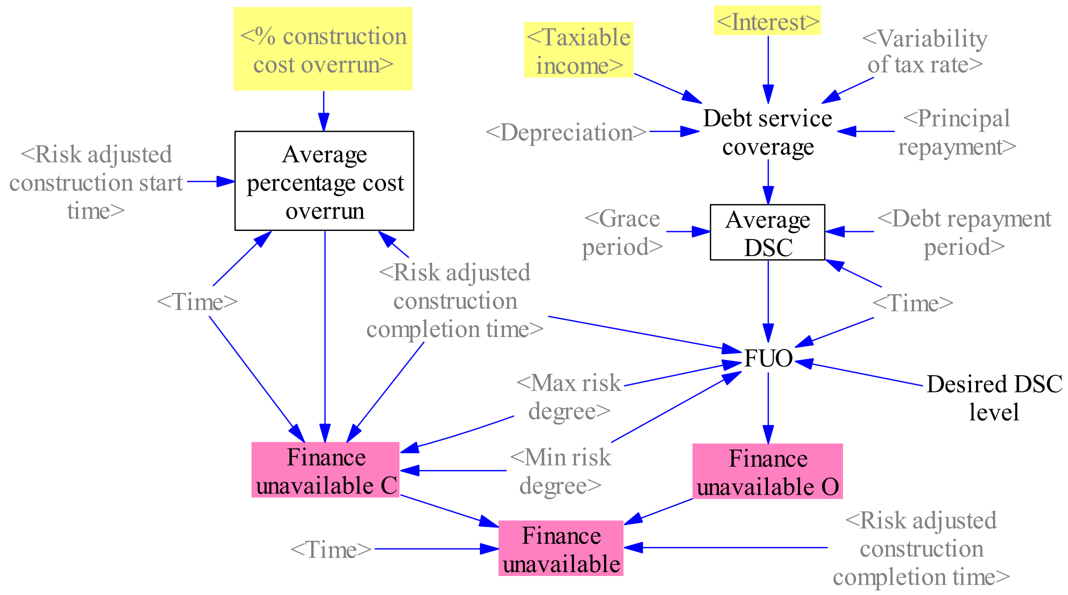
Where

D^*_{sc}: 1.2;

RD_{max}: 25;

RD_{min}: 1;

k: time period o (operation stage)



<u>Figure 6.2.9 The SD Model for 'Finance Unavailable' Risk Effect</u>

6.3 The Sample Data Analysis

As addressed in Chapter 3, the large-scale PPP projects are usually unique over a long-term life, so the historical data are imperfect. It is necessary to obtain information from the project experts (Dey & Ogunlana, 2004). The research conducted a questionnaire survey to measure the expected risk effect for the project risk events. The purposes of the questionnaire survey were: (a) to quantify risk effects by project experts; (b) to consistently scale the expected risk effect for project risk events; (c) to infer the probability distribution for exogenous risk variables in a risk cost network by probability fitting; (d) to quantify risk variable relationships by multiple-regression analysis. The plan for questionnaire survey is described in Appendix IV.

Approximately 60 to 70 questionnaires were delivered to the public sector Bureau of High Speed Rail (BHSR) for the THSR project. These respondents included the experts with a cross section of disciplines, and stakeholders who covered all areas of interest on the risk events for the THSR project as described in Chapter 5. Eventually, 43 copies were received. 6 samples were collected from those respondents who were employed at the Bureau for less than 3 years who were screened out for data analysis. This is because the respondents who had working experience of more than 3 to 5 years in a transit project are senior staff in public sector BHSR. It was reasonable to infer that they make more sensible decisions than the junior staff which have had working experience of less than 3 years to estimate THSR project risks. Thus, there were 37 samples which were valid for further analysis (Appendix IV).

6.3.1 An Example for Multiple-regression Analysis

The ANOVA analysis was performed to justify whether the multiple-regression models for relational expressions were adequate. For example, Figure 4.2 (7) showed ‘defective construction’ risk variable was caused by its independent variables including ‘defective design’ ‘default of subcontractor’ ‘resource unavailable’ and ‘complex system interface/integration’. The ANOVA analysis was applied to examine the functional relation between the risk variable ‘defective construction’ and its independent variables. In the Step 0, the ANOVA analysis started with a regression model that included linear terms, square terms and interaction terms. Some of them that were not statistically significant (p-values > α =0.05) were removed one at a time and in various sequences to see if the regression model got better. The p-value for liner term ‘poor cooperation/coordination’, square term ‘poor cooperation/coordination*poor cooperation/coordination’ and interaction terms ‘defective design*poor cooperation/coordination’ ‘default of subcontractor*poor cooperation/coordination’ and ‘resource unavailable *poor cooperation/coordination’ were greater than α =0.05, so these terms were not significant and removed from the regression model one at a time.

Step 0: the regression model included linear terms, square terms and interactions terms

Estimated Regression Coefficients for defective construction

Term	Coef	SE Coef	T	P
Constant	-86.4947	68.7219	-1.259	0.221
defective design	-17.9445	17.0044	-1.055	0.303
default of subcontractor	2.2538	1.8011	1.251	0.224
resource unavailable	13.1980	3.6789	3.587	0.002
poor cooperation/coordination	5.8947	8.9588	0.658	0.517
defective design*defective design	5.3866	2.1408	2.516	0.020
default of subcontractor* default of subcontractor	0.0516	0.0226	2.285	0.032
resource unavailable* resource unavailable	0.3413	0.1003	3.403	0.003
poor cooperation/coordination* poor cooperation/coordination	-0.0538	0.3977	-0.135	0.894
defective design* default of subcontractor	-1.0349	0.4341	-2.384	0.026
defective design* resource unavailable	-3.1535	0.8740	-3.608	0.002
defective design* poor cooperation/coordination	0.6733	1.0637	0.633	0.533
default of subcontractor* resource unavailable	0.2703	0.0799	3.384	0.003
default of subcontractor* poor cooperation/coordination	-0.0494	0.1063	-0.465	0.646
resource unavailable* poor cooperation/coordination	-0.4911	0.2475	-1.984	0.060

S = 0.0878113 PRESS = 0.749337
R-Sq = 98.32% R-Sq(pred) = 92.59% R-Sq(adj) = 97.25%

In the Step 1, the insignificant terms were removed one at a time by following the sequence: interactions terms→square terms→linear terms. It indicated that an adequate regression model that the individual interactions, square terms and linear terms were almost significant (p-value <α =0.05). The R-Sq(adj) slightly reduced from 97.25% to 97.08%, and the p-value for the whole regression model was much less than 0.05.

Step 1: removing interactions terms→square terms→linear terms one at a time

Estimated Regression Coefficients for defective construction

Term	Coef	SE Coef	T	P
Constant	-16.5042	30.6798	-0.538	0.595
defective design	-16.9875	14.2546	-1.192	0.244
default of subcontractor	2.0502	1.4370	1.427	0.166
resource unavailable	8.1481	2.7043	3.013	0.006
poor cooperation/coordination	0.4467	0.0846	5.284	0.000
defective design*defective design	4.8706	1.9962	2.440	0.022
default of subcontractor* default of subcontractor	0.0458	0.0211	2.167	0.040
resource unavailable* resource unavailable	0.2456	0.0916	2.681	0.013
defective design* default of subcontractor	-0.9408	0.4051	-2.323	0.028
defective design* resource unavailable	-2.5400	0.8107	-3.133	0.004
default of subcontractor* resource unavailable	0.2290	0.0753	3.041	0.005

S = 0.0905552 PRESS = 0.577116
R-Sq = 97.89% R-Sq(pred) = 94.29% R-Sq(adj) = 97.08%

Analysis of Variance for defective construction

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	10	9.8975	9.897531	0.989753	120.70	0.000
Linear	4	9.7797	0.262038	0.065509	7.99	0.000
Square	3	0.0273	0.068086	0.022695	2.77	0.062
Interaction	3	0.0905	0.090511	0.030170	3.68	0.025

Source	DF	Seq SS	Adj SS	Adj MS
Residual Error	26	0.2132	0.213207	0.008200
Total	36	10.1107		

In the Step 2, the insignificant terms were removed one at a time by another sequence: square terms→interactions terms→linear terms. It indicated that a better regression model was obtained that the individual interactions, square terms and linear terms were almost significant (p-value <α =0.05). The R-Sq(adj) slightly increased from 97.25% to 97.46%, and the p-value for the whole regression model was much less than 0.05. This regression equation was: defective construction = -82.93-18.61*defective design+2.40*default of subcontractors+12.58*resources unavailable+6.78*Poor cooperation/coordination +6.00*defective design^2+0.06*default of subcontractors^2+0.34*resources unavailable^2-1.15*defective design*default of subcontractors-3.26*defective design*resources unavailable+0.28*default of subcontractors*resources unavailable-0.33*resources unavailable*Poor cooperation/coordination

However, the extreme condition analysis (see section 8.5) indicated that the response variable ‘defective construction’ = 1208.32 when all of the predictor variables had a maximum value of 25; the response variable ‘defective construction’ = -80.24 when all of the predictor variables had a minimum value of 1. When the SD model ran a simulation, it indicated an ERROR message like “Unable to converge simultaneous loop at time …” Thus, this regression model could not meet the requirements. Therefore, it was necessary to kept looking for an appropriate regression model in the Step 3.

Step 2: removing square terms→interactions terms→linear terms one at a time

Estimated Regression Coefficients for defective construction

Term	Coef	SE Coef	T	P
Constant	-82.9271	41.5152	-1.998	0.057
defective design	-18.6069	13.3175	-1.397	0.175
default of subcontractor	2.3965	1.3497	1.776	0.088
resource unavailable	12.5791	3.2232	3.903	0.001
poor cooperation/coordination	6.7780	2.8677	2.364	0.026
defective design*defective design	5.9960	1.9306	3.106	0.005
default of subcontractor* default of subcontractor	0.0564	0.0203	2.780	0.010
resource unavailable* resource unavailable	0.3389	0.0953	3.555	0.002
defective design* default of subcontractor	-1.1472	0.3893	-2.947	0.007
defective design* resource unavailable	-3.2554	0.8227	-3.957	0.001
default of subcontractor* resource unavailable	0.2817	0.0742	3.798	0.001
resource unavailable* poor cooperation/coordination	-0.3307	0.1497	-2.209	0.037

S = 0.0844740 PRESS = 0.494748
R-Sq = 98.24% R-Sq(pred) = 95.11% R-Sq(adj) = 97.46%

Analysis of Variance for defective construction

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	11	9.9323	9.932341	0.902940	126.54	0.000
Linear	4	9.7797	0.154369	0.038592	5.41	0.003

Square	3	0.0273	0.100031	0.033344	4.67	0.010
Interaction	4	0.1253	0.125322	0.031330	4.39	0.008
Residual Error	25	0.1784	0.178396	0.007136		
Total	36	10.1107				

In the Step 3, the remaining terms were removed one at a time in various sequences until an appropriate regression model could be found. Consequently, a linear regression model might be able to meet the requirements. This linear regression model was: defective construction = 6.58+0.12*default of subcontractor+0.15*resource unavailable+0.31*poor cooperation/coordination. It indicated that the p-value for the individual linear terms and the whole regression model was much less than 0.05. The R-Sq(adj) for this regression model slightly reduced from 97.46% to 96.20%. It also passed the extreme value testing when the SD model ran the simulation. Consequently, we concluded that the linear regression model 'defective construction = 6.58+0.12*default of subcontractor+0.15*resource unavailable+0.31*poor cooperation/coordination'+Ramdom Normal~(μ, σ), where μ=0; σ=0.1' was adequate and appropriate to represent the functional relation between the risk variable 'defective construction' and its independent variables.

Step 3: removing remaining terms one at a time.

Analysis of Variance for defective construction

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	4	9.7797	9.77968	2.44492	236.33	0.000
Linear	4	9.7797	9.77968	2.44492	236.33	0.000
Residual Error	32	0.3311	0.33106	0.01035		
Total	36	10.1107				

Term	Coef	SE Coef	T	P
Constant	6.5782	0.815954	8.062	0.000
default of subcontractor	0.1186	0.005293	22.411	0.000
resource unavailable	0.1475	0.023740	6.211	0.000
poor cooperation/coordination	0.3137	0.083858	3.741	0.001

S = 0.103307 PRESS = 0.431655
R-Sq = 96.52% R-Sq(pred) = 95.73% R-Sq(adj) = 96.20%

Analysis of Variance for defective construction

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	3	9.7585	9.75855	3.25285	304.79	0.000
Linear	3	9.7585	9.75855	3.25285	304.79	0.000
Residual Error	33	0.3522	0.35219	0.01067		
Total	36	10.1107				

After 'boundary adequacy tests', 'structure assessment tests', 'dimensional consistency tests', 'parameter assessment tests', 'extreme condition analysis', 'integration error tests', 'behaviour reproduction tests', and 'sensitivity analysis' for SD model validation (see chapter 8), there are not unreasonable outputs in the SD simulation as a result of the choice of a linear scale.

There will be a possibility as a result of the choice of a non-linear scale. Following the same procedure of regression analysis as stated in point 1 for the possible functional relations among risk variables, there are six adequate regression models that their interactive terms or square terms are significant (p-value $< \alpha = 0.05$). These six models are shown in Table 6.3.1:

Table 6.3.1 The Nonlinear Regression Models16

Risk variables	Regression models for functional relations	Low range	High range
Defective construction(c)	defective construction = -82.93-18.61*defective design+2.40*default of subcontractors+12.58*resources unavailable+6.78*Poor cooperation/coordination +6.00*defective design^2+0.06*default of subcontractors^2+0.34*resources unavailable^2-1.15*defective design*default of subcontractors-3.26*defective design*resources unavailable+0.28*default of subcontractors*resources unavailable-0.33*resources unavailable*Poor cooperation/coordination	-80.24 < 1*	1208.32 > 25*
Contract breach(c)	Contract breach = 12.98-0.93*failed commission tests+0.19*insolvency of contractor-0.23*law/policy changes+0.07*failed commissioning tests^2	12.08	29.49 > 25*
Land unavailable(c)	Land unavailable = 6.95+0.18*approval delay+0.03*industrial dispute^2	7.15	28.31 > 25*
Defective construction(o)	Defective construction = 0.95+1.34*defective design-1.35*resource unavailable+0.25*poor cooperation/coordination+0.03*resource unavailable^2	9.78	35.75 > 25*
Contract breach(o)	Contract breach = 2.39+0.63*insolvency of contractor+0.58*law/policy change-0.02*insolvency of contractor*law/policy change	3.00	20.25
Law policy changes(o)	Law policy changes = 16.17+0.12*downside economic events+0.10*political interference-0.86*industrial disputes+0.05*industrial disputes^2+0.02*industrial disputes*Force Majeure	15.59	41.41 > 25*

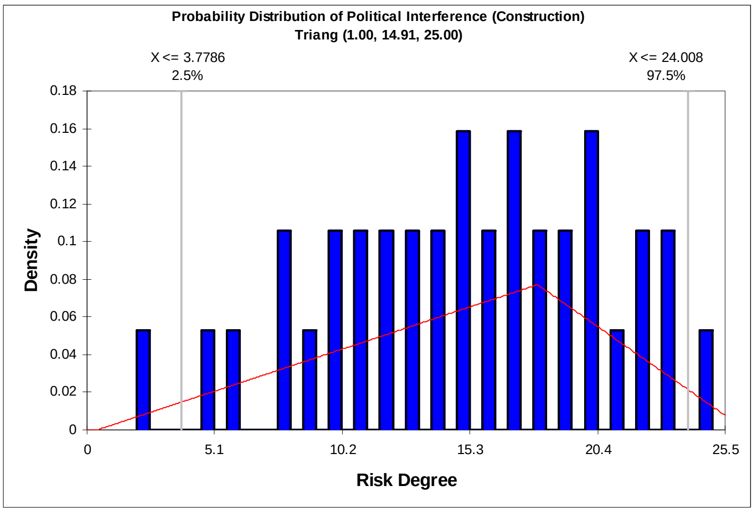
**1≤ the range values of a risk variable ≤ 25*

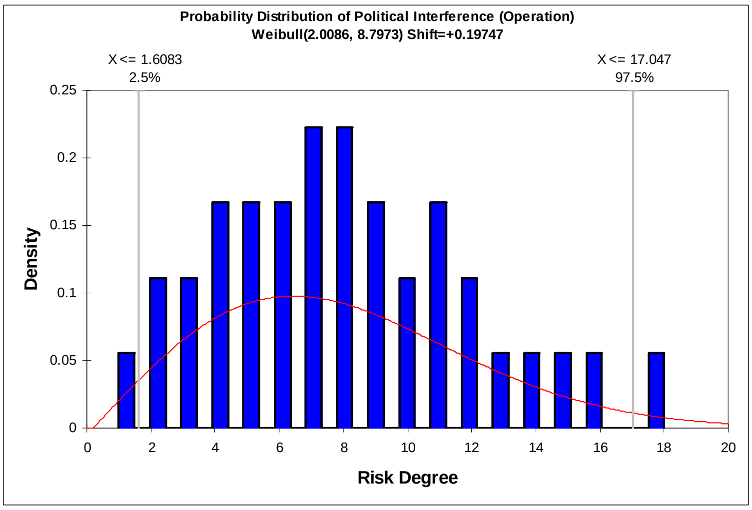
The extreme condition analysis (see section 8.5) was applied to test the above six regression models that their interactive terms or square terms are significant. It indicates that all of these regression models but “Contract breach” model have gone beyond their specified range from 1 to 25. We found out that the “Contract breach” regression model has a significant interaction term. So, the selection of a non-linear scale is still a possibility.

All of the multiple-regression models are included in Appendix VIII.

6.3.2 An Example for Probability Fitting

As described in Chapter 3, probability fitting was performed to determine the best-fitted probability distribution for the expected risk effect of the exogenous risk variables in a risk cost network. For example, the fitted probability distribution for the expected risk effect of the exogenous risk variable political interference, at the construction and operation phases, were Triangular distribution and Weibull distribution respectively, which is illustrated in Figure 6.3.1.





<u>Figure 6.3.1 The Fitted Probability Distribution for the Expected Risk Effect of 'Political Interference' At Construction and Operation Phases</u>

The probability plot, P-P plot or Q-Q plot with the chi-square statistics or Anderson-Darling statistics were conducted to examine whether the selected probability distribution can fit the exogenous risk variables. It is addressed in Chapter 8, Model Validation.

All of the parameter values for the probability distribution of exogenous risk variables are displayed in Appendix III.

6.4 Monte Carol Simulation for Risk Compounding Effects

Once the parameter values inferred from empirical data for the exogenous risk variables and the functional relation of risk variables had been confirmed by probability fitting and multiple-regression analysis, the Monte Carlo simulation with 10,000 iterations was performed on the SD model to illustrate how the compounded risks affected the project NPV.

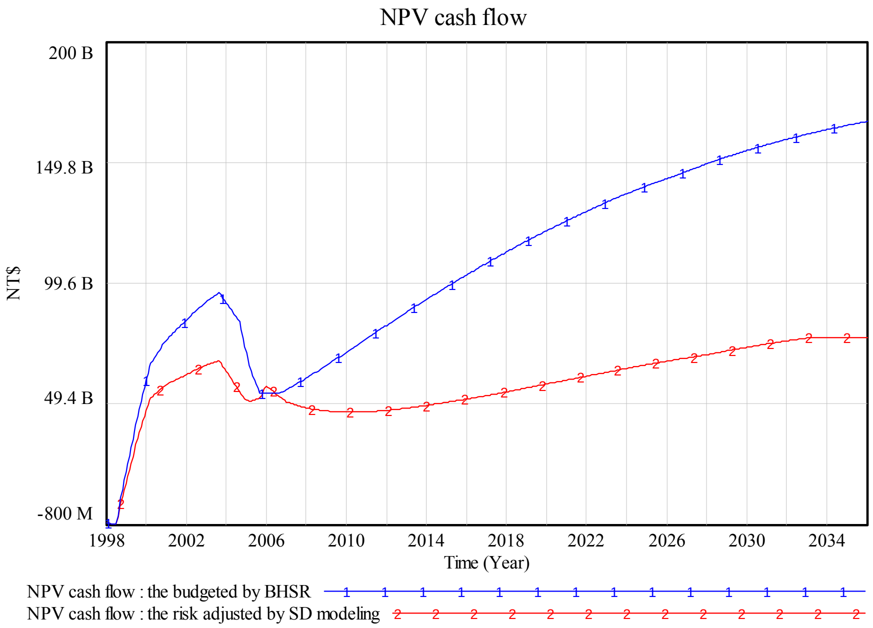


Figure 6.4.1 The Comparison of Project NPV

In Figure 6.4.1 the researcher compares two NPV cash flows: the budgeted, estimated by BHSR (the public sector), and the risk adjusted, estimated by SD modelling. The figure indicates that the expected NPV estimated by the SD modelling (no.2: red line) is much lower than the budgeted one (no.1: blue line) estimated by BHSR, which had risen from the SD models taking risk interactions on NPV into account. Figure 6.4.2 illustrates the probability distribution for the expected project NPV in year 2036, indicating that NT$156.50 billion for mean value and (-NT$13.43 billion, NT$326.42 billion) for the 95% confidence interval in year 2036.

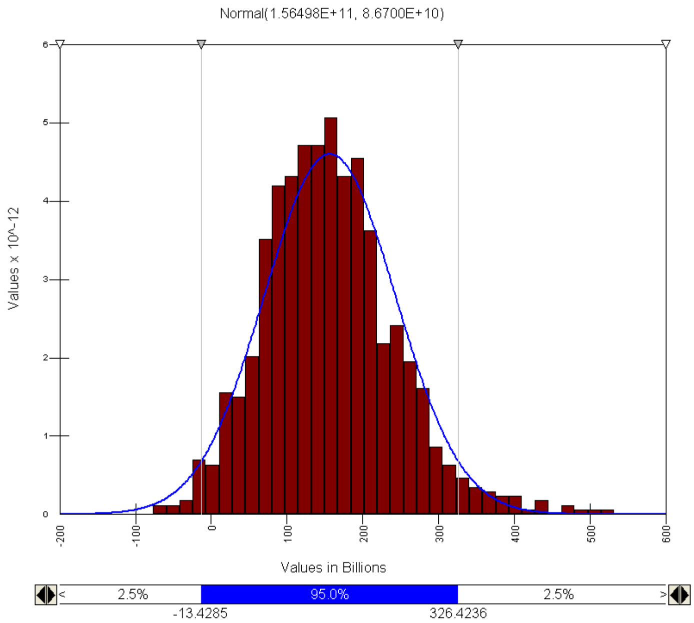


Figure 6.4.2 The Probability Distribution of the Expected Project NPV in Year 2036

Chapter 7 Bidding Proposal Modelling and Simulation

7.1 System Dynamics for Bidding Proposal Modelling

As previously stated, the core feature of a PPP project is suitable risk allocation so that risks can be transferred to a private concessionaire who is capable of cost-effectively manage and control risks to create the expected value for money (Allan, 2001; Grimsey & Lewis, 2005; Loosemore, 2007). Therefore, the methodology development for PPP project contractor selection should be based on risk analysis. The research developed a system dynamic model for risk cost network modelling in Chapter 6 to evaluate downside feedback loop effects (reinforcing risk effects) arising from risk interactions. Then based on the risk cost network model, a system dynamic model for bidding proposal modelling was developed to evaluate beneficial feedback loop effects (reducing and balancing risk effects) arising from the risk control and management schemes in a bidding proposal. As a result, the compounding effects that combined downside effects and beneficial effects on project NPV were estimated through Monte Carlo simulation. Then, some suitable decision-making methods for risky project comparison were recommended to select a preferred project option (bidding proposal).

7.1.1 The Structure of Bidding Proposals

Similar to the current practice for PPP bid selection, the research proposed that the bidding proposals submitted to the public sector for bid competition should include cost components illustrated in Table 7.1, which would be modeled to estimate the overall NPV range values for bid benchmarking. They are explained row by row as below:

(1) Raw cost: This includes direct cost and indirect cost for land acquisition, construction work package, operation and maintenance that is basically required and listed in the output specification provided by the public sector. This is a base cost without including any valuation of risk control and management. To avoid that a bidder who uses false low bidding prices to win contract award, the base case acts as the benchmark that the bidders would be asked to give a reasonable

explanation on their raw cost structure if there is a large cost gap between the bidding proposals and the base case.

Table 7.1 The Cost Components of Bidding Proposals

Cost Components of Bidding Proposals	Base Case (PSC)	Bid A	Bid B	Bid C	Bid D	Bid E
(1) Raw Cost	1. Land Acquisition schemes and costs; 2. Construction schemes and costs; 3. Operation and Maintenance schemes and costs; 4. Project Financing schemes and costs …					
(2) Transferred Risk	1. Risk Control Scheme for Finance; 2. Risk Control Scheme for Default of Subcontractors; 3. Risk Control Scheme for Latent defect; 4. Risk Control Scheme for Downside Economic Events; 5. Risk Control Scheme for Political Interference; 6. Risk Control Scheme for Unforeseen Site Conditions; 7. Risk Control Scheme for Greater Environmental Expectation; 8. Risk Control Scheme for Force Majeure; …					
(3) Retained Risk	The public sector' Risk Control scheme and costs.					
(4) Competitive Neutrality	Tax, Performance bond, Royal…					

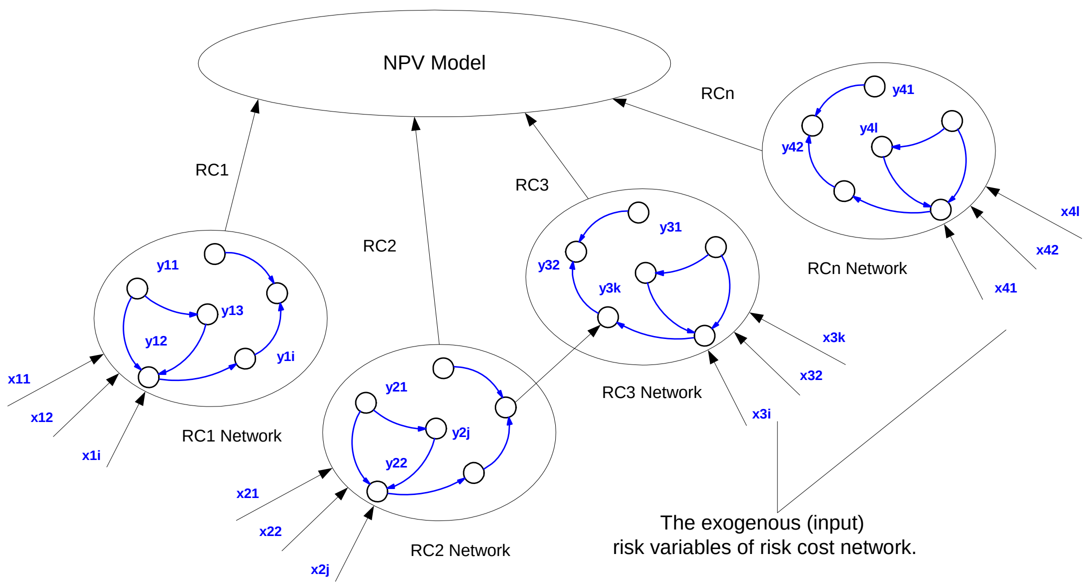


Figure 7.1.1 The Exogenous Variables, Risk Network and NPV Model

(2) Transferred risk: In addition to the plan and scheme for raw cost components, the concessionaire candidates (the private sectors/the bidders) are requested to demonstrate their capability of managing and controlling the allocated risks in their bidding proposals. On the other hand, the public

sector should examine the private sectors bidding proposals to see how efficiently the private sectors risk management and control schemes can reduce the transferred risk effect. To some extent, all of the risk control schemes for the allocated risks proposed by the private sectors would have both positive and negative influences. Using these schemes is an attempt to create better VFM in order to produce higher project NPV. The schemes will result in beneficial influences if they can reduce risk costs more efficiently. Otherwise, the schemes will result in downside influences because they have step up risk costs that then become new risk events. The private sectors should demonstrate the risk reduction schemes and costs in their bidding proposals, and the public sectors should evaluate the compounding effects and costs of the risk control schemes on project NPV to choose a preferred project concessionaire.

As illustrated in Figure 7.1.1, the sources of risk events are the exogenous risk variables (input variables/independent variables of risk cost network x_{ij}), which would cause a network of risk events that are the endogenous risk variables (dependent variables y_{ik}) that would finally link to the NPV model. As a result, the NPV and all endogenous risk variables in a risk network are the function of exogenous risk variables:

$$y_{ik} = f(x_{ij});\ NPV = f(y_{ik}) = f(x_{ij});$$

where

x_{ij}: exogenous risk variables;
y_{ik}: endogenous risk variables
i: ith risk network;
j: jth exogenous risk variable of a risk network;
k: kth endogenous risk variable of a risk network

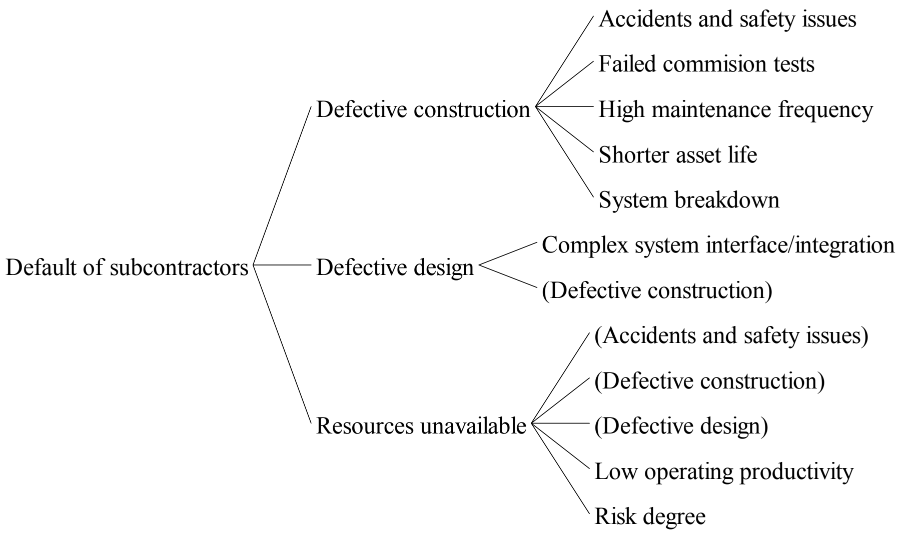


Figure 7.1.2 The Cause-effect Tree of Exogenous Risk Variable 'Default of Subcontractors'

Obviously, the exogenous risk variables are controllable variables that would influence both NPV and endogenous variables. If the exogenous risk variables can be cost-effectively controlled and reduced, then the effects of endogenous variables on the project NPV can be controlled and reduced. For example, the default of subcontractors is one of the exogenous risk variables that assumes the public sector BHSR would transfer it to the private sector for the THSR project. As discussed in chapter 4 and chapter 5, Figure 7.1.2 shows output results from the Vensim software for the cause and effect tree for default of subcontractors risk effect output. These results show that the exogenous risk variable default of subcontractors would trigger a network consisting of other risk effects such as defective construction, defective design, and resources unavailable events that are the endogenous risk variables from the upstream (left hand side) to the downstream (the right hand side). Eventually, these would link to the project NPV (the end of downstream is the cash flow NPV).

Figure 7.1.2 shows three tiers of cause-effect only. If the risk effect default of subcontractors can be controlled and reduced cost effectively, then the triggered risk effects and NPV can be controlled and reduced. Therefore, the researcher has promoted that a risk control scheme focusing on controlling and reducing the exogenous risk effects be addressed in the bidding proposal. The bidding proposal needs to include the activities/actions that can be applied to both of exogenous and endogenous risk variables. For example, the risk control scheme for default of subcontractors might be composed of several project risk management activities such as subcontractor recruitment, material procurement, staff training, design and construction quality controlling, and so on. As shown in Table 7.1.1, this scheme would be able to manage and reduce the risk effect default of subcontractors to a controllable level.

<u>Table 7.1.1 The 'Default of Subcontractors (DOS)' Risk Control Scheme</u>

The 'Default of Subcontractors (DOS)' Risk Control Scheme addressed in the Bidding Proposals:

- Activities (Zhang, 2004):
    - subcontractors recruitment
    - material procurement
    - staff training
    - design and construction quality controlling
    - …

(3) Retained risk: Retained risk is defined as the risk schemes and costs provided by public sector for those risks that are not transferred to the private sector. For a meaningful comparison, within

the bidding proposals, the bidding costs should be adjusted by the proportion of risk retained and retained risk costs.

(4) Competitive neutrality: Competitive neutrality is defined as any cost adjusted by neutralizing the competitive advantages between the public sector and private sector. For example, the public sector is exempt from the following costs: (a) operating income tax, (b) performance bonds that are used to guarantee construction performance, and (c) royalties which are balance funds consists of a percentage of net profit. The private sector is not exempt from these costs. Therefore, this should be modeled for meaningful bids comparison.

7.1.2 Risk Control Schemes Modelling

As discussed in chapters 4 through 6, there are always positive feedback loops (reinforce feedback loops) to generate, amplify and reinforce risk effects in a risk causal loop diagram. The negative feedback loops (the balance feedback loops) would reduce risk effects to seek status balance and equilibrium. Figure 7.1.3 shows a system dynamics causal loop diagram (left hand side) and a behaviour curve (right hand side) for an SD goal seeking structure. This shows that the corrective action will be initiated to bring the state of the system back in line with the goal (the desired state) if there is a discrepancy between the desired and actual state (Sterman, 2000). The larger gaps between the desired and actual states would tend to create a large response (the greater action), while small gaps would tend to generate a small response (the less action). As for risk control schemes, goals for risk reduction would require actions in order to gradually result in an exponential decay for goal-seeking behaviour to approach the goal (the desired risk effect that is under control level). This is shown in the upper curve of right hand side on Figure 7.1.3.

System dynamics goal seeking structure is applied to model the risk-reduction performance efficiency for a bidding proposal. The more efficient the scheme is, the faster the risk effects can be reduced to the desired, controllable level within the desired time. As a result, the compounding effects on NPV of combining the risk interaction effects and risk control effects can be evaluated. The risk-reduction performance efficiency is defined as:

$$\dot{\eta} = \frac{\Delta RD}{\Delta T \cdot \Delta C} \quad (7.1.1)$$

Where $\dot{\eta}$: performance efficiency;

ΔRD: the reduction of risk effect;

ΔT: risk control time;

ΔC: annual invested cost for a risk control scheme.

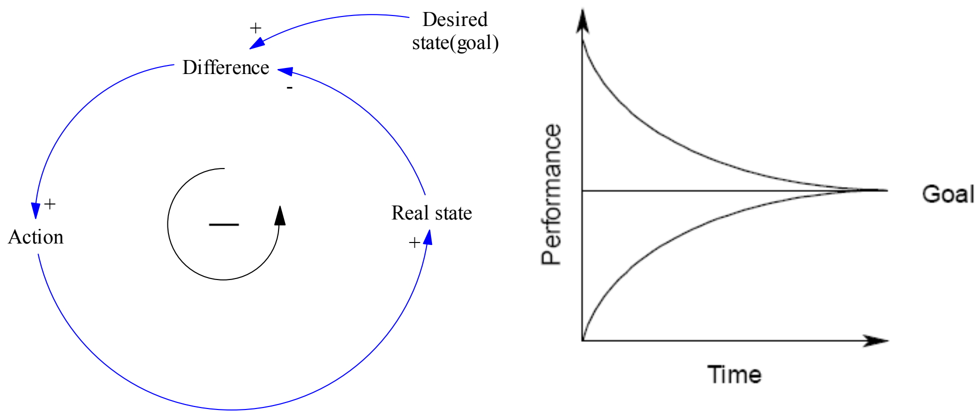


Figure 7.1.3 The 'Goal Seeking' Structure and Behaviour(Sterman, 2000)

For instance, the default of subcontractor (DOS) is one of exogenous risk variables that the risk control schemes proposed in the bidding proposals that the bidders would need to address to manage and control. Figure 7.1.4 is a risk causal loop diagram which indicates there are at least three positive (reinforcing) feedback loops that would cause reinforce downside effects triggered by exogenous variable default of subcontractor. On the other hand, a DOS control scheme that might be composed of several activities would generate a negative (balance) feedback loop to control and reduce the downside effect triggered by DOS to the desired controllable-level, risk effect = 5 (Appendix IV) under the expected time.

Figure 7.1.5 shows a case in which the SD modelling is applied to model the performance efficiency for the DOS risk control schemes among the different bidding proposals. Under the DOS risk control scheme, the DOS risk effect should be continuously reduced within the expected time until the manageable and controllable level of risk effect = 5 is achieved using the DOS risk effect reduction rate as below:

$$\dot{R}d_{ij} = \frac{Rd_{ij} - \hat{R}d}{\hat{T}_{ij}} \quad for\ Rd_{ij} \geq \hat{R}d \quad (7.1.2)$$

$$= 0,\ otherwise$$

Where

$\dot{R}d_{ij}$: the DOS risk effect reduction rate;

Rd_{ij}: the random variable for the risk effect of a risk event;

$\hat{R}d$: the desired risk effect;

$\hat{T}_{ij}$: the expected time (mean time) to reduce the risk effect to the desired level;

i: index of risk effect (this case is 'Default of Subcontractor');

j: index of bidding proposal

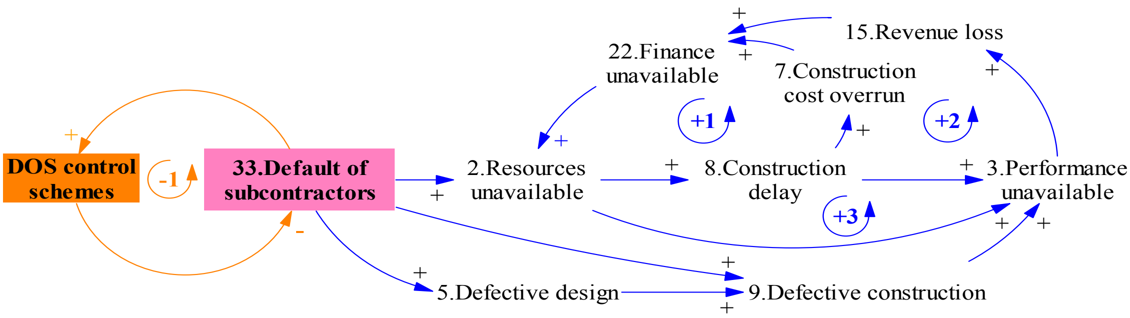


Figure 7.1.4 The Positive (Reinforce) and Negative (Balance) Feedback Loops of DOS Causal Loop Diagram

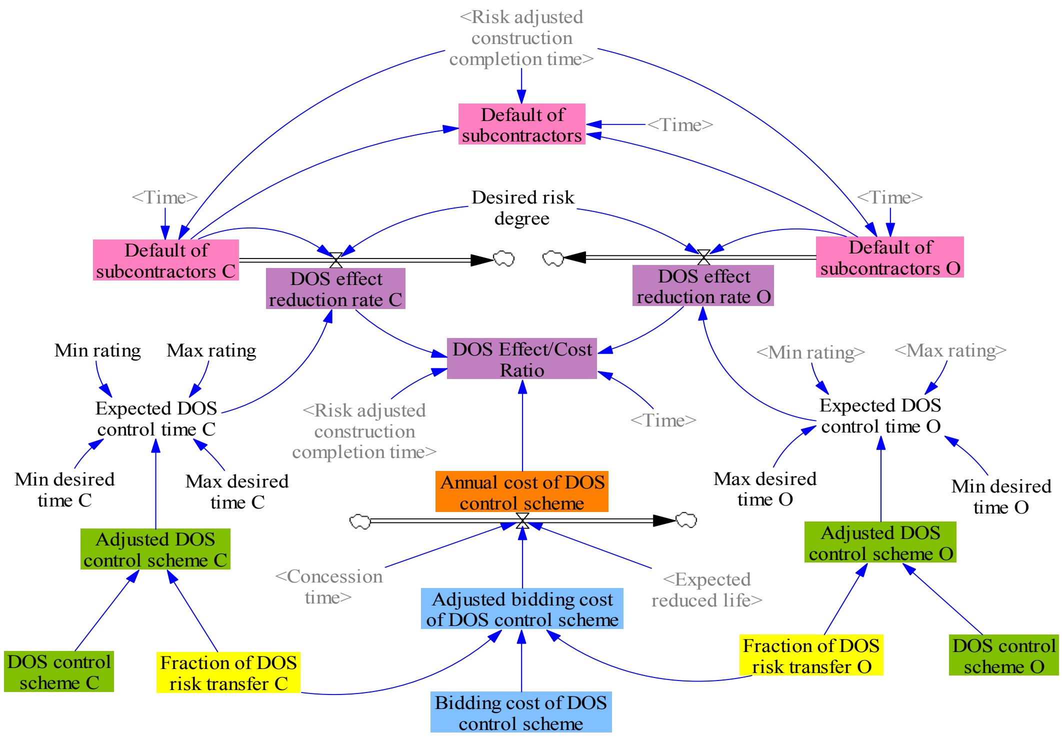


Figure 7.1.5 The SD Modelling for DOS Risk Control Scheme

A Likert scale of 1 through 9 was used to rate the expected risk-reduction effect for the risk control schemes among different bidding proposals by members of the bid evaluation panel. This reflected the probability of a successful bidding proposals risk control scheme in reducing risk effects to the desired level within the expected time. These 9 scales are defined below:

1: ‘very low’ successful probability;
2: ‘between 1 and 3’;
3: ‘low’ successful probability;
4: ‘between 3 and 5’;
5: ‘medium/equal’ successful probability;
6: ‘between 5 and 7’;
7: ‘high’ successful probability;
8: ‘between 7 and 9’;
9: ‘very high’ successful probability;

For example, Table 7.1.2 shows one of rating results from one of the bid evaluation panel members for DOS Risk Control Schemes. In this case on the bid evaluation panel, there are 30 multiple-discipline members who are responsible for rating the expected risk-reduction effect for a risk control scheme in a bidding proposal. By using this simple scoring method, 30 samples of data that show the probability distribution of how a successful risk control scheme can reduce risk effect are obtained from the bid evaluation panel members. By inferring the probability distribution of the expected risk effect as addressed in chapter 6, the probability distribution for the expected risk-reduction effect in a risk control scheme for a bidding proposal can be estimated by probability fitting the sampled data. For example, in Table 8.1.3 the researchers assumed the probability distribution for all risk control schemes applicable to both construction and operation phase, which is inferred from the rating submitted by the bid evaluation panel members.

<u>Table 7.1.2 The Rating for ‘DOS Risk Control Schemes’ Effects</u>

Rating for the expected effect of ‘DOS Risk Control Schemes’:

Base case: (○ 1)- (○ 2)- (○ 3)- (○ 4)- (◉ 5)- (○ 6)- (○ 7)- (○ 8)- (○ 9)
Bid A: (○ 1)- (○ 2)- (○ 3)- (○ 4)- (○ 5)- (○ 6)- (○ 7)- (◉ 8)- (○ 9)
Bid B: (○ 1)- (◉ 2)- (○ 3)- (○ 4)- (○ 5)- (○ 6)- (○ 7)- (○ 8)- (○ 9)
Bid C: (○ 1)- (○ 2)- (○ 3)- (○ 4)- (○ 5)- (◉ 6)- (○ 7)- (○ 8)- (○ 9)
Bid D: (○ 1)- (○ 2)- (○ 3)- (○ 4)- (◉ 5)- (○ 6)- (○ 7)- (○ 8)- (○ 9)
…

Table 7.1.3 The Probability Distribution of the Expected Effects of Risk Control Schemes Addressed in Bidding Proposals

RSC Effects	Base Case	Bid A	Bid B	Bid C	Bid D
DOS control scheme C	Nor (3,5.3)	Tri (1, 5, 9)	Nor (6, 5.5)	Nor (7, 6.3)	Tri(1, 8, 9)
DOS control scheme O	Nor (4,5.7)	Nor (7, 5.5)	Tri (1, 7, 9)	Nor (9, 6.3)	Nor (5, 7.5)
LT control scheme C	Tri (1, 5,9)	Tri (1, 6, 9)	Nor (7, 4.1)	Tri(1, 5, 9)	Tri(1, 8, 9)
LT control scheme O	Nor (3,6.1)	Tri (1, 5, 9)	Nor (6, 7.3)	Nor (5, 4.5)	Nor(6, 6.7)
PI control scheme C	Nor (9, 5.1)	Nor(6, 5.3)	Nor (4, 6.8)	Tri (1, 4, 9)	Tri(1, 5, 9)
PI control scheme O	Tri (1, 7, 9)	Tri (1, 6, 9)	Nor (7, 3.5)	Nor (6, 6.8)	Tri(1, 5, 9)
FM control scheme C	Nor (7,8.8)	Tri (1, 4, 9)	Tri (1, 5, 9)	Tri (1, 7, 9)	Nor(8, 9.5)
FM control scheme O	Nor (7,5.7)	Tri (1, 4, 9)	Tri(1, 7, 9)	Nor (7, 9.5)	Nor(7, 6.4)
GEE control scheme C	Nor (5,6.6)	Nor (7, 6.6)	Nor (8, 7.8)	Nor (6, 8.4)	Tri(1, 6, 9)
GEE control scheme O	Tri (1, 5, 9)	Tri (1, 7, 9)	Nor (6, 5.5)	Nor (7, 6.3)	Tri(1, 8, 9)
DEE control scheme C	Nor (9,6.1)	Tri (1, 7, 9)	Tri (1, 8, 9)	Nor (5, 7.6)	Nor (7, 4.9)
DEE control scheme O	Nor (9,8.8)	Nor(6, 8.3)	Nor (9, 6.7)	Nor (4, 7.9)	Tri(1, 9, 9)
USC control scheme C	Nor (3,5.7)	Tri (1, 7, 9)	Nor (7, 8.5)	Tri (1, 6, 9)	Tri(1, 9, 9)

Time variable $\hat{T}_{ij}$ is the expected time taken for a risk control scheme to reduce the risk effect until the desired level. This is assumed to be in linear proportion to the probability distribution for expected risk-reduction effect of a risk control scheme between the minimum desired time and the maximum desired time. Therefore, the expected time can be formulated as:

$$\hat{T}_{ij} = (Tmax_i - Tmin_i)*(Rcs_{ij} - Rcs_{max})/(Rcs_{min} - Rcs_{max}) + Tmin_i \quad (7.1.3)$$

where

$\hat{T}_{ij}$: the expected time to reduce the risk effect until the desired level;
Rcs_{ij}: the probability distribution for the expected risk-reduction effect of a risk control scheme;
$Tmax_i$: the maximum desired time for a risk control scheme to reduce a risk effects;

$Tmin_i$: the minimum desired time for a risk control scheme to reduce a risk effects;
Rcs_{max}: 9;
Rcs_{min}: 1;
i: index of risk effect (this case is 'Default of Subcontractor');
j: index of bids

Once a risk control scheme has been rated to estimate its expected risk-reduction effect and probability distribution and the expected time to reduce the risk effect until the desired degree has been estimated, the time-efficiency (risk-reduction rate) for a risk control scheme can be calculated by using the formula 7.1.2. Therefore, the risk effect would change by exponential decay behaviour formulated below:

$$Rd'_{ij} = Rd_{ij} - \int_0^{\hat{T}_{ij}} \dot{R}d_{ij} dt \quad (7.1.4)$$

Where
Rd'_{ij}: new status of a risk effect after risk reduction;
Rd_{ij}: the initial status of a risk effect before risk reduction.

Every risk control scheme addressed in a bidding proposal is not free. Concessionaires have to pay for the risk-reduction effect, which accounts for the risk-transfer cost. This risk-transfer cost is one of the total bidding proposal cost components. If the risk control schemes cannot efficiently manage and reduce risk effects, then the invested money of time for risk control schemes might be higher than the risk costs can be reduced. That is to say, the risk control schemes would become the new risk events. Therefore, the invested costs for the risk control schemes, $Crcs_{ij}$, are linked to the NPV model so that the time-cost effects arising from the risk control schemes on the project NPV can be compounded. For the case shown in Figure 7.1.5, the DOS effect/cost ratio is exactly the formula used in Table 7.1.1 for time-cost performance efficiency.

Moreover, the base case (PSC for all risks retained) is used as a benchmark against all of the bidding proposals. For consistent comparison, the risk transfer level proposed in each bidding proposal should reflect the risk transfer level proposed by public sector. Therefore, the expected risk-reduction effects and costs for a risk control scheme are adjusted by the fraction of risk-transferred to the private sector as follows.

$$Rcs'_{ij} = (1- \theta_{ij}) \times Rcs_i(bc) + \theta_{ij} \times Rcs_i(bids) \quad (7.1.5)$$

Where
Rcs'_{ij}: the adjustment for the expected risk-reduction effect for a risk control scheme;
$Rcs_i(bc)$: the expected risk-reduction effect for a risk control scheme proposed in the Base Case, which is rated by Bid Evaluation Panel;
$Rcs_i(bids)$: the expected risk-reduction effect for a risk control scheme proposed in the bidding proposals, which is rated by Bid Evaluation Panel;
θ_{ij}: the fraction of risk-transferred to the private sector

$$Crcs'_{ij} = (1- \theta_{ij})\times Crcs_i(bc)+Crcs_i(bids) \quad (7.1.6)$$

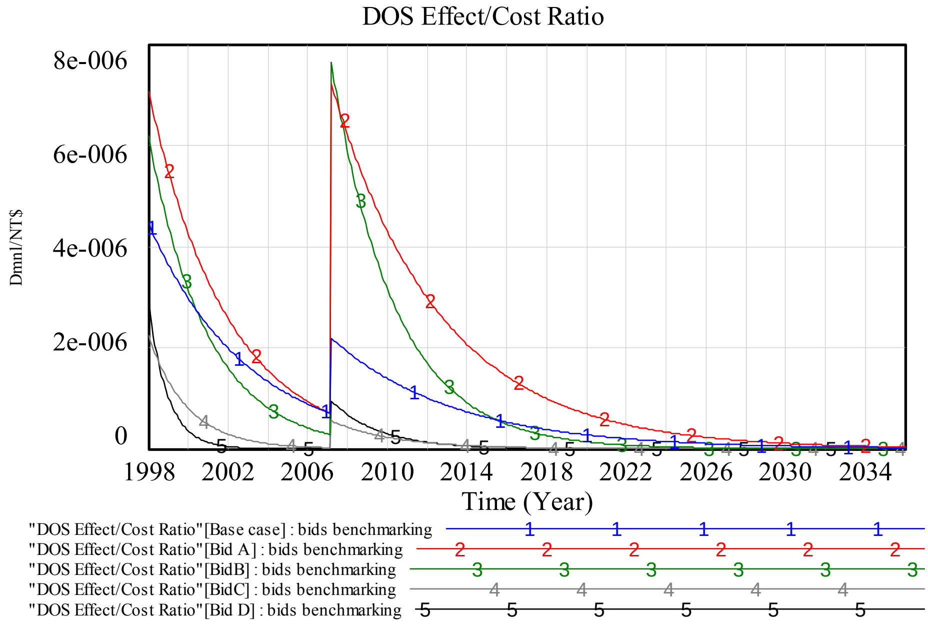
Where

Crcs'ij: the adjustment for a risk control scheme cost;

$Crcs_i(bc)$: the cost for a risk control scheme stated in the Base Case (the cost for all risks reserved);

$Crcs_i(bids)$: the cost for a risk control scheme proposed in the bidding proposals (the cost for transferred risks only);

θ_{ij}: the fraction of a risk event transferred to the private sector



<u>Figure 7.1.6 The DOS Effect/Cost Ratio for A Risk Control Scheme between Bids During Project Construction and Operation Phases</u>

The PPP project risk network is so complicated that it is difficult for officials to estimate how the project performance changes from a single individual factor because the risk effects interact with each other over time. However, using the SD model proposed by the researcher was able to estimate the compounding effects on NPV by combining a single risk effect, the risk interaction effects and the reduction effect for a single effect and risk interaction effects. Figure 7.1.6 shows the output of Figure 7.1.5 for the risk-reduction effect per unit cost of risk control schemes among bids over time. The results comprise an exponential decay curve. The steeper the slope, the more efficient is the risk-reduction effect for a risk control scheme. As a result, the default of subcontractors (DOS) risk effect (assume the starting risk effect of DOS is 15) is gradually reduced until reaching the desired risk effect (assume ending risk effect of 5). This shows an exponential decay for goal-seeking behaviour as shown in Figure 7.1.7. Consequently, Figure 7.1.8 shows the compounding effects on NPV by combining the risk effect of DOS risk-reduction effect of DOS and interaction of DOS with other risks over project life.

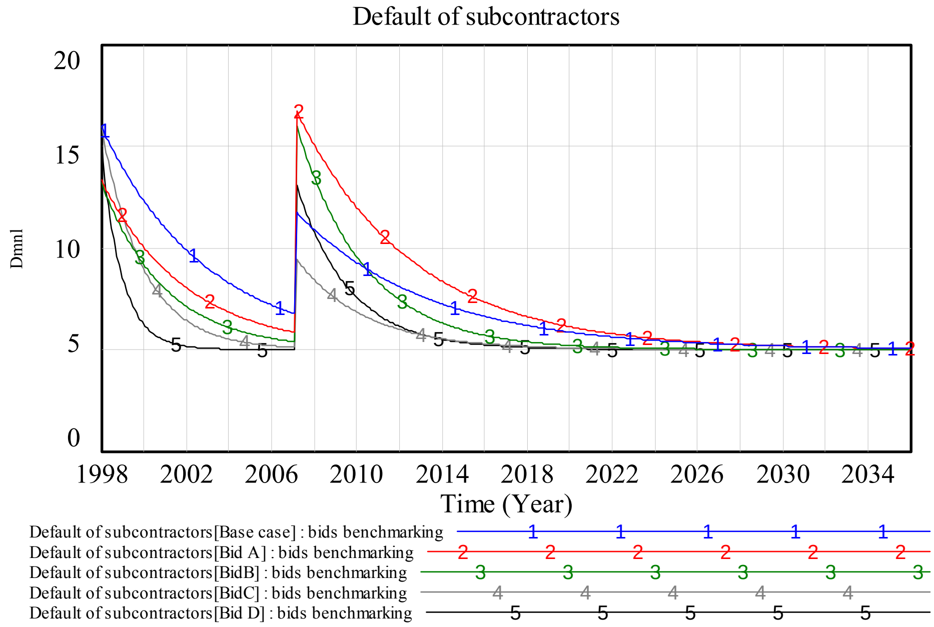


Figure 7.1.7 The 'Default of Subcontractors' Risk Effect Reduction over Project Construction and Operation Phases among Bids

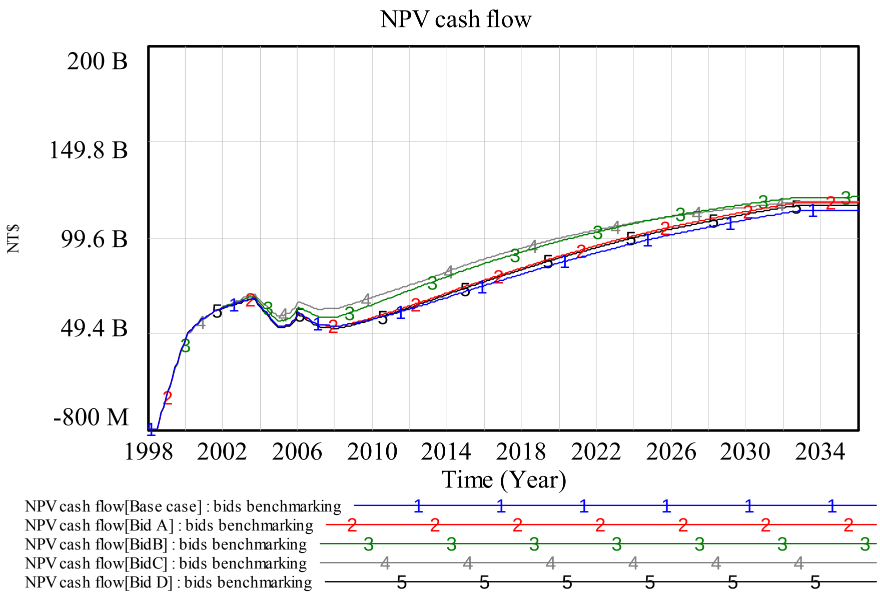


Figure 7.1.8 The Compounding Effects of 'Interaction of Risk Effects' and 'Effect/Cost of Risk-reduction Effects' on the Project NPV Cash Flow

Discount rate is very sensitive to project NPV cash flow. As discussed in chapter 3, the discount rates used to estimate NPV cash flow for the base case should be consistent with those used to assess private sectors bids. Different discount rates should be adjusted to consistently analyze and benchmark the different cash flow between the base case and bidding proposals due to different fraction of risk allocation.

As described in chapter 6, the weighted average cost of capital (WACC) is calculated to determine discounted rate for project cash flow modelling, which is used to estimate cost of capital based on capital structure by combining the return on debt and equity as follows (Park & Sharp-Bette, 1990).

$$r_{wacc} = w_e r_e + w_d r_d (1-t_m) \quad (7.1.7)$$

Where

r_{wacc}: Weight Average Cost of Capital;
w_e: equity fraction;
r_e: return on equity;
w_d: debt fraction;
r_d: debt interest;
t_m: tax rate

The return on equity r_e is used to adjust r_{wacc} to calculate NPV cash flow for the bidding proposals with different fraction of risk allocation, which generally refers to the annual rate of return that an investor expects to earn on an investment in conjunction with the exposed risks. Then, the capital asset pricing model (CAPM) is widely recommended for estimating the expected return on equity(Hirst et al., 2007; Partnerships Victoria, 2003; Queensland Treasury, 2006). The CAPM refers to a firm's cost of equity capital which is equal to the risk free rate of return on the market, plus a premium above the risk free rate, to reflect the relative risk of the investment, which can be expressed as (Hirst et al.; Partnerships Victoria, 2003; Queensland Treasury, 2006):

$$r_e = r_f + \beta_e (r_m - r_f) \quad (7.1.8)$$

Where

r_e: expected return on equity;
r_f : risk-free interest rate;
r_m: market rate of return;
$r_m - r_f$: risk premium;
β_e: equity beta measures the correlation between the asset's risk and the overall market;

Since '$r_m - r_f$' is risk premium, r_e needs to be adjusted by adjusting '$r_m - r_f$' based on the fraction of risk transferred to private sectors as follows.

$$r'_e = r_f - p_j \beta_e (r_m - r_f) \text{ for } F_n > 0 \quad (7.1.9)$$
$$= r_f + p_j \beta_e (r_m - r_f) \text{ for } F_n < 0$$

$$p_j = \sum_{i=1}^{n} w_i \theta_{ij}$$

where

r'_e: expected return on equity adjusted by risk allocation;
p_j: the total portion of project risk premium transferred to the private sector;
w_i: the percentage for the relative importance of a risk effect on NPV;
θ_{ij}: the fraction of a risk premium transferred to the private sector;
r_f : risk-free interest rate;
r_m: market rate of return;
$r_m - r_f$: risk premium;
β_e: equity beta measures the correlation between the asset's risk and the overall market;
F_n: net cash flow in nth year

The percentage for the relative importance of a risk effect on NPV, w_i, is calculated based on the Pearson correlation coefficients. The Pearson correlation coefficients are obtained by conducting sensitivity analysis for Monte Carlo simulation. An example for Pearson correlation, relative risk importance, risk allocation, and the percentage of risk premium transferred to the private sector for Bid A is shown in Table 7.1.4.

The comments on the low values of the Pearson correlation coefficients (e.g., those Pearson correlation coefficients near zero in Table 7.1.4) as a result of correlation analysis are as follows:

(1) A Monte Carlo simulation with 10,000 iterations was performed on the *SD* model. Therefore, the correlation analysis for the exogenous variables (model input) and NPV values (model output) is based on 10,000 samples (sample size N=10,000).

(2) As addressed in 8.8.3 the Pareto chart for the relative importance of risk effects on project NPV, the *p*-value is the measure criteria to judge if the correlations are STATISTICALLY significant. If the p-value is less than $\alpha = 0.05$, then the risk variables significantly affect project NPV at $\alpha = 0.05$. Otherwise, they are not statistically significant. The results of correlation analysis indicate that most of the exogenous variables listed in Table 7.1.4 are not statistically significant except for those economical and financial risk variables. The *p*-value for variability of less demand, variability of interest rate, variability of exchange rate and variability of tax rate is close to zero, so they are statistically significant. This result can consistently interpret the *SD* model behaviour that *only financial difficulties at operation stage* will lead to the most detrimental feedback loop (see Figure 8.8.4): revenue loss → finance unavailable → resource unavailable → performance unavailable → revenue loss, and

the current situation of THSR project that the VFM has been eroded because of less revenue from lower demand for operation cannot outweigh high private financing cost (high interest rate of debt for construction).

(3) The correlations in Table 7.1.4 indicates that exogenous risk variables, *Force Majeure C* (The same events may have two variables at construction stage and operation stage respectively used for *SD* model; C means construction stage and O means operation stage.) and *unforeseen site conditions C* have small Pearson correlation values which are near to zero. This means they have little effects on project NPV.

Relative to the question,"How were the public: private risk allocations determined for those risks that are not statistically significant?" this depends on the risk management capability and risk utility (risk-averse, risk-neutral, or risk seeking) of the public sector. A major purpose of the PPP arrangement is the transfer and allocation of risks to the party who is the most capable of efficiently managing these risks (HM Treasury, 2004b). In other words, if the public sector officials feel that private sector contractor can be more cost-effective in managing a risk than it does, then the larger part of the risk premium will be transferred to the private sector regardless of statistically significance. Most of the public sectors are risk-aversive, especially for an infrastructure project, since they will need to protect public interests. Hence, the public sectors would generally intend to transfer risks to the private sector contractors if they have little confidence of managing a risk. For example, the Australia government's guideline on risk allocation and contractual issues states that the. For example, the Australia government's guideline on risk allocation and contractual issues states that:

> "the government shares a *Force Majeure* risk only to the extent that the materialised risk prevents it from receiving the contracted services. As an example, *Force Majeure* risk can be shared to the extent that the private party is relieved of the risk of contract termination, but effectively retains the financial risk of the *Force Majeure* event. (Partnerships Victoria, 2001)"

This guideline also suggests that the preferred allocation for *unforeseen site conditions* is at private party level.

Table 7.1.4 An Example: the Percentage of Risk Premium Transferred to the Private Sector for Bid A

Bid A			Risk Allocation		Risk Premium transferred to Private Sector
Risk Effect	Correlation (Pearson)	Relative Importance	public	private	%
Default of subcontractors C	0.124	0.047	0.2	0.8	0.038
Default of subcontractors O	0.066	0.025	0	1	0.025
Downside economic events C	0.013	0.005	0.3	0.7	0.003
Downside economic events O	0.065	0.025	0.2	0.8	0.020
Equity fraction	0.18	0.068	0	1	0.068
Force Majeure C	0.006	0.002	0.2	0.8	0.002
Force Majeure O	0.015	0.006	0.3	0.7	0.004
Greater environmental expectation C	0.069	0.026	0.3	0.7	0.018
Greater environmental expectation O	0.081	0.031	0.4	0.6	0.018
Latent defect C	0.061	0.023	0	1	0.023
Latent defect O	0.02	0.008	0	1	0.008
Political interference C	0.128	0.049	0.6	0.4	0.019
Political interference O	0.065	0.025	0.6	0.4	0.010
Unforeseen site conditions C	0.001	0.000	0	1	0.000
Variability of exchange rate	0.372	0.141	0	1	0.141
Variability of inflation rate	0.03	0.011	0	1	0.011
Variability of interest rate	0.448	0.170	0	1	0.170
Variability of less demand	0.738	0.281	0	1	0.281
Variability of tax rate	0.147	0.056	0.3	0.7	0.039
Total	2.629	1			**0.901**

As shown in Figure 7.1.9 (left), if the net cash flow for the public sector (the base case: PSC) is greater than 0 (net cash inflow), then the discount rates for the private sectors bidding proposals are adjusted by reducing in reverse proportion to the fraction of risk transferred to the private sectors. On the contrary, as shown in Figure 7.1.9 (right hand side, if the net cash flow for the public sector (the base case: PSC) is less than 0 (net cash outflow), then the discount rates for the private sectors bidding proposals are adjusted by increasing in linear proportion to the fraction of risk transferred to the private sectors. Therefore, the discount rates shown in formula 7.1.7 are adjusted by risk allocation for NPV estimates for the bidding proposals are:

$$r'_{wacc} = w_e r'_e + w_d r_d (1-t_m) \quad (7.1.10)$$

where

r'_{wacc}: adjusted WACC for bidding proposals;
w_e: equity fraction;
r'_e: adjusted return on equity for bidding proposals;
w_d: debt fraction;
r_d: debt interest;
t_m: tax rate

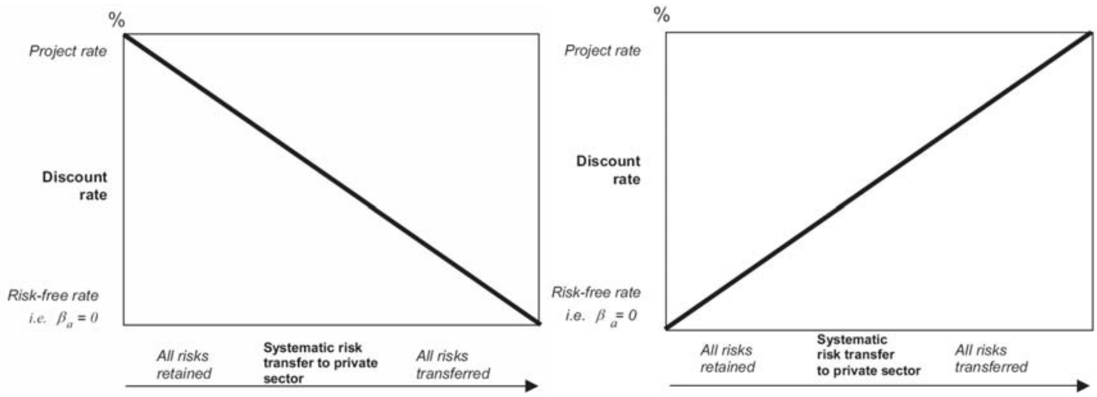


Figure 7.1.9 The Adjusted Discount Rates for Bidding Proposals for Net Cash Inflow (the Left Hand Side) and Net Cash Outflow (the Right Hand Side) Basing on the Proportion of Risk Transferred to the Private Sectors

7.2 Monte Carlo Simulation for Bidding Proposals

There are four bidding proposals, Bid A, Bid B, Bid C, and Bid D which were evaluated to compare with the base case. The respective bidding costs and basic information for each are displayed in Table 7.2.1(They are hypothetical data.).

A Monte Carlo simulation with 10,000 iterations was performed on the above SD bidding proposal models by the software, Vensim, to estimate the compounding effects on NPV. This combined downside effects arising from risk interactions and balance effects arising from bidding proposal performance. Figure 7.2.1 shows the histogram plots with a probability fitting curve on normal distribution to display NPV probability distribution for the base case and the bidding proposals. Figure 7.2.2 shows the boxplot to compare mean with a 95% confidence interval for the expected project NPV between the base case and bidding proposals.

Table 7.2.1 The Price of Bidding Proposals

Bidding Cost (NT$)	Base Case	Bid A	Bid B	Bid C	Bid D
Transferred risk	0.00E+00	4.89E+10	4.47E+10	4.02E+10	3.24E+10
Raw cost	3.77E+11	3.97E+11	3.58E+11	3.66E+11	3.56E+11
Retained Risk	5.42E+10	5.26E+09	9.49E+09	1.40E+10	2.18E+10
Total costs	4.32E+11	4.52E+11	4.12E+11	4.20E+11	4.10E+11
% risk transfer	0	0.903	0.825	0.741	0.597
***The total cost has adjusted according to Competitive Neutrality addressed above.					

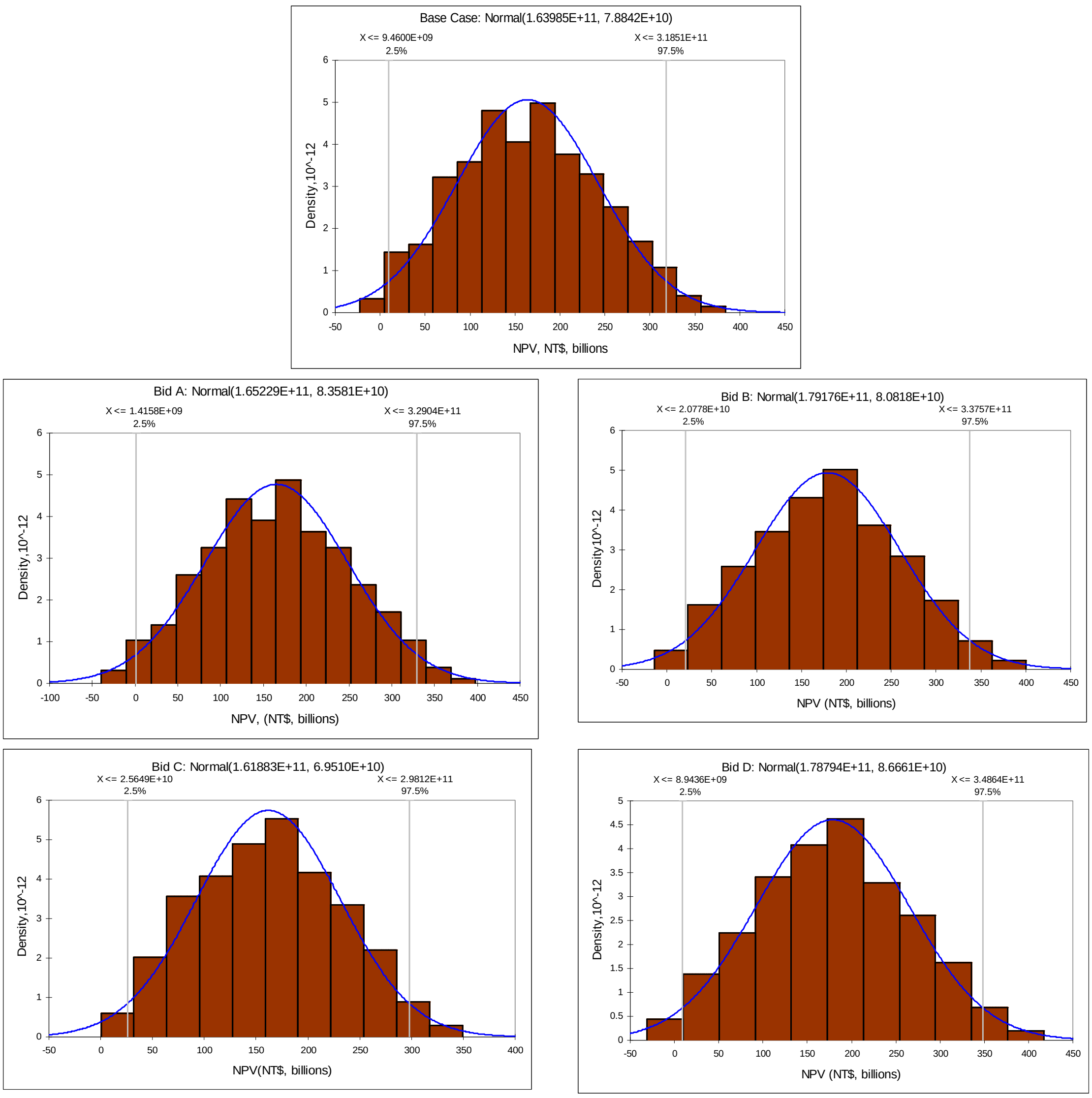


Figure 7.2.1 The NPV Probability Distribution of Base Case and Bidding Proposals

7.3 Comparison Methods for Bids Competition

The boxplot shown in Figure 7.2.2 indicates that there are large overlaps for the 95% confidence bonds between the base case and bidding proposal so that, basing on $\alpha = 0.05$, there is no significant evidence to tell the bidding proposals NPV performance apart. It is difficult to make decision about a preferred bidder from the boxplot.

There have been some methods developed to compare risky projects. The researcher introduced some methods that are appropriate and easy to use in comparing bidding proposals and in choosing a bidding proposal.

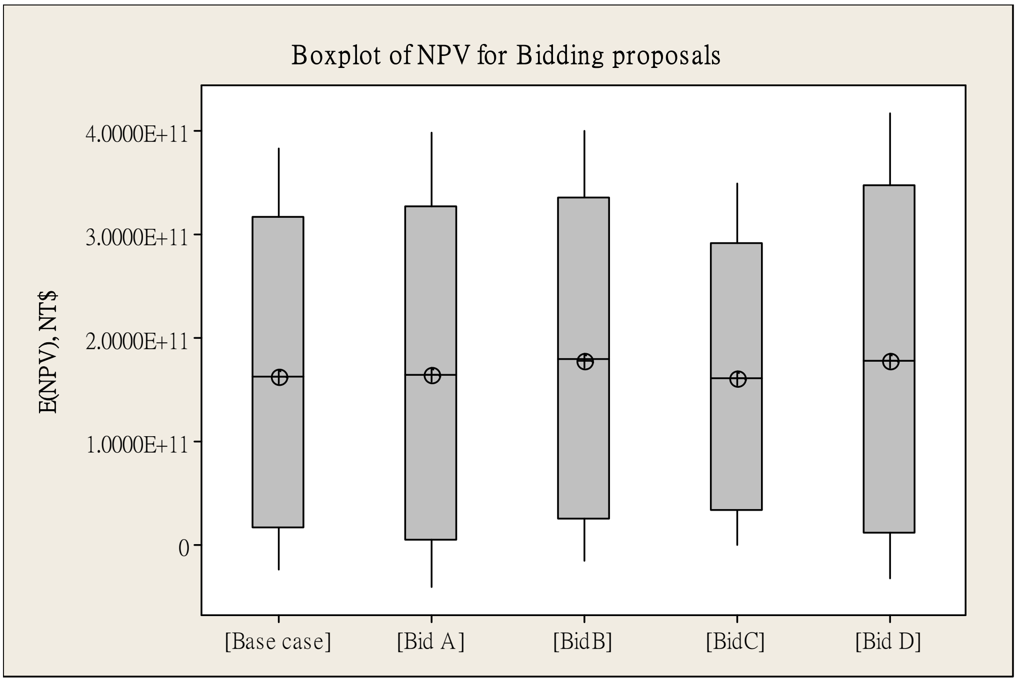


Figure 7.2.2 The Boxplot with Mean and 95% Confidence Interval for the Expected NPV of Base Case and Bidding Proposals

7.3.1 Mean-variance and Mean-Semivariance

The first method is to apply mean-variance *(E-V)* criterion for risky project selection. This means that the greatest mean (outcome) and the smallest variance (risk) would be the preferred option (Park & Sharp-Bette, 1990).

Figure 7.3.1 shows the mean-variance plot to compare *E (NPV)* and *Var (NPV)* among the base case and bidding proposals. This indicates that the base case is on the efficiency frontier that is a curve drawn through the points representing options that are not dominated by other options (Park & Sharp-Bette, 1990). There is no bidding proposal to dominate the base case by E-V rule. Therefore, there is no preferred bidding proposal because the primary condition is that the bidding proposals should have better NPV than the base case to demonstrate value for money.

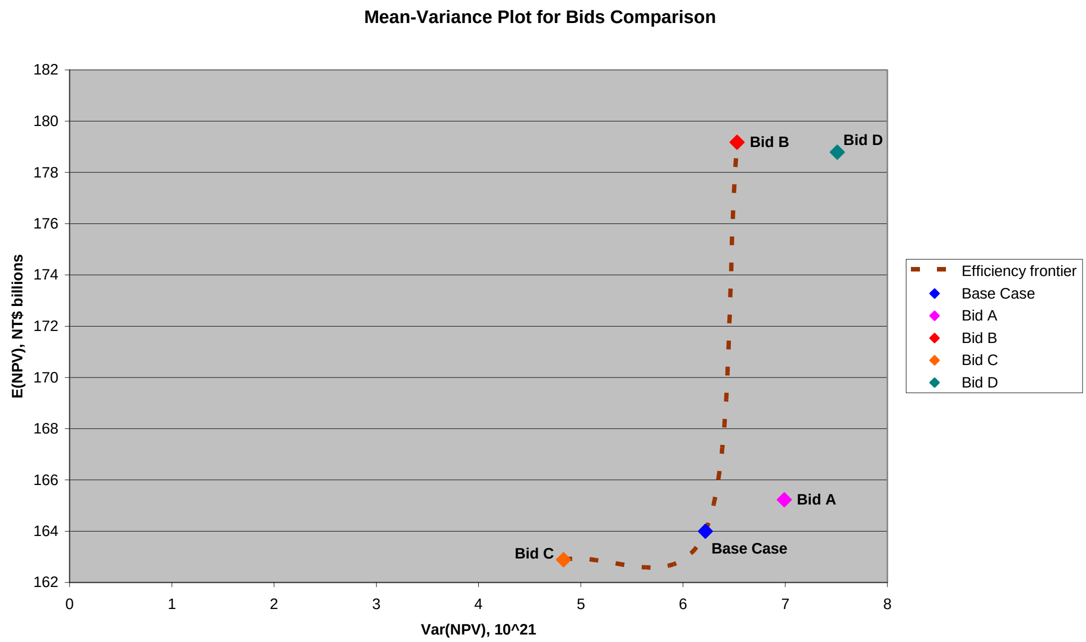


Figure 7.3.1 The Mean-Variance Plot for Bids Comparison

To differentiate the bidding proposals from the base case, the mean-semi variance (E-S_h) criterion is a good option. However, it is suggested that only NPV variability is below the acceptable level is desirable; the variability within the acceptable region was not. Thus, the mean-semi variance rule modifies variance that captures only the desirable NPV variation for bidding proposals is defined as (Park & Sharp-Bette, 1990):

$$S_h = E[(x-h)^-]^2 = \sum_j [(x_j - h)^-]^2 p_j \quad (7.3.1)$$

where : S_h : *semivariance* S_h;

$(x-h)^- = x-h$ *when* $x \le h$;

$= 0$ *when* $x > h$;

h: a reference value considered as a lower limit, below which risk is occurred;

P_j: *probability of* x_j *occurring*

The bidding proposals should have greater NPV performance than the base case (a reference project that is implemented by traditional public procurement approach rather than PPP approach) does in demonstrating VFM. Therefore, $h = E\ (NPV)\ of\ base\ case$ = NT\$1.64e + 11 is selected for $E\text{-}S_h$ analysis.

Figure 7.3.2 shows the mean-semi variance plot to compare *E (NPV)* and *Var (NPV)* among the base case and the bidding proposals. This indicates that the efficiency frontier has been disappeared. As a result, Bid B dominates the base case and other bids, because it has greatest *E (NPV)* and smallest variance now. Therefore, the Bid B is the preferred option.

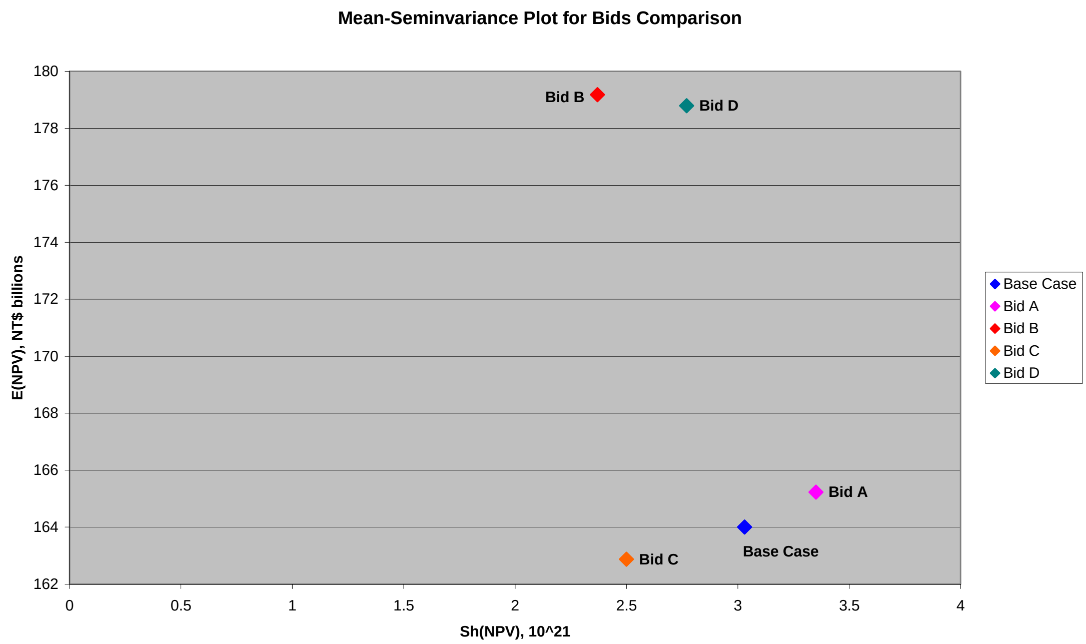


Figure 7.3.2 The Mean-Semivariance Plot for Bids Comparison

However, we still cannot tell apart Bid A vs. Bid C, Bid A vs. base case, Bid C vs. Bid D, and Bid C vs. base case if we would like to rank them. The mean-variance or mean-semi variance is criticized in that it would become unreliable if the outcomes are not normally distributed (Oryczak, 2000; Ye & Tiong, 2000). As shown in Figure 7.2.1 and Figure 7.2.2, the shapes of histogram plot and boxplot for Bid B are skewed to the left, so the probability distribution for Bid B does not fit normal distribution parameters well. Therefore, it may be necessary to test whether Bid B chose by mean-semi variance is really the preferred bidding proposal with superior VFM than the others presented proposals when other comparison methods without limitation on probability distribution are applied.

7.3.2 Stochastic Dominance

As addressed in Chapter 2, stochastic dominance is applied to analyze mutually exclusive projects by comparing the entire cumulative distribution for possible outcomes; this does not require specification of the form of a decision makers utility function (Oryczak, 2000, 2003; Park & Sharp-Bette, 1990; Pribasi et al., 2006). The first-degree stochastic dominance is defined as (Park & Sharp-Bette):

Let F(x) and G(y) be cumulative distributions for random variables x and y. Let U be any non-decreasing function with finite values for any finite x. x stochastically dominates y to the first order, denoted by 'x D y', if and only if:

$$F(x) \leq G(y) \text{ for every } x \quad (7.3.2)$$
$$\text{And } F(x_o) < G(yo) \text{ for some } x_o$$

Thus, if the cumulative distribution function (CDF) of x is equal to or below that of y everywhere, then x dominates (is preferred to) y; this definition is applicable only if CDF of x and y do not cross each other.

In addition to the first-degree stochastic dominance, there is second-degree and third degree stochastic dominance. Since they are computationally very difficult (Oryczak, 2003), the researcher recommends the first-degree stochastic dominance only.

Figure 7.3.3 shows the empirical CDF for the base case and all bidding proposals. The figure shows that the CDF curves for all options across each other so that it cannot be determined which option is preferred by the first-degree stochastic dominance decision rule.

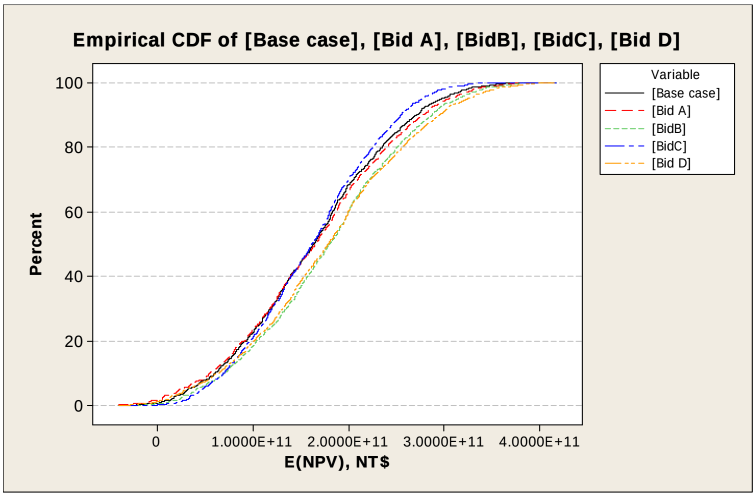


Figure 7.3.3 The Empirical CDF of Base Case and Bidding Proposals

7.3.3 The Expected-Loss ratio

Since mean-variance, mean-semivariance, stochastic dominance cannot help to choose the preferred option, the expected loss ratio based on the probability for the expected loss and expected value of outcome is introduced. This is defined as below (Limbu et al., 2006; Stahr, 2006; Watson, 2005):

$$R_{el} = L/(L+V) \quad (7.4.3)$$

where

$$L\ (loss) = P(x<NPV_{BC}) = F(NPV_{BC}) = \int_{NPV_{\min}}^{NPV_{BC}} f(x)dx\ ;$$

$$V(VFM) = P(x \geq NPV_{BC}) = F(NPV_{max}) - F(NPV_{BC}) = \int_{NPV_{BC}}^{NPV_{Max}} f(x)dx\ ;$$

NPV_{BC}: *the expected NPV for the Base Case*

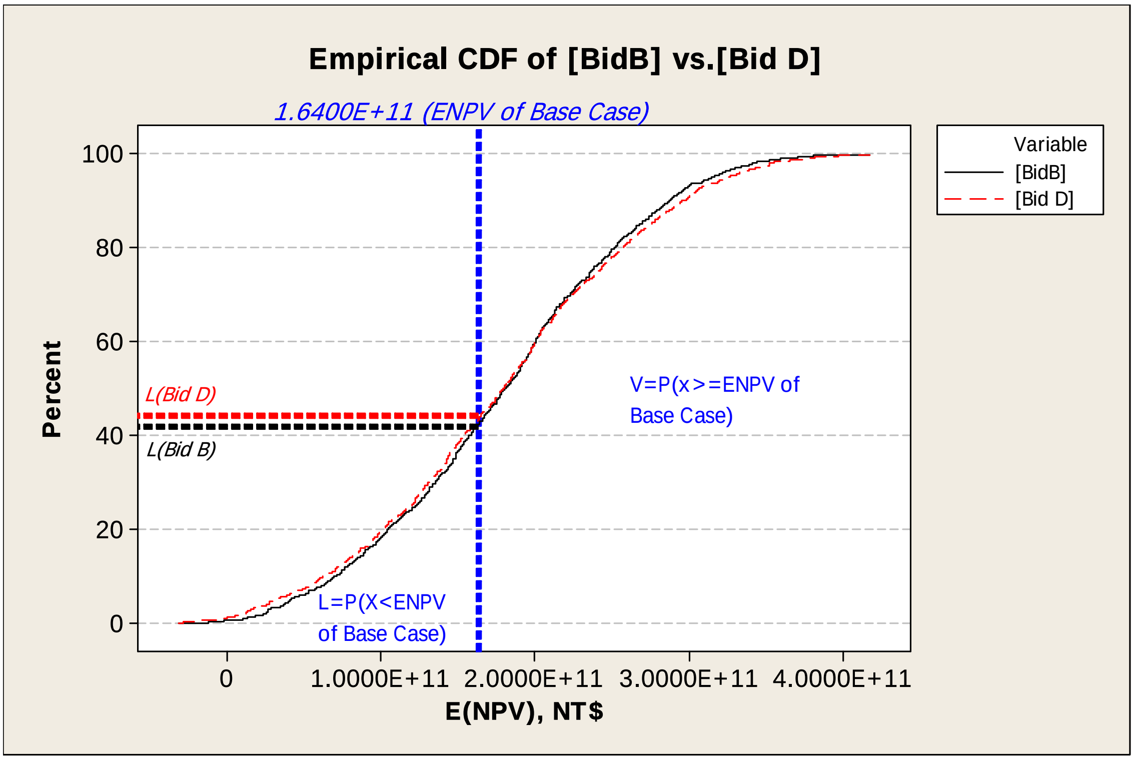


Figure 7.3.4 The Empirical CDF for the Base Case and Bidding Proposals with the Expected Loss

The bidding proposal should have better NPV performance than the base case does in order to demonstrate VFM. Therefore, the expected NPV for the base case, NPV_B, is provided as the minimum acceptable level. *Loss (L)* refers to the cumulative probability of NPV less than NPV_B (the expected loss), whereas *V (VFM)* refers to the cumulative probability of NPV greater than NPV_B (the expected gain). The expected loss ratio R_{el} is equal to L/(L+V). The lesser the expected loss ratio is, the less risky, and greater VFM the option is. The less the expected loss ratio, the more preferred is the bidding proposal. Figure 7.3.4 is used to show the L and V values for Bid B vs. Bid D. The R_{el} is calculated in Table 7.3.1 which indicates that Bid B dominates Bid D which dominates Bid A which dominates the base case which dominates Bid C (Bid B→Bid D→Bid A→Base Case→Bid C). As a result, the Bid B is the preferred option.

Table 7.3.1 the Expected-Loss Ratio for Bids Benchmarking

Bids Benchmarking	Base Case	Bid A	Bid B	Bid C	Bid D
L=p(x<ENPV of Base Case)	50.299	49.399	42.099	50.899	44.299
V=p(x>=ENPV of Base Case)	49.711	50.611	57.911	49.101	55.701
The Expected-loss Ratio = L/(L+V)	0.50	0.49	0.42	0.51	0.44

Chapter 8 Model Validation

As far as model validation was concerned, a variety of tests were developed to diagnose flaws and to improve system dynamics modelling. Even though these tests might have different terminologies in terms of classification, the testing contents are similar. Sterman (2000) proposed 12 testing approaches that were summarized from previous studies (Barlas, 1989, 1990, 1996; Forrester, 1973; Forrester & Senge, 1980) for various purposes. The researcher applied some of them which are extensively applied by the current research (Ferreira, 2002; Hao, 2002; Kazeli et al., 2003; Lee et al., 2005; Martin, 2002; Nguyen & Ogunlana, 2005; Tvedt, 1996) to test SD modelling including: boundary adequacy tests, structure assessment tests, dimensional consistency tests, parameter assessment tests, extreme condition analysis, integration error tests, behaviour reproduction tests, and sensitivity analysis. In Table 8.1, the researcher summarized these tests by displaying measure of performance and the results of measures that are addressed in detail in the following sections.

8.1 Boundary Adequacy Tests

Boundary adequacy tests were used to assess the appropriateness of the model boundary for the model purpose (Sterman, 2000). Before starting SD quantitative modelling, the researcher created causal loop diagrams (CLDs) based on the generic case scenarios from surveys to interpret risk interrelationships for the generic PPP projects. Then, the direct causes and direct consequences of the risk variables displayed in CLDs were assessed to make sure the model boundary and causal structure for risk interrelationships were adequate and applicable to the specific project case. In this assessment, the researcher used evidence gathered from an interview survey with project experts and key participants in the THSR project from the Bureau of High Speed Rail (BHSR) in the public sector. All of these details have been addressed in chapter 4, chapter 5 and Appendix II.

The researcher used Vensim, a software package, for system dynamics modelling. Vensim includes a variety of tools such as causal tracing analysis tools with cause tree and use tree diagrams available to help in easily checking to assure if the exogenous variables of SD models quantitative stock flow diagram were consistent with those addressed in the qualitative CLDs. The causal tracing tool is a powerful tool for moving through a model tracing what causes something to change, and can be configured to show the causes of a variable (cause tree) or the uses of a variable (use tree) (Ventana Systems, 2007).

For example, Figure 8.1.1 shows the cause tree of risk variable default of Subcontractors C, which displays the succeeding risk variables caused by default of Subcontractors C. On the other hand, Figure 8.1.2 shows the use tree of risk variable default of Subcontractors C which displays the preceding risk variables that would lead to default of Subcontractors C. Since use tree (Figure 8.1.2) showed that there were no preceding risk-variable for default of Subcontractors C, so default of Subcontractors C is an exogenous risk variable and the remaining risk variables shown in cause tree (Figure 8.1.1) are endogenous risk variables.

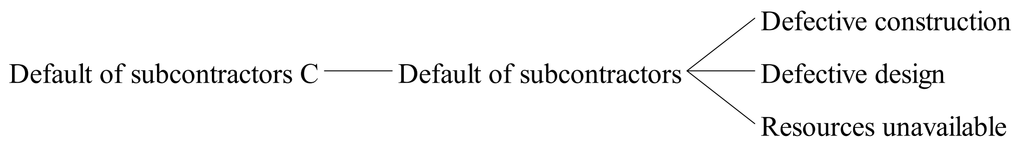


Figure 8.1.1 The Cause Tree for Risk Variable 'Default of Subcontractors C'

Default of subcontractors C

Figure 8.1.2 The Use Tree for Risk Variable 'Default of Subcontractors C'

Table 8.1.1 is a model boundary chart the researcher used to summarize the model scope identified by the above approaches, listing key variables including endogenous variables, exogenous variables, and those variables excluded from the model. In general, the whole project life cost and benefits should be estimated to calculate project NPV. However, the major purpose was to standardize bidding proposals with the base case. For the broad costs or benefits such as social benefits and ecological impact, the bidding proposals and base case are the same. This does not change the benchmarking results without taking those broad costs and benefits into account, so they are excluded from SD models.

Table 8.1 Measures of Performance

Section	Category	Measures of Performance	Criteria	Results
8.1	Boundary adequacy (Barlas, 1996; Lee et al., 2005; Nguyen & Ogunlana, 2005; Sterman, 2000; Tvedt, 1996)	Direct cause and consequence variables of causal loop diagram	Reviewed by project client (the public sector)?	Yes
		Exogenous risk variables	Confirmed by Vensim structure assessment tools?	Yes
8.2	Structure assessment (Barlas, 1996; Kazeli et al., 2003; Lee et al., 2005; Nguyen & Ogunlana, 2005; Sterman, 2000; Tvedt, 1996)	Model equations	Pass Vensim model checking?	Yes
		Exogenous and endogenous risk variables, feedback loops	Confirmed by Vensim structure assessment tools?	Yes
		Net cash flow	F(t)	F(t)<=0, t<=Tc F(t) >=0, t>=Tc Tc: construction completion time
8.3	Dimension consistency (Barlas, 1996; Kazeli et al., 2003; Lee et al., 2005; Sterman, 2000; Tvedt, 1996)	Equation units	Pass Vensim unit checking?	Yes
8.4	Parameter Assessment Tests (Ferreira, 2002; Hao, 2002; Kazeli et al., 2003; Lee et al., 2005; Martin, 2002; Nguyen & Ogunlana, 2005; Tvedt, 1996)	Fits multiple-regression equations for endogenous risk variables	R^2-adj/ s (mean-squared error)	>= 80%
			P-value	< α=0.05
			Residual plots/Outlier detection	Meet assumptions of regression
		Fits probability distribution for exogenous risk variables	Probability plot	Close to straight line within 95% C.I.
			P-P/Q-Q plot	Close to straight line
			P-value for Anderson-Darling statistic/ Ch-sq statistic	> α=0.05
8.5	Extreme Condition Analysis (Barlas, 1996; Lee et al., 2005; Nguyen & Ogunlana, 2005; Sterman, 2000; Tvedt, 1996)	Risk effect	1<=Rd<=25?	Yes
		NPV time profiles with 95% C.I. over project life	Implausible changes?	No

8.6	Integration Error Tests (Barlas, 1996; Lee et al., 2005; Sterman, 2000)	ΔNPV/ΔT (year 2036)	Time step ΔT	• ΔNPV/ΔT=16.59, when 0.08333331<ΔT <=1; • ΔNPV/ΔT=3.92, where 0.0078125<=ΔT<= 0.0833333
		NPV time-profiles over project life	Time step ΔT	• Unstable and sensitive when where 0.08333331<ΔT <=1; • Stable when time where 0.0078125<=ΔT<= 0.0833333
8.7	Behaviour Reproduction Tests (Ferreira, 2002; Hao, 2002; Kazeli et al., 2003; Lee et al., 2005; Martin, 2002; Nguyen & Ogunlana, 2005; Tvedt, 1996)	% of construction cost overrun	Forecasting error (%)	14.63%
			Test of hypotheses by 95% C.I.	No reject
		% of construction delay	Forecasting error (%)	15.59%
			Test of hypotheses by 95% C.I.	Not reject
		Demand for average daily ridership (year 2007)	Forecasting error (%)	0.46%
			Test of hypotheses by 95% C.I.	Not reject
8.8	Monte-Carlo multi-variate Sensitivity Analysis (Ferreira, 2002; Hao, 2002; Kazeli et al., 2003; Lee et al., 2005; Martin, 2002; Nguyen & Ogunlana, 2005; Tvedt, 1996)	NPV time profiles with 95% C.I.	Implausible changes	No

8.2 Structure Assessment Tests

Structure assessment tests are used to test whether the SD models are consistent with knowledge of the real system relative to model purpose (Sterman, 2000). The purpose of the whole SD decision model created by the researcher was to compare long-term NPV values with risk interactions among bidding proposals and then choose a preferred bid with best NPV performance. According to accounting principles, an aggregated SD decision model is structured with a major model: NPV project cash flow model which is linked by six sub-models consisting of: (a)construction cost sub-models, (b) project financing sub-model, (c) operating cost sub-model, (d) operation revenue sub-model, (e) depreciation sub-model, and (f) discount rate model). Among these sub-models, the risk interrelationships described by CLD are modeled and linked to the related sub-model. This forms the whole structure of SD decision model.

<u>Table 8.1.1 Model Boundary Chart for a Long-Term NPV Model of Risk Interactions</u>

Exogenous Risk Variables	Endogenous Risk Variables	Excluded
Default of subcontractors C **Default of subcontractors O** **Downside economic events C** **Downside economic events O** **Force Majeure C** **Force Majeure O** **Greater environmental expectation C** **Greater environmental expectation O** **Latent defect C** **Latent defect O** **Political interference C** **Political interference O** **Unforeseen site conditions C** **Variability of exchange rate** **Variability of inflation rate** **Variability of interest rate** **Variability of less demand** **Variability of tax rate** **Equity fraction**	Land Unavailable Resources unavailable Performance unavailable Finance unavailable … Scope changes Defective design Design changes Defective construction Construction changes Complex system interface/integration Failed commission tests Low operating productivity System breakdown High maintenance frequency Poor cooperation/coordination Accidents and safety issues NPV cash flow Revenue Expense Risk adjusted annual total construction cost Annual total operating cost Fare increase rate Daily ridership demand Interest Principal repayment Depreciation Inflation adjusted discount rate	Social benefits Ecological impact GDP growth National economic loss

The researcher used the Vensim software to provide varieties of structure analysis tools for model structure assessment including use tree, cause tree, loops, units check, check model, and check syntax. The use tree and cause tree can be used to ensure that the structures of risk cause and effect relationships are correct. Unit check will be addressed in the next section. The check model and check syntax are used to check syntax or semantic errors of model equations (Ventana Systems, 2007). Figure 8.2.1 shows that SD models created by the researcher have passed the model checking.

Figure 8.2.1 The Vensim' Message Window of 'Check Model'

Table 8.2 The Partial Display of The Loop List for 'Default of Subcontractor' Risk Variable

Loop Number 1 of length 6 Default of subcontractors Resources unavailable Risk degree Time delay effect Increased completion time Workpackage duration Risk adjusted construction completion time Loop Number 2 of length 9 Default of subcontractors Defective construction Failed commission tests Contract breach Has the Contract terminated? Risk degree Time delay effect Increased completion time Workpackage duration Risk adjusted construction completion time …

As for the structure of feedback loops for risk interactions, the researcher checked this using the Vensim Loop tool which displays a list of all feedback loops passing through a variable. The loop list is ordered from the shortest loop (the one involving the least number of variables) to the longest loop (Ventana Systems, 2007). This type of tool shows useful summary information on risk variable interactions. For example, the Vensim Loop tool showed that there are 40 loops that passed through risk variable default of subcontractors. Table 8.2 displays a partial list of the loop for risk variable default of subcontractors.

Structure is the set of physical and information interconnections that generates behaviour (Ventana Systems, 2007). An alternative option in diagnosing the structural issues of a whole model is to examine whether the model output patterns violate physical laws. For example, in reality, there would be no revenue generated during the construction phase because revenue would only start to accrue during the operation phase when the project begins to deliver a service; there would be significant expenditure for infrastructure construction during the construction phase and less expenditures during the operation phase. As a result, by totaling revenue and expense over project life, the cash flow for a large scale infrastructure project would be generally negative, F(t) < = 0, at the construction phase (t < =Tc: construction completion time) and positive, F(t) > = 0, at the operation phase (t > =Tc). Figure 8.2.2 shows the model output to display the cash flow profiles of THSR project cash flow during the concession period. Apparently, these results show that common sense of a cash flow profile addressed above that curve for taxable income (#3 green line) is negative at the construction phase and positive at the operation phase, respectively. It would be a basic structural issue if any unusual pattern of cash flow is showing up which would mean that the models structure and equations should be individually checked.

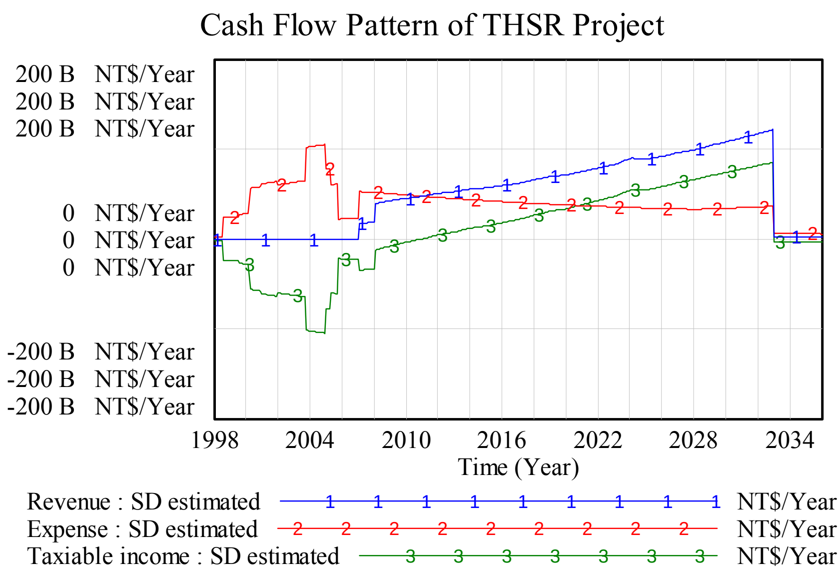


Figure 8.2.2 The Cash Flow Pattern to Test Model Structure

8.3 Dimensional Consistency Tests

The purpose of dimensional consistency tests is to ensure all SD model variables are consistent with the mathematical equations and objective meaning. To check unit errors, the researcher employed the software package, Vensim, which has automated dimensional analysis function. Figure 8.3 shows that the units used in the SD model were checked and passed testing.

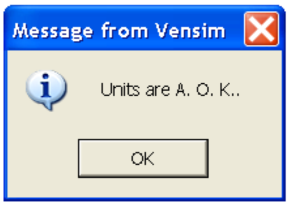


Figure 8.3 The Vensim's Message Window of 'Unit Check'

8.4 Parameter Assessment Tests

The parameter assessment test is used to estimate whether the values of a parameter are reasonable (Sterman, 2000). The researcher used the questionnaire survey to gather data on the expected risk effects measured by the project experts. Multiple regression analysis was applied to model and quantify the risk interdependencies (cause-effect interrelationships) among risk variables. Therefore, a set of residual plots including residuals versus variables plot histogram of residuals, normal plot of residuals, residuals versus fits, and residuals versus order are conducted to test whether these multiple-regression models were adequate and that the regression assumptions were met. For example, the multiple-regression model for risk variable resource unavailable was calculated and output was produced by the software application, Minitab, as follows:

```
The regression equation is
resource unavailable = 10.9 + 0.155 default of subcontractor
+ 0.103 Force Majeure + 0.143 industrial disputes+ 0.0990
finance unavailable


Predictor                     Coef    SE Coef      T      P
Constant                   10.9449     0.5946  18.41  0.000
default of subcontractor  0.154821   0.007249  21.36  0.000
Force Majeure             0.102746   0.005392  19.05  0.000
industrial disputes        0.14269    0.05713   2.50  0.018
finance unavailable       0.098964   0.006691  14.79  0.000
```

```
S = 0.159302   R-Sq = 96.8%   R-Sq(adj) = 96.4%

Analysis of Variance

Source          DF        SS      MS       F      P
Regression       4   24.5624  6.1406  241.98  0.000
Residual Error  32    0.8121  0.0254
Total           36   25.3745
```

From the above ANOVA table, the p value for regression was close to 0. The p value for each model coefficient test is close to 0 as well. It appears that both coefficients and regression relationship between predictors and response are statistically significant at $\alpha = 0.05$. The four predicators account for 96.4% (R-Sq (adj) = 96.4%) of variance of resource unavailable so that the model can fit the data extremely well. Moreover, the sign of each coefficient was positive indicating the same direction of relationship between predictors and response, thereby meeting the assumed risk relationships addressed in the risk causal loop diagram described in chapters 4 and 5.

In addition to the above tests, the following plots were conducted to exam if the models were adequate and the assumptions of regression were met. Figure 8.4.1 shows a plot of the residuals versus the predictor, which was used to examine whether there was any non-random pattern where a predictor variable was related to the residuals. Figure 8.4.1 indicates, except for 2 or 3 outliers for each predictor, that there were no specific patterns or relationships such as curvature and differences in the magnitude of the residuals that would have additional effects on the response. Therefore, the model is adequate in its linear relationship between response and its predictors.

The plot for histogram of residuals shown in Figure 8.4.2 indicates there is a normal distribution shape without a skewed tail. But there is a bar with standardized residuals more than 2, which may be outliers. The points in the normal probability plot shown in Figure 8.4.2 form a straight line. Therefore, both the histogram and normal probability plots indicate that the assumption made by the researcher that residuals are normally distributed is valid.

Figure 8.4.2 shows the plot for residuals versus fits, showing a random pattern for the residuals on both sides of 0. Most of points are equally spread within the interval of standardized residual between -2 and +2 except for 2 points slightly outside this range. Therefore, this data show that the assumption that residuals has constant variance is valid.

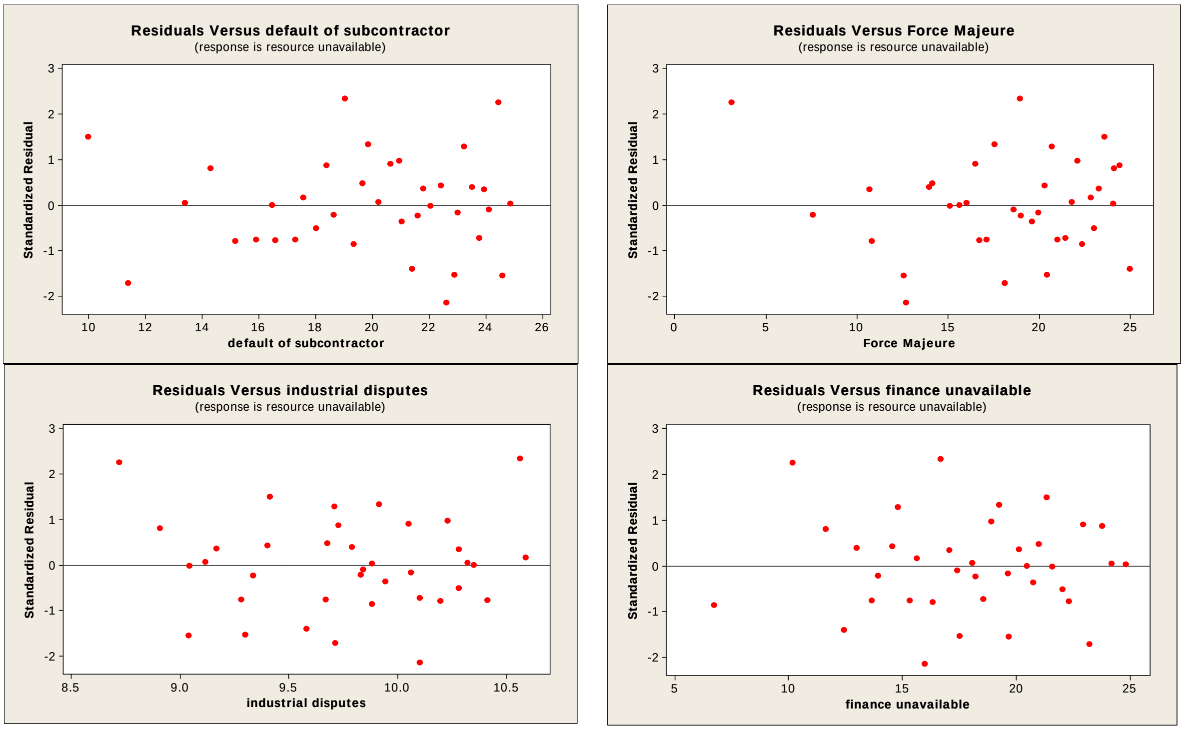


Figure 8.4.1 Residuals versus Predictors

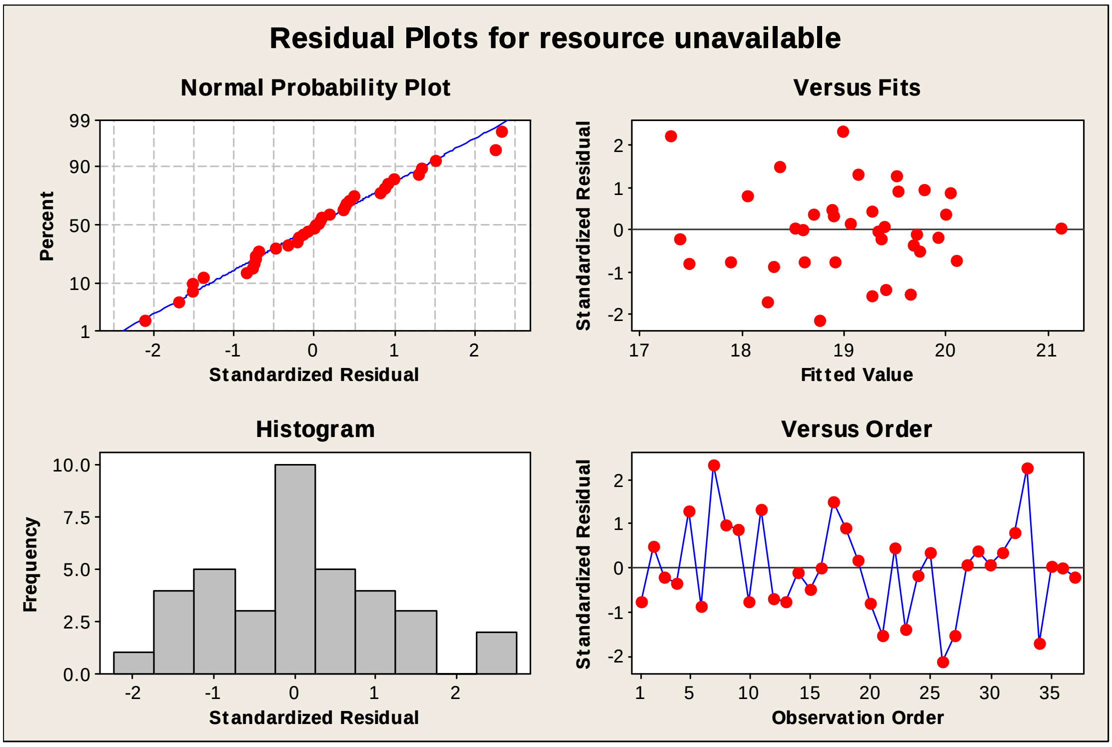


Figure 8.4.2 Four Types of Residual Plots for Response 'Resources Unavailable'

The plot for residuals versus order shown in Figure 8.4.2 was used by the researcher to find non-random errors. The figure shows that there is not any specific clustering of residuals with positive correlation or negative correlation. Therefore, the residuals are not correlated with one another, thus the assumption that the residuals are independent is valid.

As far as handling with outliers for the inconsistency of expert inputs is concerned, an absolute value of the standardized residual larger than 2 indicated an suspect outlier and a number larger than 3 indicated a suspect extreme outlier (Barnett & Lewis, 1994; Rousseeuw & Leroy, 2003). The software application, Minitab, was used by the researcher to display a table of unusual observations with high leverage and standardized residuals. From regression output, Minitab labels observations with a standardized residual greater than 2 with an R indicated that the observation had an unusual response. This helped the researcher to identify outliers for inconsistent data of expert inputs. Once an observation was identified as the suspect outlier points, the researcher fit the regression equation with and without the suspect points by reviewing the *s* (mean-squared error) and *R*-sq from the two models (Barnett & Lewis, 1994; Rousseeuw & Leroy, 2003).

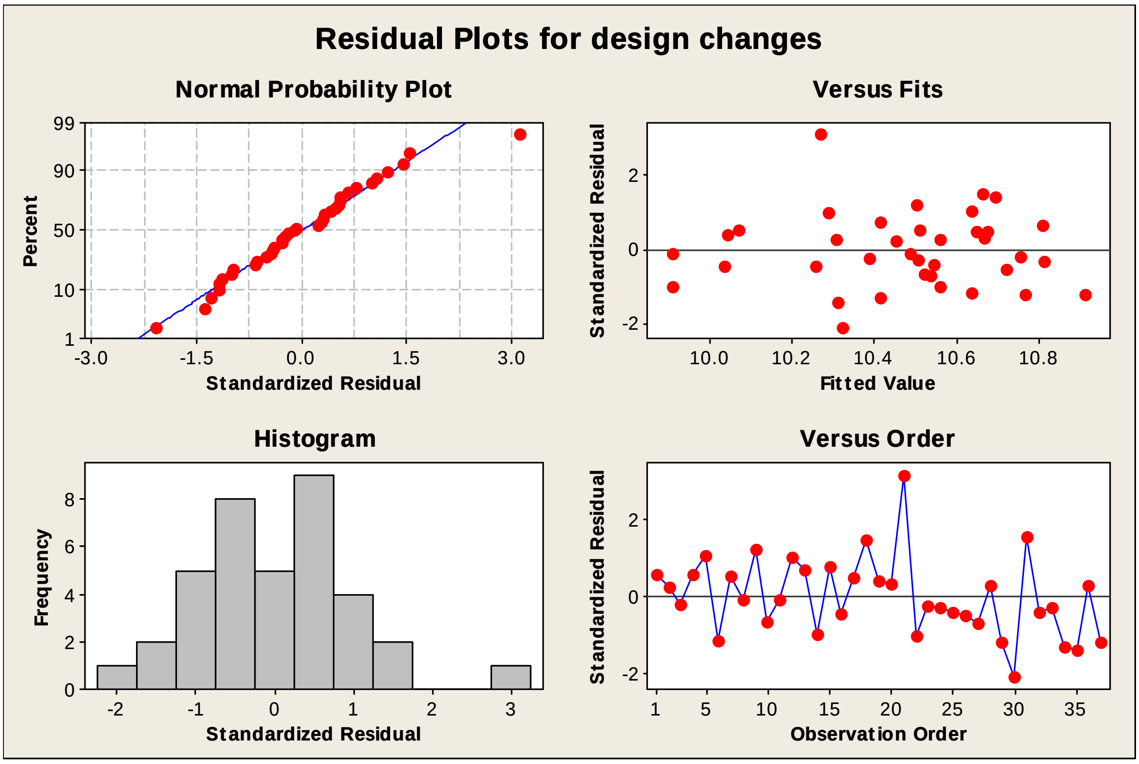
For example, the residual plots shown in Figure 8.4.3 for the regression model of risk variable design changes are outlined below. The data indicated that observation 21 is more than 3 sigmas from center line and observation 30 is less than -2. These two points are therefore classified as suspect extreme outlier and outlier respectively and are obviously inconsistent with other points. The researcher fit the regression equation with and without these suspect points by reviewing the changes of s and R-sq values from the two models as the following Table 8.4:

Table 8.4 The Comparison of Regression Models 'With Suspect Outliers' and 'Without Suspect Outliers'

With suspect outliers	The regression equation is design changes = 3.56 + 0.249 scope changes + 0.218 contractual disputes Predictor Coef SE Coef T P Constant 3.5577 0.7522 4.73 0.000 scope ch 0.24873 0.04094 6.08 0.000 contract 0.21826 0.03340 6.54 0.000 S = 0.1615 R-Sq = 72.2% R-Sq(adj) = 70.6%
Without suspect outliers	The regression equation is design changes = 3.38 + 0.257 scope changes + 0.222 contractual disputes Predictor Coef SE Coef T P Constant 3.3813 0.6100 5.54 0.000 scope ch 0.25652 0.03290 7.80 0.000 contract 0.22183 0.02685 8.26 0.000 S = 0.1289 R-Sq = 81.5% R-Sq(adj) = 80.4%

The *s* value is reduced from 0.1615 to 0.1289 and R-sq is increased from 72.2% to 81.5%. Therefore, the regression model is acceptable: design changes = 3.38 + 0.257 scope changes + 0.222 contractual disputes + Nor~(0, 0.248), when we remove the outliers from collected data.

There are 44 multiple regression models used to address risk relationship parameters which are all tested by the above approaches. The results showed that all of the regression models were adequate and the regression assumptions were met.



<u>Figure 8.4.3 the Residual Plots for 'Design Changes' Regression Model with Suspect Outliers</u>

Another parameter assessment test was conducted for exogenous risk variables. The researcher applied probability fitting to infer the probability distribution of seven exogenous risk variables. Therefore, the probability plot, P-P plot or Q-Q plot with Anderson-Darling statistics or Chi-square statistics were applied to examine if the data could follow the specified distribution. The example shown in Figure 6.3.1 indicates whether Weibull distribution fits the political interference risk variable during operation phase. Figure 8.4.4 shows three types of plots that were used by the researcher to examine the probability fitting. The probability plot was used to plot each value versus the percentage of values along a fitted distribution line. This indicated that most of plotted points fell on or close to the fitted straight line and within the 95% confidence intervals. The *p* value (>0.25) for the Anderson-Darling (AD) statistic was over α = 0.05. In addition, the probability-probability (P-P) graph plots the p-value of the fitted distribution versus the *p* value of the fitted result, with the quantile-quantile graph (Q-Q) plotting the plot percentile values of the fitted distribution versus percentile values of the input data. If the fit is "good," both plots will be nearly linear. Figure 8.4.4 indicates that both P-P and Q-Q plots are close to being linear. The *p* value for the Chi-square statistic test was 0.8639, which was over α = 0.05. From the above diagnostic plots, the researcher concluded that Weibull distribution could fit the data for the political interference risk effect variable.

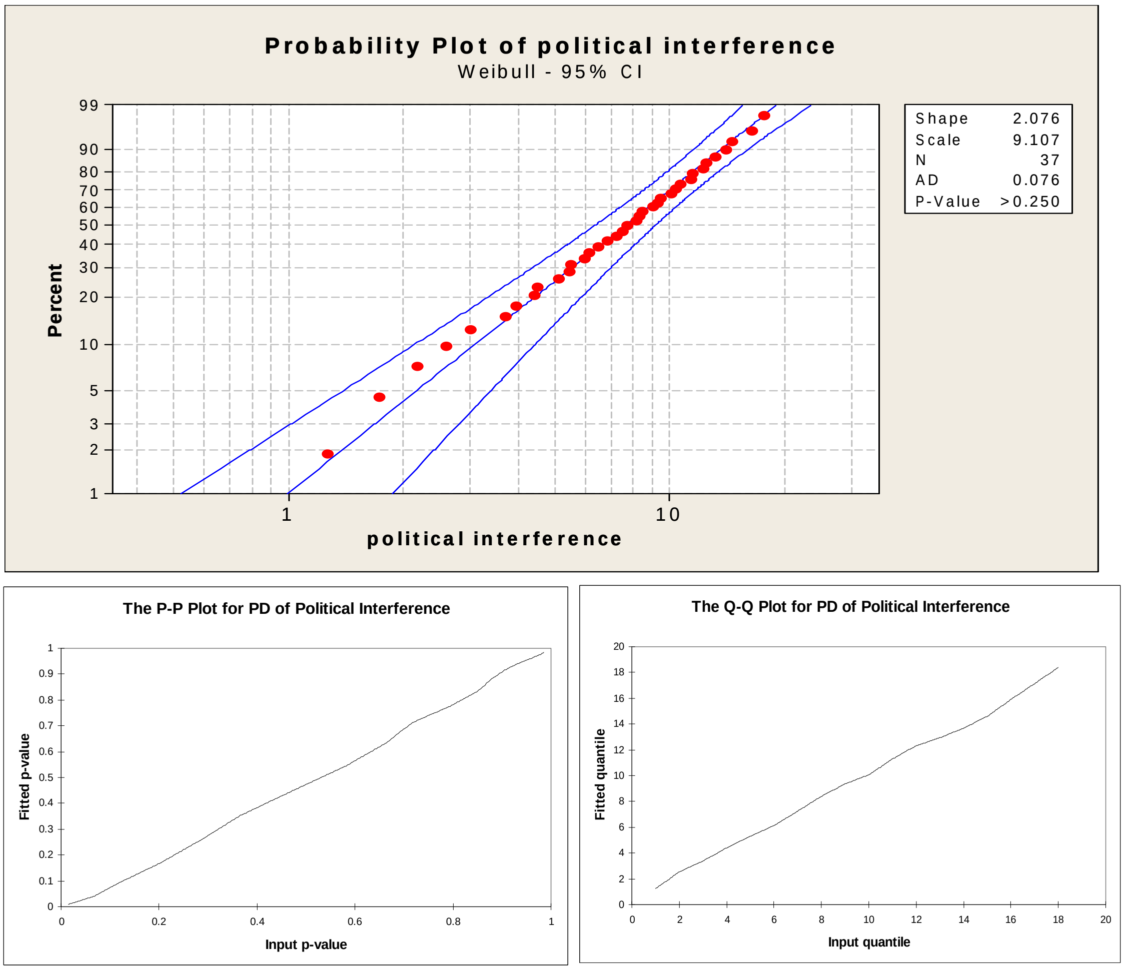


Figure 8.4.4 The Probability Plot, Q-Q and P-P Plot for Response 'Political Interference'

8.5 Extreme Condition Analysis

The "extreme condition analysis" was performed according to the System Dynamics based textbooks or journal articles (Barlas, 1996; Lee et al., 2005; Nguyen & Ogunlana, 2005; Sterman, 2000; Tvedt, 1996). The extreme condition analysis refers to the tests that ask whether models behave appropriately when the inputs take on values at extreme conditions such as zero or infinity. Models should be robust in extreme conditions. Robustness under extreme conditions means the model should behave in a realistic fashion no matter how extreme the inputs or policies imposed on it may be. The extreme condition analysis can be carried out in two main ways: by direct inspection of the model equations and by simulation. Be sure to examine whether the output of the model is feasible or reasonable when each input to the equation takes on its maximum and minimum values (Sterman, 2000). The extreme condition analysis has been performed to see whether there is floating point error computing or any unusual output that is not in reality.

For example, the researcher quantified and scaled the expected risk effect of risk events with the risk effect ranged from 1 to 25. The maximum risk effect of 25 and minimum risk effect of 1 for exogenous risk variables were input into the model simultaneously and a simulation run to see whether the endogenous risk variables, such as resource unavailable performance unavailable and financial unavailable, had gone beyond their specified low/high range.

Figure 8.5.1 indicates the risk effect for resource unavailable, performance unavailable and financial unavailable endogenous risk variables were still ranged between 1 and 25 when the effect for exogenous risk variables had a maximum value of 25. Figure 8.5.2 indicates the risk effect of endogenous risk variables, resource unavailable events, performance unavailable events, and financial unavailable events were also scaled within the range between 1 and 25 when the risk effect of exogenous risk variables had the minimum value of 1. After extreme condition analysis involving the verification of individual equations and by running values at extreme conditions simulation, the researcher observed that the output patterns were still in reality.

When the setup for risk effect is other than the range values from 1 to 25, the output for these variables is not feasible or reasonable. Moreover, the simulation results indicate an ERROR message like "Unable to converge simultaneous loop at time…". This error message arose from variables that have gone beyond their specified low/high range. For example, the risk variable 'performance unavailable' may likely go beyond the specified range from 1 to 25 if a more complex model than a linear regression model for the functional relations of the risk variables is applied to the System Dynamics model. Since ‘performance unavailable’ is a simultaneous function, the SD simulation will compute all the simultaneous equations in the loop of ‘performance unavailable’ iteratively until the values of the loop variables no longer change significantly. The iterative computation fails to converge when ‘performance unavailable’ has gone beyond their specified low/high range. Then we will receive an error message “ .... unable to converge simultaneous loop at time ....”

In addition, it yields unreasonable outputs for variable DeT (‘the number of trains that would likely delay on-time service’ stated in the section 6.2.3 and Appendix VII3) when ‘performance unavailable’ has gone beyond their specified low/high range. For instance, the value of ‘the number of trains’ becomes negative when the value of ‘performance unavailable’ is less than its minimum value 1. Obviously, it violates the physical laws.

Similarly, other variables such as TD_{ij} (‘time delay effect’) stated in Appendix VII8, *EFA* (‘the expected fare adjustment rate’) stated in Appendix VII14, EASL (‘the expected accident and safety loss’) stated in Appendix VII18 and ERL (‘the expected reduced life’) stated in Appendix VII36 are calculated based on the risk variables that have a range of values from 1 and 25. When the risk variables are outside this range, the outputs for these variables are not feasible or reasonable.

Moreover, the exogenous risk parameters were assigned maximum and minimum values along with random distributions that were drawn from the probability distribution. The Monte Carlo multivariate sensitivity was performed by sampling a set of numbers from within bounded domain that impacted model behaviour when the extreme values of all of parameters were simultaneously sampled. This is addressed in Section 8.8: sensitivity analysis.

8.6 Integration Error Tests

Integration error tests were used to ensure that the SD model outputs were not sensitive to choice of time step or integration method (Sterman, 2000). The researcher formulated the SD model in continuous time over the project concession period from 1998 to 2036; this encompassed the construction phase and the operation phase. There were many variables solved by numerical integration over time. The integration error due to time step or integration method may have lead to undesired dynamics to the model. Therefore, the researcher used an integration method to try different time steps to examine whether there was major difference between them.

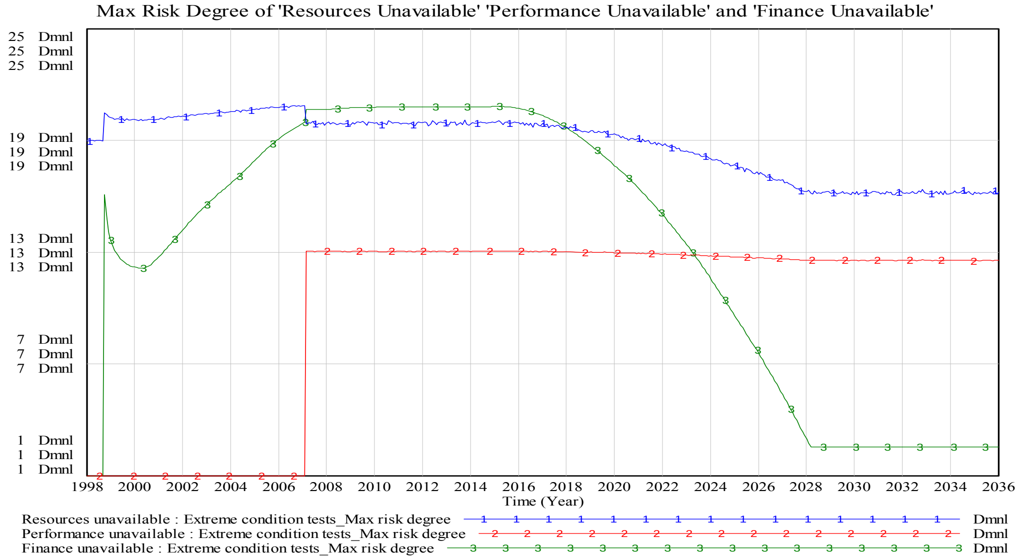


Figure 8.5.1 The Risk Effect for Endogenous Risk Variables When the Risk Effect for Exogenous Risk Variables Have A Maximum Value 25

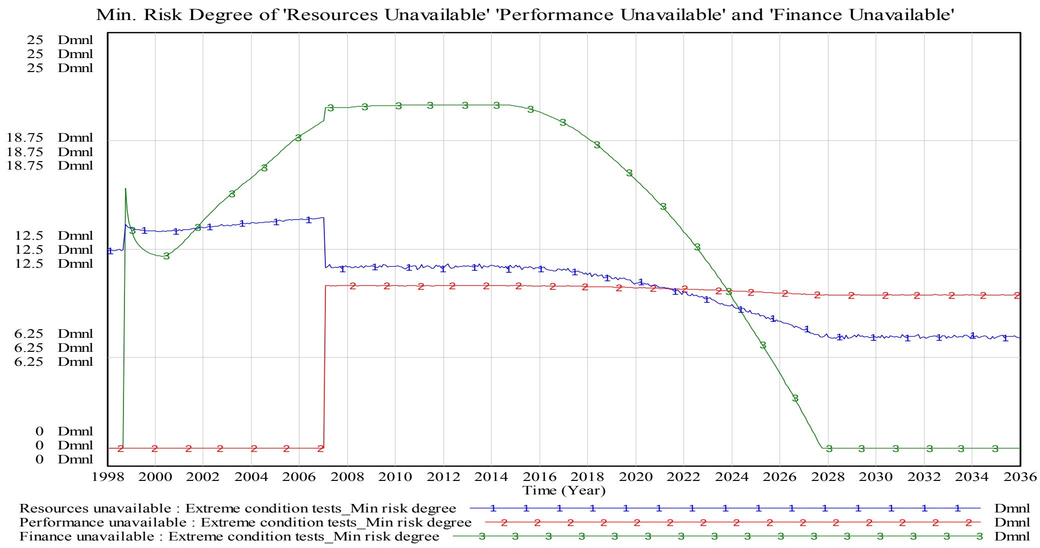


Figure 8.5.2 The Risk Effect for Endogenous Risk Variables When the Risk Effect for Exogenous Risk Variables Have A Minimum Value 1

The researcher used the Vensim software package to build SD models for the risk network and bidding proposal benchmarking. This analysis showed six integration technique options that traded off speed and accuracy; these option were: (a) Euler, (b) Diff, RK4 Auto, (c) RK4 Fixed, (d) RK2 Auto, (e) RK2 Fixed, (f) comment for run (Ventana Systems, 2007).

However, these options can be classified as two major methods: (a) Euler integration, and (b) Runge-Kutta integration. The best integration technique choice depends on the model application purpose (Sterman, 2000). The Euler integration is a simple linear extrapolation method that is suitable for most business and management models with related confusing problems where there are large errors from aggregation, mismeasurement, simplification, and lack of information. The Runge-Kutta integration is preferred for physical systems models, especially those involving oscillation (Ventana Systems, 2007). The SD models built by the researcher is essential in comparing project NPV values over long-term among the bidding proposals and then selecting a preferred bidding proposal that would have better NPV performance in the future. This model is a good tool to demand long-term stable output rather than a precise numerical projection. Moreover, the models used by the researcher do not involve oscillation output behaviour. Therefore, the Euler integration was suitable and was chosen for the research.

The researcher used the different default time steps in the Vensim software application to run models to examine whether there were apparent NPV changes over the life of the project, as shown in Figure 8.6.1 and Table 8.6.1. In the Vensim application, the maximum setup for time step ΔT was 1 and minimum was 0.0078125. The researcher used 0.0833333 as the base case for time step which meant 1 month at intervals of 1/12 of a year (0.0833333 years). The researcher tested ΔT from 1 to 0.0078125 in order to calculate the NPV values in year 2036 and to examine NPV profile over time.

The results indicated the NPV time-profile and values were significantly different between time steps greater than base case 0.0833333 (line 1 to line 3) and those less than 0.0833333 (line 4 to line 9), especially when they were split into two groups at the end of concession period in year 2036. Therefore, the researcher calculated the NPV changes in year 2036 against $0.08333331<\Delta T <=1$ and $0.0078125<=\Delta T<= 0.0833333$. Apparently, $\Delta NPV/\Delta T = 16.59$ where $0.08333331<\Delta T <=1$ was significantly more than $\Delta NPV/\Delta T = 3.92$ where $0.0078125<=\Delta T<= 0.0833333$. In addition, the researcher examined the ranking of the expected NPV values in year 2036 among bidding proposals. The results showed in Figure 8.6.2 indicated that the NPV time-profile of all bidding proposals was the same among time steps, which did not change the NPV ranking in year 2036 either.

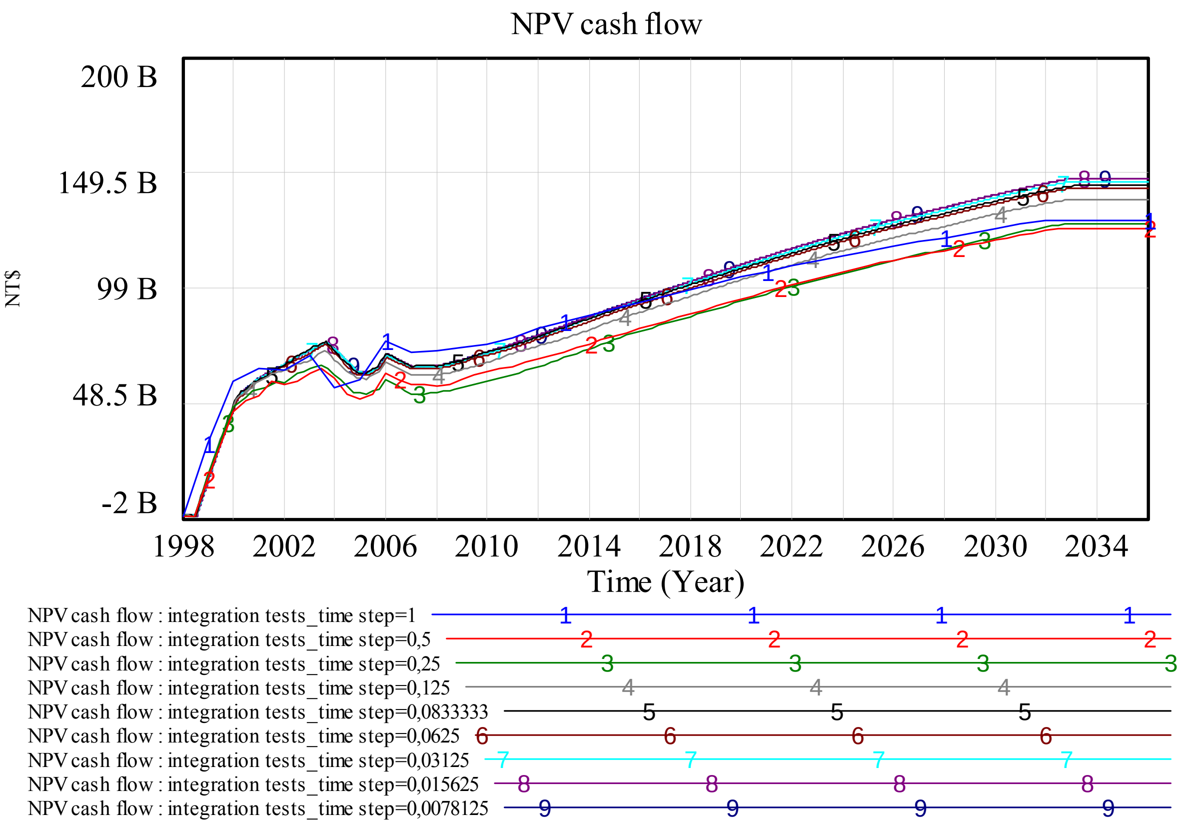


Figure 8.6.1 The Integration Tests for NPV Changes by Time Step for Risk

Table 8.6.1 The Integration Tests on Time Step

Time Step ΔT (unit: year)	1	0.5	0.25	0.125	0.0833333 (base case)	0.0625	0.03125	0.015625	0.0078125
NPV in Year 2036 (unit: NT$ billions)	128.52	125.10	127.19	137.92	143.73	142.74	145.74	147.10	146.97
Time Step ΔT		0.08333331< ΔT <=1				0.0078125<=ΔT<= 0.0833333			
Average ΔNPV/ΔT (year 2036)		16.59				3.92			

From the integration tests, the researcher concluded that the integration error was sensitive to long-term NPV values and NPV time-profile when time step was set up as 0.08333331<ΔT <=1. The long-term NPV values and NPV time-profile were stable when time step was set as 0.0078125<=ΔT<= 0.0833333. The researcher used 1 month at intervals of 1/12 of a year (0.0833333 years) for simulation. The researcher did this because some output like construction delay and cost overrun are normally reviewed and examined each month.

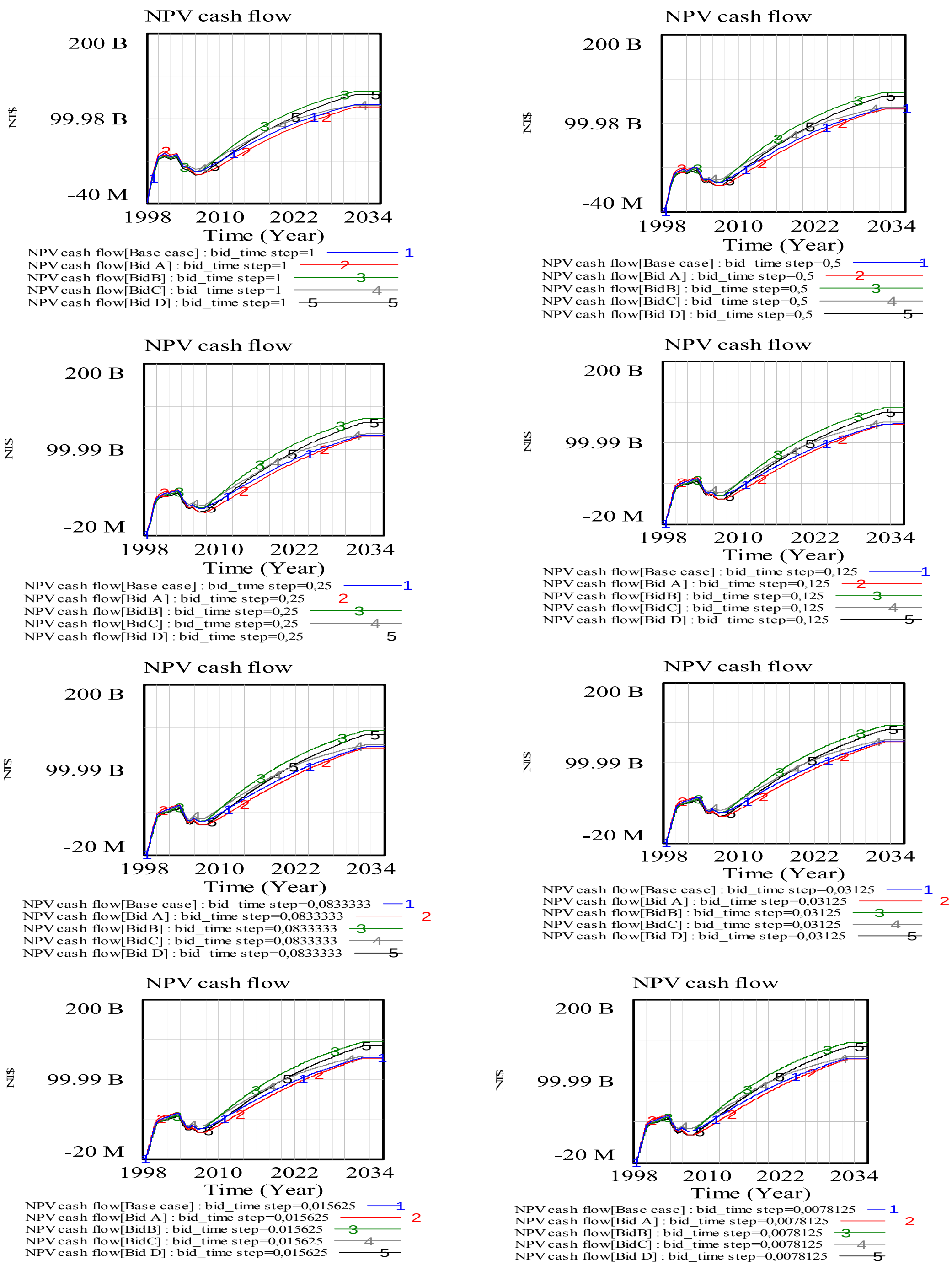


Figure 8.6.2 The Integration Tests on NPV Changes by Time Step for Bidding Proposals Model

8.7 Behaviour Reproduction Tests

The behaviour reproduction test was used to assess the ability of the model to reproduce the behaviour of a system (Sterman, 2000). Discrepancies between the simulation results and real data were examined to ensure that a model can properly function to represent reality. There were three types of real data available to test the ability of the model to reproduce reality behaviour by discrepancy comparisons over THSR project life during construction stage and operation stage respectively including: (a) construction cost overrun at completion time, (b) construction delay at completion time, and (c) operation demand for the first year during operation stage.

The forecast error was applied as one of the measuring criteria to test the ability of the model in reality reproduction. As shown in the Figure 8.7, Bozarth and Handfield (2006) defined this as the deviation of the forecasted quantity from the actual, which can be calculated by the following mathematic equation:

Forecast error (%) = $\frac{|(actual - forecast)|}{actual} \cdot 100\%$ (Bozarth and Handfield, 2006)

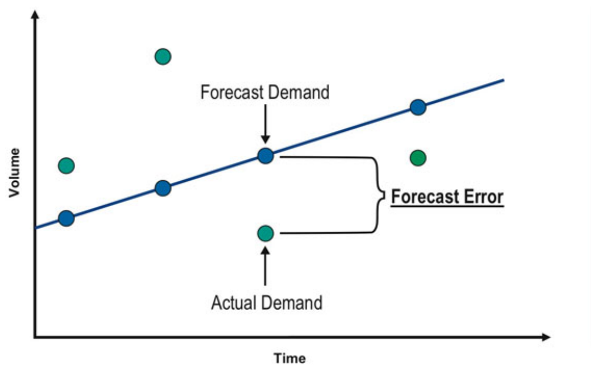


Figure 8.7 The Forecast Error

Forecast accuracy is defined by Bozarth and Handfield (2006):

Forecast Accuracy = maximum of (1–Forecast Error, 0) (Bozarth and Handfield, 2006)

As far as the construction cost overrun is concerned, the actual percentage of cost overrun was about 4.54% (Yang, 2005) at construction completion time of January 2007. As illustrated in Figure 8.7.1, the simulation result was 3.88% for mean and (-13.02%, 20.77%) for 95% confidence interval.

The forecast error was approximately 14.63% for cost overruns which was 85.37% for high accuracy. In addition, the testing of hypotheses with a 95% confidence interval showed that the 95% confidence interval contained the null hypothesis value (the actual cost overrun percentage). There was no significant evidence to reject the null hypothesis that the simulation value is equal to the actual cost overrun percentage at α=0.05.

To evaluate the model validity at operation phase, the real data for demand since the THSR began operations in January 2007 to December 2007 were used for model testing. The actual demand for average daily ridership in year 2007 was about 125,000 people/day (Yang, 2007). As shown in Figure 8.7.2, the simulation results showed 124,426 people/day for mean and (30,240 people/day, 218,162 people/day) for 95% confidence interval. It appears that the forecast error was 0.46% for daily ridership demand which meant a very high accuracy rate of 99.54% for 2007. Moreover, the testing of hypotheses with a 95% confidence interval indicated that the 95% confidence interval contained the hypothesis value (the actual daily ridership demand) in 2007. There was no significant evidence to reject the null hypothesis that the simulation value was equal to the actual daily ridership demand in 2007 at $\alpha = 0.05$. The demand forecasting by the officials of the BHSRs for 2007 was about 288,000 people/day, which had a very high margin of error; 130% (forecast accuracy = 0) was related to actual demand. These results indicated that the demand projection from the public sector were overly optimistic. Additionally, the results indicated that the model created by the researcher that considered optimism bias can more accurately predict the demand than the public sector current approach.

From the above discrepancy comparisons of simulation results against real data, the researcher concluded that the model created can robustly predict the expected outcomes for both construction and operation phases and thereby suggests a valid model.

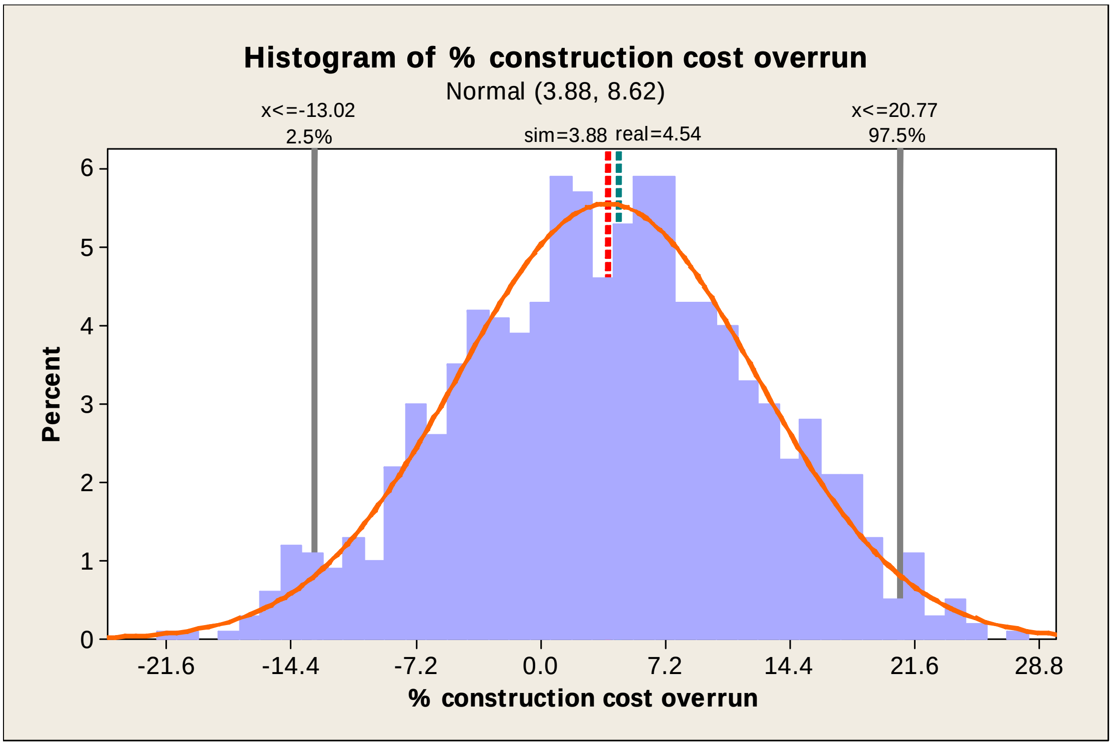


Figure 8.7.1 Discrepancy between Simulated and Real Data for Construction Cost Overrun Percentage

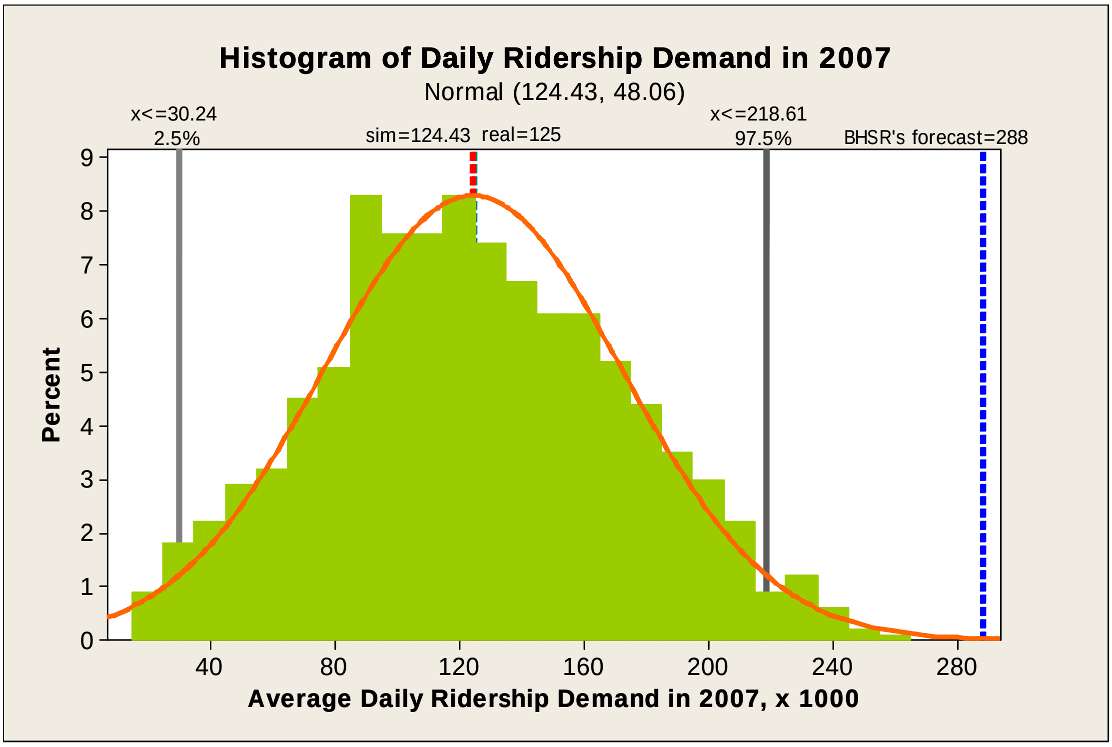


Figure 8.7.2 Discrepancy between Simulated and Real Data for Average Daily Ridership Demand in Year 2007

8.8 Sensitivity Analysis

The sensitivity analysis test was used to test the robustness of the model behaviour in uncertain conditions. Numerical sensitivity, behaviour mode, and policy sensitivity are usual types of sensitivity, that depend on the purpose of model (Sterman, 2000). Numerical sensitivity is used to examine whether the numerical values of the results would change when the assumptions are changed. Behaviour mode sensitivity is used to evaluate whether the behaviour pattern of model would change when the assumptions are changed. Policy sensitivity is examined to view impacts on the desirability of a proposed policy when the assumptions are changed. The researcher conducted Monte Carlo simulation for multivariate sensitivity analysis by simultaneously changing the assumptions of all exogenous risk parameters along the bounded random distribution. This evaluated the changes of project NPV arising from the least downside risk effect and the most downside risk effect as listed below:

- Behaviour mode sensitivity: Figure 8.8.1 shows the multivariate sensitivity analysis by defining the probability distribution values inferred from the empirical data for each exogenous risk parameter. By performing 10,000 Monte Carlo simulations, the time graph sensitivity output shown in Figure 8.8.1 shows the behaviour of the THSR project NPV over the whole concession period including both the construction and the operation phases. The spread NPV values in term of 50%, 75%, 95% and 100% confidence bounds are shown at any period in time. The expected NPV for base case is highlighted by the central red line which reflects the most expected results under the expected risk impact. Figure 8.8.1 showed that the base case was raised in the beginning due to continual funding. It then began to decline during the latter half of construction phase due to the investment of lots of capital for construction. Once the project began operations with a stable revenue stream, it began to climb until the end of concession period in year 2036 with NPV value at NT$156.49 billion. A notable feature of this sensitivity was that the confidence bounds grew over project life. The outer bounds of uncertainty (100%) show maximum NPV values of approximately NT$532.15 billion for the best case and minimum values of approximately -NT$76.41 billion for the worst case in 2036 respectively. There was a widened difference between the best case scenario and worst case scenario in 2036, which meant a high degree of uncertainty existed over the long-term life of the project. The best case scenarios existed only in the world under the least downside risk effect during project concession period. This may have been due to a very optimistic ridership demand-forecast with the least unexpected impact being from the exogenous factors changes (Flyvbjerg et al., 2003; Flyvbjerg, 2004). Therefore, the net positive cash flow increased rapidly over the life of the project due to the optimistic estimations. On the other hand, the worse case scenarios reflected the fact the project is under the most unexpected risk impact. The project performance would encounter the compounding downside effects as William (2002) addressed, which are arising from combining both individual risk effect and risk interaction effect. With the reinforce feedback of compounding downside effects over time, the project performance will gradually worsen over project life. As addressed in the causal loop diagram of chapter 4, due to exogenous factors changes, the ridership demand may be much less than forecasted, which would result in generating more revenue loss during operation stage. This fact could possibly lead to financial difficulties with the project contractor being unable to repay the large debt invested during the construction stage. As a result, the project couldn't provide required services without enough capital to pay for operation labor, material or equipment. ***This interprets the debate on PPP as addressed in the section 2.3.2 that the value for money will be eroded if the private project contractor cannot cost efficiently outweigh the incremental cost of private financing.***

Figure 8.8.2 shows the multivariate sensitivity analysis for the project NPV of bidding proposal model that was built on the risk network model. The results indicate that the NPV profile pattern for each bidding proposal is similar to the result of multivariate sensitivity analysis for risk network model illustrated in Figure 8.8.1. The only difference is that the confidence bounds shown in Figure 8.8.2 are much narrower than those shown in Figure 8.8.1. Specifically, the results show that the width of 100% confidence bound for bidding proposal model at the end of concession period 2036 reduced to two thirds of that for risk network model. This is because the interactions of downside reinforce feedback has been controlled and reduced by balance feedback arising from the actions of bidding proposals over project life.

The NPV profile patterns generated by the above multivariate sensitivity analysis for both risk network model and bidding proposal model indicated the behaviour of model is still very stable and plausible to explain in the real world when the researcher changes the alternative assumptions of parameters.

- Numerical and policy sensitivity: From the multivariate sensitivity analysis, the Pearson correlation coefficients between exogenous risk variables and NPV values were used to calculate the relative importance expressed by percentage. This was displayed by the Pareto chart (Figure 8.8.3). These results showed that those economical or financial risk variables such as variability of less demand, variability of interest rate, variability of exchange rate, equity fraction and variability of tax rate accounted for almost 70% of total effects on NPV and the non-financial risk variables accounted for the remaining 30%. The p value < 0.05 for the correlation test also showed that there was strong evidence to support those economical and financial risk variables that significantly affect NPV at $\alpha = 0.05$.

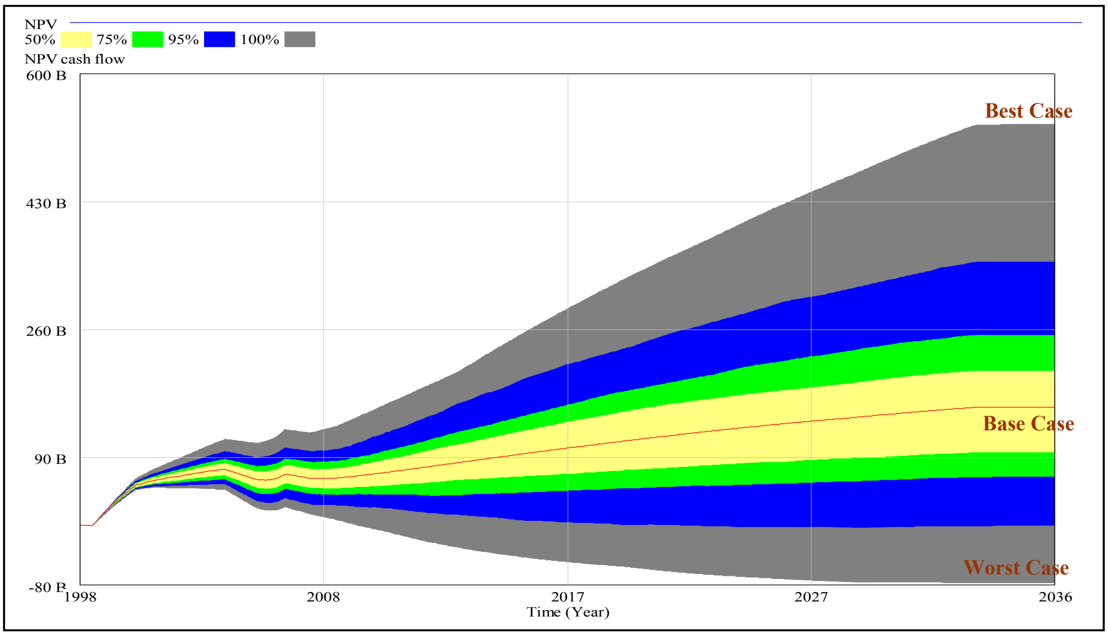
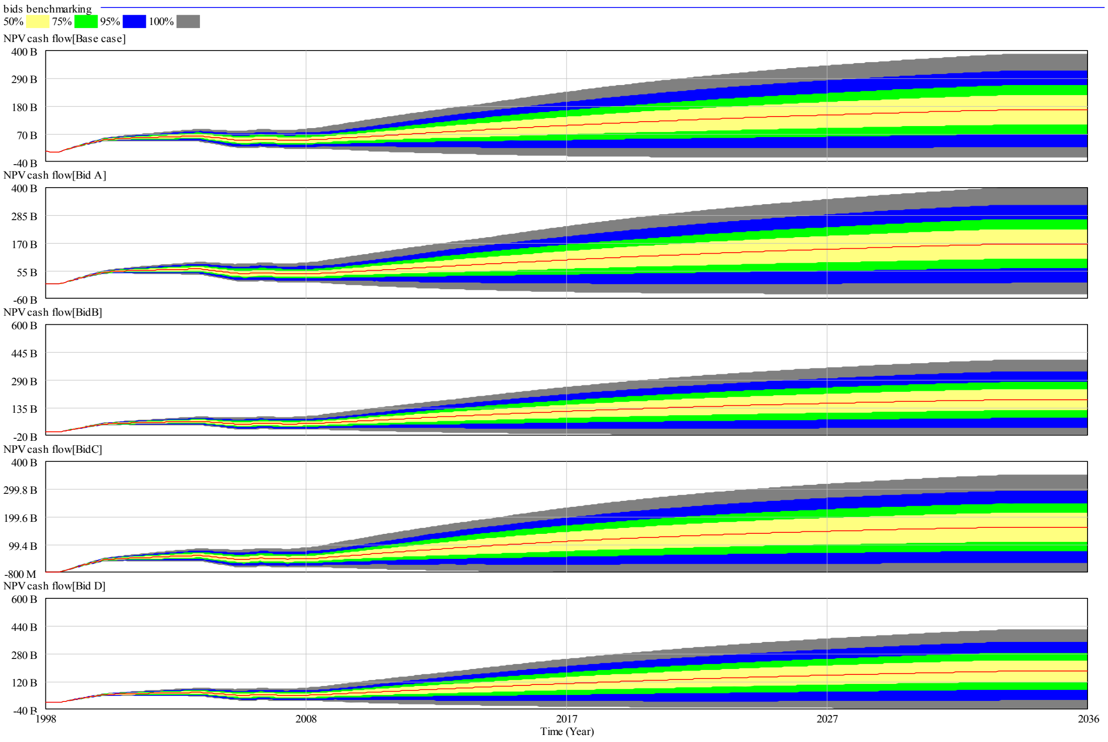
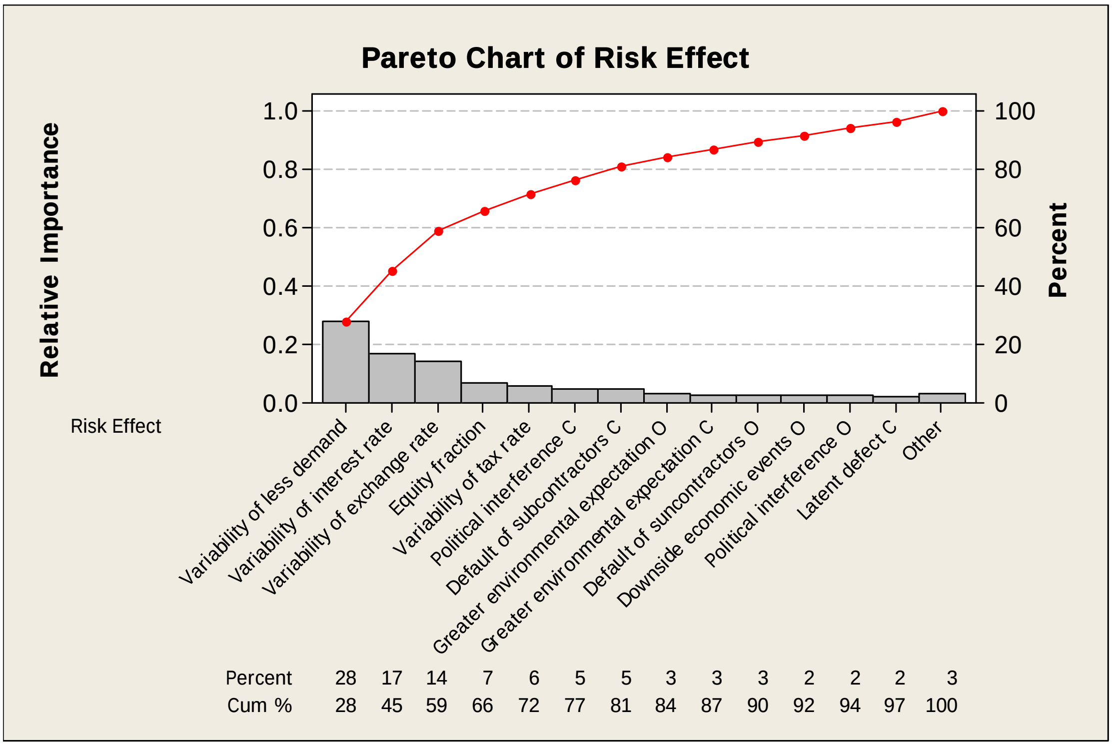


Figure 8.8.1 The Multivariate Sensitivity Analysis for The Project NPV of Risk Network Model



<u>Figure 8.8.2 The Multivariate Sensitivity Analysis for The Project NPV of Bidding Proposal Model</u>



<u>Figure 8.8.3 The Pareto Chart for the Relative Importance of Risk Effects on Project NPV</u>

Figure 8.8.3 showed that variability of less demand was the most important risk variable significantly affecting NPV performance. This would be likely to create a most vicious feedback loop: revenue loss → finance unavailable → resource unavailable → performance unavailable → revenue loss as shown in Figure 8.8.4. ***From the SD risk net work model and causal loop diagrams, we observed that this is the most essentially common path for most casual loops to pass.*** These results showed that there are 957 reinforce-feedback loops interacting in risk variable revenue loss, 10718 ones interacting in risk variable finance unavailable events, 8051 ones in resources unavailable, and 5263 ones in performance unavailable. The interactions of reinforce-feedback loops accumulate and enlarge thereby compounding effects over time. Using these results we can interpret the SD model behaviour on why the curve of worse case shown in Figure 8.8.1 declined largely over the project life to cause a broad difference from the best case at the end of 2036.

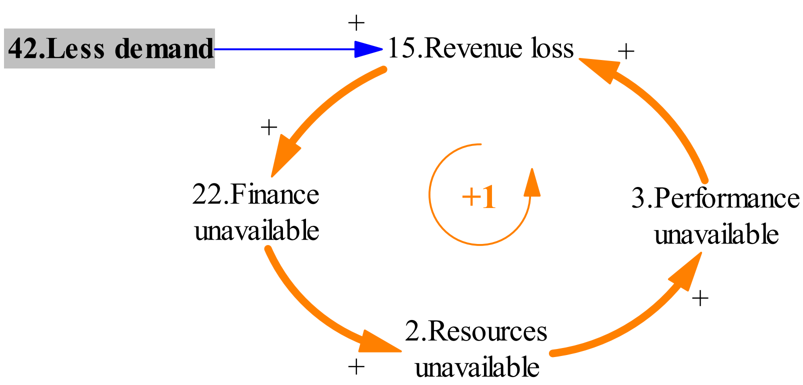


Figure 8.8.4 The Most Important Feedback Loop in SD Model and Causal Loop Diagram

Currently the project contactor THSRC has encountered financial difficulties by two risk events. First, the high interest rate for debt is making the fact that the operating revenues cannot cover the large debt invested during the construction stage. Second, the global financial crisis emerged since the end of year 2008 has made it a large operating loss after a big fall in ridership demand. THSRC has an accumulated operational loss of NT$67.5 billion (US$1.93 billion) since the THSR started to operate on January 5, 2007. Both risk events have made the company that may not be able to sustain operations (Shan, 2009), which shown as two most important risk effects in Figure 8.8.3. Moreover, the trend for THSR at the moment seems to be towards the worst case shown in Figure 8.8.1 and vicious circle shown in Figure 8.8.4. This truth has proved the research results.

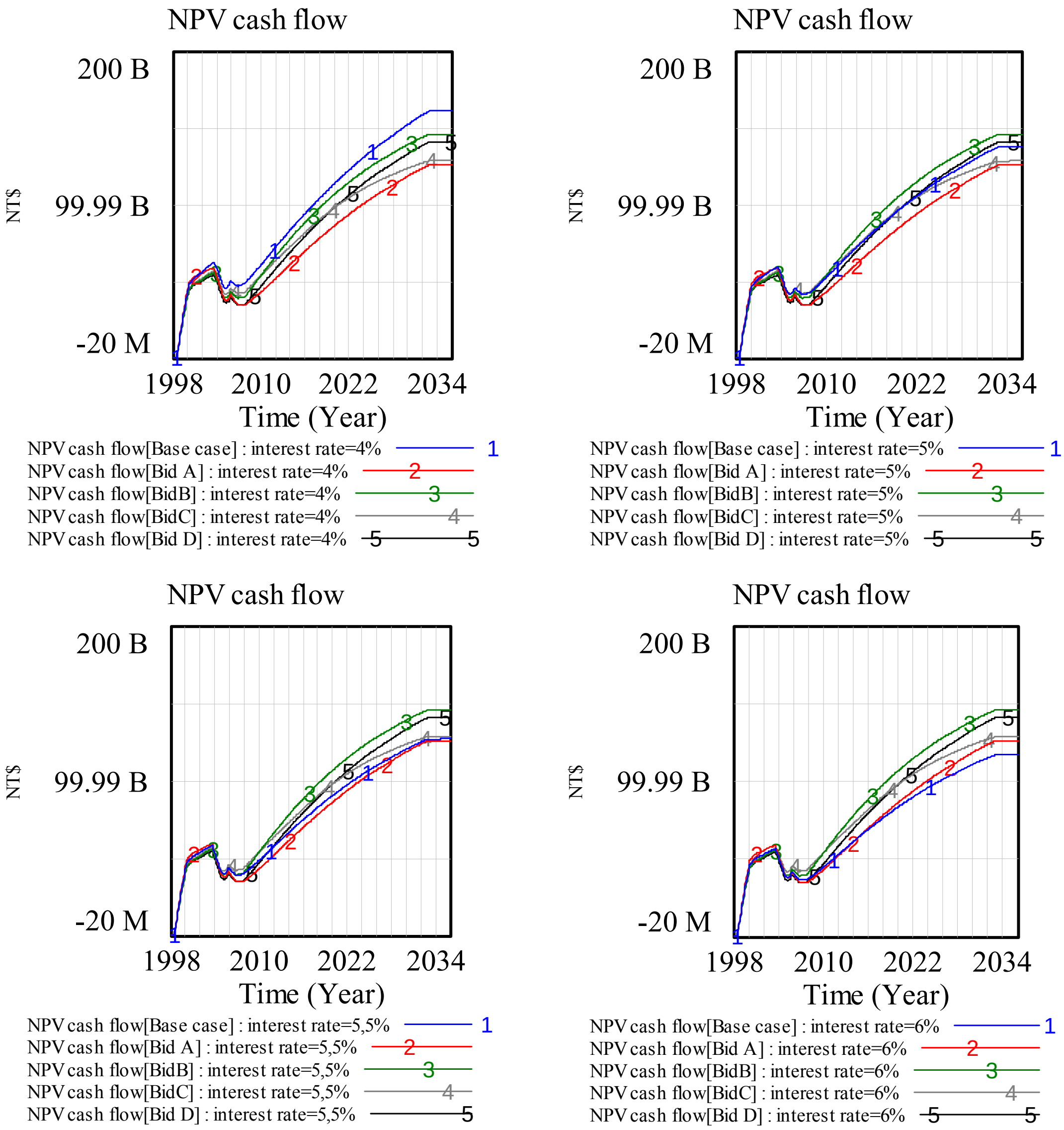


Figure 8.8.5 Policy Sensitivity Analysis for Interest Rates

The assumptions for the significant risk variables would be sensitive enough to influence the policy when selecting a preferred bidding proposal. For example, the variability of interest rates of the capital sources would influence the NPV performance which would change the benchmarking order of bidding proposals. Figure 8.8.5 showed the expected NPV values of project proposals over project life when the interest rates were 4%, 5%, 5.5% and 6% respectively. By the use of decision methods proposed in the Section 7.3, the benchmarking order ranked by NPV in 2034 was Bid A→Bid D →Bid B→Bid C→base case when the interest rate was equal to or less than 4%; the benchmarking order was Bid A→Bid D →Bid C→Bid B→base case when the interest rate was 5%; the benchmarking order was Bid A→Bid B →Bid D→Bid C→base case when the interest rate was 5.5%; the benchmarking order was Bid B→Bid A →Bid D→Bid C→base case when the interest rate was 6%. Obviously, the benchmarking order changed when the interest rates changed. This concluded that the selection of a preferred bidding proposal was very sensitive to interest rates.

The central policy for PPP project procurement is aimed at improving VFM by selecting a proper private contractor that is capable of efficiently manage risks to provide better NPV performance than traditional public procurement methods (Grimsey & Lewis, 2005; Shaoul, 2005). Since VFM is demonstrated by the difference of project NPV between the base case and bidding proposals, the researcher promoted the fact that assumptions of risk parameters in the base case should be carefully set up to reflect the reality under the public procurement, so that the benchmarking was meaningful in choosing the preferred bidder who is really capable of deliver value for money. For example, the sensitivity analysis indicated that the long-term NPV comparison was sensitive to an interest rate. Therefore, the researcher proposed that the estimation of a possible range of values for risk variables to minimize sensitivity effects arising from the changes of a single parameter value. For example, the major government capital source of government is a long-term bond with a probable interest rates of 5.5%, and an extreme range from 5% to 6% for large-scale public infrastructure projects under central government policy. The researcher inferred range values for variability of interest rate risk variable would be close to a random triangular (5%, 5.5%, 6%) from the real data. Similarly, following the above principles, the parameter assumptions for other financial risk and non-financial risk variables are set up as range values according to real empirical data. SD models would then put out range values of NPV for each bidding proposal as a result of concurrently changing multiple parameter assumptions, which could accommodate the assumption changes for a single value.

8.9 Justification of "Univariate" Approach

8.9.1 The Problems

The "univariate" approach was originally proposed in the submitted PhD thesis that it used a risk matrix for the conversion of the 2 dimensional measures of likelihood and impact into a single measure of risk. This approach has the following technical limitations:

1. Using a risk matrix for conversion is arbitrary and arguable.

Since the expert judgment regarding risk effect measurement is very subjective, the observation and interpretation of the same risk factors may be inconsistent among different project experts. In addition, the risks involved in PPP projects are unique. There may be the same type of risk factors among different projects, but different likelihood and impact exist. A clear definition of risk likelihood-impact scales are designed and tailored to reflect the specific risk characteristics of a particular project that may be helpful to reduce risk measurement bias. Therefore, the risk matrix used in this thesis research originally intended to provide the consistent definition of categorized scales with the corresponding numerical scales for risk likelihood-impact measures to reduce potential subjective bias when the project experts measured risk effects (see Appendix IV).

However, using a risk matrix for converting two-dimension categorical data to one-dimension ordinal numerical data for risk effect rating seems arbitrary and arguable. For example, there will be a question about why is LOW PROBABILITY MEDIUM IMPACT (numerical rating: 10) in the risk matrix worse than VERY HIGH LIKELIHOOD LOW IMPACT (numerical rating: 11)? Even though the numerical ranking depends on "RF values" calculation which depends on the "numerical weights" which are tailored to suit a particular project (see Appendix IV), the settings of "numerical weights" are arbitrary and also difficult to be justified according to the project characteristics.

2. Using a risk matrix to produce ordinal data for regression analysis is unreliable.

There are fundamental issues in using ordinal data for regression analysis. First, in general it implies the data must be interval in nature if regression ananlysis is used. There has been a continuing debate about whether it is legitimate to use ordinal data in parametric statistical procedures in the literature (see Appendix IXG). Second, the "rankings" of the ordinal values in the risk matrix are sensitive to the numerical scales. The different sets of numerical scales produce different weights which produce different rankings in the risk matrix (see Section 2.1, Appendix IX). Since the ordinal values produced by the risk matrix are critical input to the regression analysis, there will be a fundamental error in the analytical process for the use of regression.

Most of the literature simply used the two-dimensional risk matrix for prioritising or categorising the importance of risk factors only. It seems to be unsupported by any extensive literature or research that using a risk matrix for the conversion of the 2 dimensional measures of likelihood and impact into a single measure of risk, especially the issue that impact and probability are not commensurate dimensions. Thus, a “multivariate (bivariate)” approach using a two-dimensional independent set of values for probability and impact was undertaken to examine if it can resolve some of the concerns about the use of ordinal nature of data for regression.

8.9.2 A Statistical Analysis

As shown in Appendix IX, a statistical analysis was performed to examine the reliability and appropriateness of “univariate” and “multivariate (bivariate)” approaches in the use of regression by testing the sensitivity of risk relationships (including both ordinal and ratio relationships) to the numerical scales. It was performed from two different perspectives: “single-observed data (sample size / number of project experts = 1)” and “multiple-observed data (sample size / number of project experts = 37 in this thesis research)”, because this provided us with an insight to clarify and justify reliability and appropriateness in using both approaches for regression analysis.

As a result, when data are based on “single-observed data”, the statistical analysis appears that the ordinal and ratio relationships are very sensitive to the numerical scales regardless of which approaches are used to measure risks. As data are based on “multiple-observed data”, the ordinal and ratio relationships are consistent among different sets of numerical scales at 95% confidence level if “univariate” approach is used. On the contrast, as data are based on “multiple-observed data”, the ordinal and ratio relationships are inconsistent among different sets of numerical scales at 95% confidence level if “multivariate (bivariate)” approach is used.

8.9.3 Summary

From the results of this statistical analysis (see Appendix IX), we can draw the following conclusions:

1. Both the “univariate” and “multivariate (bivariate)” approaches are inappropriate in the use of regression in the circumstance of “single-observed data (sample size/number of project experts = 1)”. That is because the individual outcomes are easily subject to the numerical scales. Using different sets of numerical scales will change both ordinal and ratio relationships of risk factors.
2. The “univariate” approach is not supported by any extensive literature and has potential technical limitations on converting two conceptually distinct dimensions (Impact and Probability) into one single measure, but the “univariate” statistical analysis supports the data are reliable in the use of regression in some circumstances (see Appendix IX). First, the data from conversion and expert judgment are arbitrary and arguable, but they have face validity. Second, using ordinal data in parametric statistical procedures has drawn much debate in the literature. However, this has received wide range of acceptance. It is used not only in psychology and marketing researches but also in other areas. Many researches have noted that the ordinal data can be treated as interval data in parametric statistical procedures under certain conditions. The “univariate” approach can generally meet these conditions for the use of regression (see Appendix IXG). Third, the rankings of the ordinal values in the risk matrix are sensitive to the numerical scales, but the “univariate” statistical analysis (see Appendix IX) appears that this effect will be reduced as sample size (number of project expects) increases. As the sample size increases, the standard error of the mean decreases and hence the data characteristics in terms of expected risk effect values (mean values), ordinal and ratio relationships among different sets of numerical scales remain consistent. Therefore, the “univariate” approach is reliable in the use of regression in the circumstance of “multiple-observed data (sample size / number of project expert = 37 in this thesis research)”.
3. The “multivariate (bivariate)” statistical analysis (see Appendix IX) has shown that the data characteristics in terms of expected risk effect values (mean values), ordinal and ratio relationships among different sets of numerical scales don’t come up with consistent results at $\alpha=0.05$ significance (95% confidence level) in the circumstance of “multiple-observed data.” Because of the technical problem that impact and probability are not commensurate dimensions, the compounding data variation respectively arisen from each of the “Impact”

and “Likelihood” scale values will become a greater data variation which have a great effect on mean values. As the sample size (the number of project experts) increases, this doesn’t greatly contribute to reduction of the sensitivity of risk ordinal and ratio relationships to numerical scales. In addition, most of the literature simply used the two-dimensional scales (impact and probability) for prioritising or categorising the importance of risk factors, rather than for the use of regression. Therefore, the “multivariate (bivariate)” approach is not reliable and not recommended in the use of regression.

4. Due to some potential technical limitations in the proposed “univariate” approach, the System Dynamics (SD) model itself may well be based on some slightly suspect data, and so the conclusions this thesis research has drawn may not be 100% reliable. Since the SD model testing results (Chapter 8) are generally acceptable, the problems of the proposed “univariate” approach do not detract from the basic structural validity of the SD model or affect the fundaments of the methodology that are proposing in the rest of the thesis. This thesis research suggests that the future researchers look into the numerical-scale problems concerning risk measurement and may attempt to solve problems for the legitimate use of ordinal data in parametric statistical procedures.

8.10 Justification of the expert judgment

Expert judgment seeks to reflect the range of credible scientific judgments (Hora & Jensen, 2002). Technical knowledge, experience, and judgment ability play critical roles to define *good* experts. Technical knowledge refers to an understanding of the body of literature for the problem of interest. Experience and judgment refers to the ability to integrate information and theories beyond the reported data (Hetes & Richmond, 2009).

However, motivational bias arises when experts may frequently have direct or indirect vested interests in influencing the outcome to the question at hand. Their judgments may be influenced by motivational bias, whether consciously or unconsciously (McAndrew et al., 2009; Pronin et al., 2004.). The stakes may be clear or subtler in some cases. For example, in the former cases, the outcome of a question may impact employment or investments; in the latter cases the professional reputation of a particular expert may be associated with a particular point of view or theory, making it difficult to express an alternative perspective (Morgan & Henrion, 1990).

Motivational bias is perhaps difficult to identify and manage, but it can be reduced through appropriate approaches for the selection of experts (Hillson & Hulett, 2004). The selection of experts is critical to the success of expert judgment. Not only can a suitable approach help to identify and chose experts who span the range of credible views, but it can help to reduce motivational biases (Cooke, 2004). A number of approaches have been cited in the literature for nominating and selecting the experts. The common principles on the selection of experts are (Cooke, 2004; Keeney & Winterfeldt, 1991; Keith, 1996; Macgill et al., 2000; Morgan & Henrion, 1990; Rosqvist, 2003; USNRC, 1996; USEPA, 2009; USEPA, 2006):

(a) Multiple disciplines: The selection of experts should seek to ensure diversity in background. If experts are selected from multiple legitimate perspectives and relevant expertise to address the questions, the expert judgment will indicate of the range of plausible opinions.

(b) Technical balance: The selection of experts should seek to ensure that their disciplines can be represented equitably. This includes institutional or stakeholder balance. The balance of views can help to avoid or reduce potential motivational bias due to specific vested interests.

(c) Transparent process: For highly influential problems that are likely to attract controversy, transparency in the selection process is essential to help establish that the selection of experts can be done carefully to represent the range of credible viewpoints and to reduce the opportunity that will choose a highly influential expert with the vested interests. One possible principle is to use a transparent process with public comments for the nomination process.

(d) Independent peer review: Another selection principle is to employ an independent peer review group. Independence means that the participants in the peer review group have no vested interests in choosing an expert. The outside groups are allowed to participate in the expert selection process by accepting nominations from the public for consideration. This principle can reduce the motivational bias arisen from the influential stakeholders who will try to choose an expert with the judgment towards their viewpoint.

The researcher conducted interview surveys (see Appendix II) and questionnaire surveys (see Appendix IV) to collect information on the risk scenarios and risk effects of the THSR project from the project experts. Those experts were from a cross section of disciplines and stakeholders that covers all area of interest on the 52 risks described in chapter 4. They had ever participated in THSR project and had wide experiences on mass transit projects that were similar to THSR project. They were the senior members of the THSR project authority, Bureau of High Speed Rail (BHSR), and the project financing institute, International Commercial Bank of China (ICBC), which included project managers and project teams, discipline engineers, commercial specialists, safety and environmental specialists, contract managers, financial specialists, and the like. The experts were selected based on multiple disciplines and technical balance principles addressed in the aforementioned point (a) and (b) to ensure that the expert judgment employed in the data collection reflected the range of credible scientific views.

The researcher proposed a Bid Evaluation Panel to account for the expert judgment in evaluating the bidding proposals (see Section 7.1.2 and Table 7.1.2). The Bid Evaluation Panel members should follow the regulation Government Procurement Act set forth by the government procurement authority, Public Construction Commission, Executive Yuan, Taiwan, ROC, to selecting an appropriate group of experts. It states that a panel selected to participate in evaluation and selection of a preferred bidding proposal should include individuals who:

> (i) have possessed and demonstrated the necessary knowledge and expertise on procurement matter; (ii) shall be appointed within or outside the entity. Among them, at least one third of the total number shall be outside experts or scholars; (iii) shall be selected from a recommended list complied by the responsible entity acting together with the Ministry of Education, the Ministry of Examination and other relevant entities. The recommended list shall be made public on the Information network; (iv) shall not be selected for interests of specific suppliers. The same experts or scholars shall be avoided for different procurements (PCC, 2007).

The motivational bias may be difficult to identify and manage, but it can be reduced through appropriate approaches for the selection of experts. The above selection condition (i) and (ii) represent a broad diversity of independent opinions; condition (iii) represents the fact that the experts are selected through a transparent process by the independent peer review group; condition (iv) represents the fact that the direct vested interests can be avoided. All of these conditions conform to the aforementioned principles (a)-(d) for the selection of experts which are designed to reduce the motivational bias.

Chapter 9 Conclusions

9.1 Summary of Research Findings

Due to the impacts of financial difficulties, technical inefficiency, incorrect pricing, and poor quality of services under traditional public procurement, large-scale infrastructure project procurement officials began turning to the private sector in the 1980s. Officials of public sector engaging the private sector infrastructure financing and operations are expected to mitigate risks, save costs, improve innovation and services and enhance revenues, employment and economic growth (The World Bank, 1999b).This approach is called public-private partnership (PPP) and is defined as "a cooperative venture between the public and private sectors, built on the expertise of each partner, that best meets clearly defined public needs through the appropriate allocation of resources, risks and rewards" (Kernaghan, 1993). Value for Money (VFM) is a core objective of the PPP projects. The VFM concept refers to the optimal combination of whole life costs and benefits of the project under consideration to meet the users requirement; it does not simply mean the lowest costs or cheapest price (HM Treasury, 2004; United Nations, 2002). By PPP arrangement, risks are transferred and allocated to the party who is the most capable of managing them in a cost effective manner. This requires the optimization of risk allocation between public and private sector in order to achieve the best VFM. Many researchers have revealed in previous studies that a critical contributor to the success of a PPP project is the selection of the right private-sector partner, the concessionaire, who would provide the best overall performance and value throughout the PPP development process (Aziz, 2007; Chan et al., 2001; Zhang, 2005). However, many common issues concerning the current contractor selection methods for PPP projects are learned from literature survey below:

1. The current concessionaire-selection methods are not based on risk assessment. The PPP infrastructure projects, such as build-operate-transfer (BOT) transportation projects, are usually very complex with highly dynamic and interdependent risks and uncertainties over a long-term project life cycle (Reilly, 2005). Based on this fact, the risk assessment is critical for the PPP project procurement (Dey & Ogunlana, 2004) in order to select a proper project partner and examine the project VFM performance.

2. The current concessionaire-selection methods usually lack the global perspective of project life cycle. The risk problems of cost, schedule, quality, and the like dynamically reflect over the whole project life cycle. For example, many evaluators focus on the construction stage only, excluding the project design and operation phase. They are therefore unable to supply data on the project performance over the whole project life cycle (The Scottish Government, 2005).

These issues lead to the first research question: What are the generic types of risks inherent in the PPP transport projects over the life of the project? The researcher needed to investigate what kinds of risk factors including both quantitative and qualitative data would impact project performance over the construction and operation phases.

3. The current concessionaire-selection methods usually do not address interdependently dynamic and non-linear risk interactions. In reality, the risks of a mega PPP project are interdependent on each other with nonlinear relationships over the long-term project life cycle (Williams, 2002). However, based on current practices evaluators assume risk factors are independent. "Ignoring or underestimating correlations between variables will tend to understate the variance of outcome" (Balcombe & Smith, 1999) so that this could eventually lead to wrong judgments on the overall project risk estimates.

This issue leads to the second research question: How can the interdependencies and interactions of risk events be modeled over PPP project life cycle? The researcher needed to explore and model the interrelationships of risks.

4. The concessionaire-selection methods are normally unable to deal with semi-structured or unstructured real world problems. The domain problems for a large-scale infrastructure concern finance, technology, economy, contract management, organization, politics, regulation, and the like which are heterogeneous, structured, and also unstructured. For example, current methods incorporating the cost-benefit analysis (CBA) were criticized by experts that these methods were difficult in nature to quantify non-monetary terms (Mackie et al., 2003).

This issue leads to the third and fourth research questions, respectively: How can the qualitative risk effects be quantified while using CBA for cash flow analysis? How can the risk interrelationships be quantified? The researcher needed to infer mathematic equations for risk interrelationships.

5. Officials using the current concessionaire-selection methods usually ignore the uncertainty of outcomes. In the current practices for bids comparison officials also ignore the dispersion of outcomes and depend on deterministic outcomes only. Minor changes in the underlying assumption will cause the model to yield completely different results (Grimsey & Lewis, 2002, 2005; Ye & Tiong, 2000). Therefore, the PSC in terms of risk cost estimates is intended to be so subjective that it can be easily manipulated (Blyth, 2002; Shaoul, 2005;Turner, 2003). It is necessary to move from single value estimates to range values estimates for PPP infrastructure projects (Grimsey & Lewis, 2005; Reilly, 2005; Reilly & Brown, 2004;).

This issue leads to the fifth, sixth and seventh research questions, respectively: How can the probability distribution of risk effects be estimated? How can the probability distribution of overall project NPV be estimated with compounding both downside and beneficial effects over project life? How can range values of project NPV be compared to rank bidding proposals? The researcher needed to estimate probability distribution of both exogenous risk variables and the overall project NPV. The researcher needed to apply suitable decision rules to rank range values of NPV between bidding proposals as well.

Table 9.1 shows the research questions, research answers/findings with related reliability, and validity processing to ensure research answers/findings are reliable and accurate to all of the research questions.

To address the first research question: What are the generic risks inherent over a PPP project life? the research performed a literature review and survey to investigate the generic PPP project risk factors that would influence project performance. The 52 generic risk factors presented were drawn from the current empirical studies and official publications, which included journal articles, conference papers, research reports, textbooks, commercial or organizational documents, governments practice guidance, records, reports, and the like. The 52 generic risk factors were collected and identified through cross-checking the multiple sources of evidence, and were well defined and documented to ensure reliability and applicability to most of the rail transit PPP projects.

Table 9.1 The Research Results for 7-Research Questions3

Research Questions	Research Answers/ Findings	Reliability and Validity
1. What are the generic types of risks inherent in a PPP project over project life?	52 generic risk factors	• Cross-checking the multiple sources of evidence • Well defined risk factors • Well documented data
2. How can we model the interdependencies and interactions of risk events over the PPP project life?	52 causal loop diagrams	• Cross-checking the multiple sources of evidence • Boundary adequacy test and model structure assessment • Well documented data
3. How can we quantify the qualitative risk effects?	37 samples for risk effect rating	• Well defined questionnaire and risk effect rating scales • Well documented data
4. How can we estimate the probability distribution of risk effects?	13 fitted theoretical probability distribution of exogenous risk variables.	• The Probability Plot/P-P plot /Q-Q plot • Anderson-Darling statistic or Chi-Sq statistic tests
5. How can we quantify the risk interrelationships?	31 multiple-regression models	• Residual plots • R-sq and p-values statistic tests
6. How can we estimate the probability distribution of overall project NPV with compounding both downside and beneficial effects over project life?	A NPV time profile with 95% confidence interval	• Behaviour Reproduction Test • Monte-Carlo multi-variant Sensitivity Analysis • Extreme Conditions tests, etc.
7. How can we compare range values of project NPV to rank bidding proposals?	Project ranking methods including Mean-variance/Mean-semi variance, Stochastic Dominance, and the Expected-loss Ratio	Cross-checking the multiple sources of evidence

To address the second research question: How can the interdependencies and interactions of risk events be modeled over PPP project life cycle? the researcher explored and modeled the risk interdependencies and interactions using literature surveys and an interview survey. The multiple-case scenarios were investigated from literature for each of generic risk factors including the direct cause variables, direct consequence variables and immediate variables to form 52 causal loop diagrams (CLD) that addressed interdependencies and interactions for each risk factor. By interviewing the project experts and key participants, the researcher cross-checked and confirmed the CLDs drawn and constructed from multiple-case scenarios against THSR facts to ensure reliability and validity. The CLDs were modified and transformed into quantitative stock-flow diagrams by System Dynamics modelling to address dynamic risk interactions over project concession period. The researcher conducted model validation using boundary adequacy tests and structure assessment tests to ensure the risk variables that were used to address the direct cause and consequence in a causal loop diagram, the exogenous and endogenous risk-variables, and the risk variables in a feedback loop, and the like were well-defined in order to meet the output purpose of SD model for a rail transit PPP project.

To address the third research question: How can the qualitative risk effects be quantified? the researcher measured and quantified risk effects using results from a questionnaire survey and expert judgment. The questionnaires were sent to project experts and key participants to measure and rate the expected risk effects of qualitative risk events as risk effect scaled from 1 to 25. The 37 samples for risk effect rating were collected. The questionnaire is included in this dissertation with the standardized two-dimension matrix and clear scale definitions used to reduce ambiguity and inconsistency arising from subjective expert judgment. Moreover, the researcher detected the outliers of sampled data by conducting residual plots to reduce measure errors. All of these measures ensured data collected from questionnaire survey was reliable and valid in order to be used to address the expected risk effects for a rail transit PPP project.

To address the fourth research question: How can the risk interrelationships be quantified? the researcher inferred and quantified risk interdependencies and interactions by multiple-regression analysis. The multiple-regression models were used to represent the equations of risk interrelationships addressed in the causal loop diagrams and stock-flow diagrams for research question 2. The researcher performed a set of residual plots to check the model adequacy assumptions. The R^2 and p values statistics were used to explore if the model could explain variability and would fit the data well. The researcher performed these calculations to ensure that multiple regression models can validly represent risk interrelationships of a rail transit PPP project.

To address the fifth research question: How can the probability distribution of the expected risk effects (the exogenous variables) be estimated? the researcher estimated the probability distribution of the expected risk effects by probability fitting. The probability plot, P-P plot or Q-Q plot with Anderson-Darling statistic or Chi-square statistics were conducted by the researcher to discern whether the data would follow the specified theoretical distribution to ensure data validity for the probability distribution of the expected risk effects for the Taiwan high speed rail project.

To address the sixth research question: How can the probability distribution of overall project NPV be estimated with compounding both downside and beneficial effects over project life? the researcher estimated the probability distribution of project NPV with overall compounding downside and beneficial effects over project life using System Dynamics modelling and Monte Carlo simulation.

The researcher used a risk network model applying System Dynamics techniques to estimate risk interaction effects on NPV over time. The researcher used another SD model built on the risk network model to estimate the beneficial effects of bidding proposals on NPV over time and to see how efficiently the risk effects can be reduced and the NPV performance can be improved. Then the researcher input the multiple-regression models for research question 4 and probability distribution for research question 5 into the SD model. By performing Monte Carlo simulation, the probability distribution of the overall NPV with compounding both downside and beneficial effects over project concessionaire period was estimated. The entire SD models were examined by a set of tests including behaviour reproduction test, Monte-Carlo, multi-variant sensitivity analysis, and extreme conditions tests, and the like to ensure model validity that was applicable to a rail transit PPP project.

To address the seventh research question: How can the range values of project NPV be compared to rank bidding proposals? the researcher examined suitable decision methods gained from the literature survey including mean-variance/mean semi variance, stochastic dominance and expected-loss ratio to compare range values of NPV among different bidding proposals. The current studies by Oryczak, (2000, 2003), Park and Sharp-Bette (1990), Rich (2003), and Ye and Tiong (2000) were addressed in Chapter 3, and provided information to the researcher on each of the risky project comparison methods. Each method had specific advantages and disadvantages, which depended on the conditions of NPV probability distribution and project clients risk utility (risk-averse, risk-neutral, or risk seeking) in order to select a preferred bidding proposal. The researcher suggested using mean-variance/mean-semi variance to rank bidding proposals if the NPV probability distribution was close to a normal distribution, otherwise stochastic dominance was suggested. The researcher determined that if these two approaches could not determine the best proposal from all of bidding proposals, then expected loss ratio can be used as a tool to help a project manager make a final decision in bidding proposals ranking.

The objective of the thesis research is to develop a theoretical approach that is able to solve the common issues of the current PPP project concessionaire selection methods. The developed theoretical approach can build a decision support model that is specific to a particular PPP project for the public sector to choose a concessionaire which is capable of creating value for money.

The thesis research relies on analytical generalization (generalize theories) to a broader theory on the PPP project concessionaire selection rather than statistical generalization (enumerate frequencies) to the PPP project populations or universes. By aggregating these validated small-N research methods, a broad and complete theoretical approach can be formed to answer all of research questions (Flyvbjerg, 2006; Jacobs, 1961; Yin, 2003). The thesis research has generated conclusions from Table 9.1 suggest that each research finding (research answer) had resulted from each of small-six research methods and was reliable and valid to each corresponding research question through processing. Since the proposed theoretical approach can solve the common issues (see Table 9.1 for the seven research questions) of the current project concessionaire selection methods regardless of the type of PPP projects, it can be reasonably concluded that the developed theoretical approach aggregated by six research methods is applicable to any type of PPP projects. The Taiwan High Speed Rail project was applied to demonstrate SD decision model. The SD model developed by the proposed theoretical approach has been validated by a variety of tests (see chapter 8). It was showed that the SD model can properly function to represent the reality behaviour of the THSR project. Since the proposed theoretical approach can solve the common issues of the current PPP project concessionaire selection methods, it can build a decision support model that is specific to a particular PPP project for the public sector to choose a concessionaire which is capable of creating value for money.

The proposed theoretical approach aggregated by six research methods is summarized below:

1. Investigate the generic risk factors: Find out the generic risk factors that have downside effects on a specific type of PPP project performance during concession period by literature survey from the current studies.
2. Model causal loop diagrams: Model and interpret the risk interdependencies and interactions of a risk network by literature survey, interview survey, and System Dynamics modelling techniques.
3. Estimate risk effect and probability: Measure and quantify qualitative risk effects through a questionnaire survey by the group of expert judgments. Estimate risk effect probability distribution by probability fitting.
4. Formulate the functional relations of risk variables for risk network modelling by multiple-regression analysis.
5. Estimate overall NPV probability distribution: Model the compounding effects arising from both downside feedback loop of a project risk network and beneficial feedback loop of a

bidding proposal over project life by System Dynamics modelling techniques; estimate the probability distribution of project NPV time-profile by running Monte Carlo simulation.

6. Apply decision theories to compare NPV range values: Investigate and apply appropriate decision methods and stochastic analysis to compare the probability distribution of NPV among the bidding proposals by literature survey, and then apply these methods to help the decision-makers to select a preferred bidding proposal.

9.2 Strengths and Contributions

With the research, the researcher provided significant contributions in PPP project procurement in the following distinct areas:

1. Many researchers mentioned that the risk events of a PPP project are interdependent over project life cycle. Sterman (1992) stated that a large-scale construction project that is complex and has highly dynamic and interdependent risks and uncertainties over long-term project life cycle. Williams (2002) also mentioned that the risk usually interact each other with nonlinear relationships over time in a complex project. Dey and Ogunlana (2004) contended that there is a need to analyze risk interactions of complex infrastructure projects such as build-operate-transfer (BOT) projects over their long-term project life.

   In modern approaches to PPP project risk management, experts assume risk factors are independent and ignore the risk interaction effects over project life cycle, so the project risks cannot be effectively managed and controlled. For example, the risk assessment approaches such as cost estimate validation process (CEVP) proposed by officials of the Washington State Department of Transport (Reilly et al., 2004), value for money (VFM) assessment guidance proposed by the officials of the UK government (HM Treasury, 2004), and public sector comparator-technical note proposed by the Australia government officials (Partnerships Victoria, 2001; Partnerships Victoria, 2003) employ Excel spreadsheet to analyze project risk costs. In all of these approaches, officials presume project risks are independent and therefore do not assess the interaction effects.

   The researcher developed causal loop diagrams to address the cause-effect interrelationship between risk variables discussed in Chapter 4. The researcher also conducted the multiple-regression analysis outlined in Chapter 6 to quantify the functional risk interrelationships over PPP project life cycle and developed a SD model to assess the risk interaction effects on project net present value (NPV) over project life cycle. The goal of the researcher was to develop a model to assist project managers in identifying where the significant risks are in a project and how these risks can be controlled and mitigated.

2. Shaoul (2002, 2005) stated that officials using the current VFM methods based on the discounted cash-flow analysis should not forget to address the non-financial risk issues such as technical obsolescence, changing regulation and demand.

    Experts using current PPP project cash flow analysis approaches only focus on financial risk-factors and ignore the effects of non-financial risk-factors on project cash flow so the real costs are underestimated (Zhang, 2004). For example, Liou and Huang (2008) reported on their automated approach to negotiations of BOT contracts and Deng (2004) cited expert and decision support system for the project financing and cash flow management of large-scale infrastructure projects only take financial risk into account without non-financial risk thinking.

    The researcher has developed an approach to quantify the effects of non-financial risk factors on project NPV over project life cycle, so the overall project NPV can be assessed in reality.

3. Grimsey and Lewis (2005) summarized the criticisms from studies by Broadbent et al. (2003), Broadbent and Laughlin (2003), Heald (2003) and Shaoul (2005) which outlined that current approaches for PPP project comparison using a single point estimate will cause the model to give completely different results when minor changes are made in the underlying assumption when the two alternatives are reasonably close together. Current researchers, including Blyth (2002), Grismsey and Lewis (2005) and Reilly (2005) proposed that it is necessary to move from single value estimates to range values estimates for PPP infrastructure project comparisons on the grounds that the spread of values highlights the volatility of the project and introduces risk exposure into the PPP evaluation. This provides a meaningful evaluation judgment.

    The researcher has developed an approach to estimate the probability distribution of overall project outcomes with impact from compounding downside and benefit effects, which evaluate the dispersion of outcomes rather than deterministic outcomes, so that it provides the whole range of project outcomes for bid comparison with less bias.

9.3 Limitations and Future Research

Although the Taiwan high speed rail (THSR) was applied to demonstrate the SD model developed by the proposed theoretical approach, the researcher still lacked some real data. Due to commercial confidentiality, the public sector officials of THSR were not allowed to disclose any data in terms of cost. For example, the researcher could not obtain bidding proposals with bidding costs and project cash flow during construction stage. Most of data in terms of cost obtained by the researcher heavily relied on the current literature and this data was limited. The researcher used hypothetical data to model risk-reduction effects of bidding proposals. Without comparing simulation results against real data, there is inadequate evidence to support the position that the model can properly function to represent reality. As a result, the model validation for bidding proposal modelling is very limited. Therefore, applying a case with sufficient real data in the future research to test the concessionaire selection model developed by the proposed theoretical approach is suggested.

The researcher investigated the soft (human factor) effect at the organizational level (i.e., poor cooperation/coordination between parties) rather than at the personal level (i.e., philosophical factors such as de-motivation and physical factors such as exhaustion). Traditionally, the *soft* effects are investigated to improve performance in project management. For example, multiple design changes in a software development project will lead to de-motivation and exhaustion in the software designers. The project manager may want to estimate effects these issues would have on the design and engineering department of a software project company. Risk allocation is the focus of the thesis research. Risk allocation is very different from the traditional project risk management model. Under the PPP arrangement, the public sector officials seek those risks that are suitably under the control of the private party. The private party officials need to submit a bidding proposal to the public sector officials to demonstrate how they are capable of managing risks that are transferred from the public sector. The objective of the thesis research is to develop a theoretical approach in building a decision model for the PPP project concessionaire selection. This process started with exploring generic risk factors from the literature survey. The literature survey indicated that generic risks that would affect a large-scale construction project do not include the soft (human factor) effect at the personal level (i.e., philosophical factors such as de-motivation, and physical factors such as exhaustion) which are usually investigated to improve performance in the traditional project management (see Appendix I). Only soft effects at the organizational level (i.e., poor cooperation/coordination between parties) are discussed. For example, the literature, specifically EC (2002) and Lu (2004), indicated that the soft effect such as poor cooperation/coordination between parties at the organizational level would critically affect PPP performance. This is an indication that the soft effect at the organizational level, instead of the personal level is a critical issue. The human factors of de-motivation and exhaustion at the personal level occur in people affiliated with either the private or the public sector. The public sector officials or the private party officials may be capable of managing these issues. Thus, these soft issues are excluded in the risk allocation. The organization risk (i.e., poor cooperation/coordination between parties) has been summarized in Table 4.1.3 and addressed in Appendix V21 and Appendix VI21.

In addition to the detrimental soft factors that are addressed in chapter 4 and 6 and Appendix V and VI, the beneficial soft factors relevant to the project management capability are addressed in chapter 7. In the thesis research, there are two stages used to build a systems dynamic (SD) decision model for PPP concessionaire selection. In chapter 6, a system dynamic model was developed to estimate project downside effects. In addition to the downside effect model built in chapter 6, additional system dynamic models for bidding proposal modelling were developed in chapter 7 to evaluate the beneficial effects arising from the risk control and management schemes in a bidding proposal. Integrating both models creates a decision model used to select a preferred PPP concessionaire. A bidding proposal is used to identify the project risk management capabilities of the private party, which would include the beneficial soft factors such as leadership, design and construction quality control, configuration control, staff training, and so forth. These beneficial soft factors are used to reduce the downside effects of a PPP project. Because of lack of real data, the researcher used hypothetical data to model risk-reduction effects of bidding proposals. As for the future research, using real data of bidding proposals to explore the efficiency of beneficial soft factors on project risk control and management is suggested.

The researcher tried Bayesian analysis with two-dimensional measures for risk network modelling for Taiwan High Speed Rail (THSR) project. Fifty-two risk events have been identified in risk network modelling. This would involve pair wise measures to identify conditional probability $P(A|B)$ among 52 risk events for joint distribution for Bayesian analysis. It would possibly need numbers of measures of approximately 2704 ($_{52}C_2 \times 2 + 52 = 2704$) in a questionnaire survey. Too many questions in a questionnaire survey will not be supported or proposed in most of the literature (Groves et al., 2004). Moreover, the qualitative risk events are almost heterogeneous so that it is difficult to directly estimate the relative effect and conditional probability. During thesis research, the researcher tried a pre-test to ask project experts to evaluate the conditional probability among some heterogeneous risks. Most of the project experts were not able to answer questions. It seemed that the Bayesian analysis with two-dimensional measures had no advantage over one-dimensional measures for THSR project. However, the risks involved in PPP projects are unique (Li & Zou, 2008). It is unclear if the technical difficulties on measuring relative effect and conditional probability for Bayesian analysis in a risk network modelling for other PPP projects will be the same as THSR project. Therefore, the future researchers can compare the results of risk network modelling by Bayesian analysis with two-dimensional measures with one-dimensional measures proposed by the thesis research for other PPP projects.

Cost benefit analysis (CBA) is typically used by government officials to evaluate investment feasibility for public projects. Benefits and costs are often expressed in money terms, and are adjusted for time value of money. The researcher applied CBA with the discounted cash-flow analysis and risk analysis to calculate NPV, which is the single criteria to measure and compare project economic efficiency over time among the bidding proposals. The accuracy of the outcome of a CBA depends on how accurately costs and benefits have been estimated. Some benefits cannot be readily monetized. Although the researcher has developed a technique to quantify costs and benefits in monetary term, project experts are still relied upon to measure costs and benefits. That is the accuracy of NPV that estimated by CBA is heavily subject to project experts. The cost effectiveness analysis (CEA) is another form of economic analysis for project investment that compares the relative costs and outcomes (effects) of two or more project proposals. The CEA often incorporates multi-criteria decision making (MCDA) to weigh multiple outcomes in obtaining a single composite measure. Although the use of MCDA relies on subjective decision, it avoids inaccuracy problems on monetizing costs and benefits when these are difficult to be monetized. In the future research, it would be beneficial to compare the results of ranking project bidding proposals by CBA with CEA.

As addressed in the Section 2.3.3, the performance based payment (PBP) mechanism is an important source of assurance to the public sector members that the private sector parties are meeting the obligations to deliver services. The PBP mechanism should include appropriate incentives for the private sector members to deliver the service in a manner that gives the best value, and promotes partnership working. In the thesis research, the transportation project THSR was the case used to develop PPP contractor selection methodology. Since the revenues of a transportation project are provided by the end users instead of the public sector, the developed methodology did not include PBP for THSR project in the research. There was no incentives mechanism. Therefore, a future researchers may investigate different types of PPP projects as compared to transportation projects, (e.g., the healthcare or education projects that will need to include PBP). Future researchers may attempt to model payment and incentive mechanisms and discover how these mechanisms will affect the project performance.

This thesis research proposed a "univariate approach" that used a risk matrix for the conversion of the 2 dimensional measures of likelihood and impact into a single measure of risk. This approach is not supported by any extensive literature and has potential technical limitations. First, the data from the conversion of a risk matrix and expert judgment are arbitrary and arguable. For example, there will be a question about why is LOW PROBABILITY MEDIUM IMPACT (numerical rating: 10) in the risk matrix worse than VERY HIGH LIKELIHOOD LOW IMPACT (numerical rating: 11)? Even though the numerical ranking depends on "RF values" calculation which depends on the "numerical weights" which are tailored to suit a particular project (see Appendix IV), the settings of "numerical weights" are arbitrary and also difficult to be justified according to the project characteristics. Second, using ordinal data in parametric statistical procedures has drawn much debate in the literature. In general, the data must be interval in nature if regression analysis is used. Third, the rankings of the ordinal values in the risk matrix are sensitive to the numerical scales. The different sets of numerical scales produce different weights which produce different rankings in the risk matrix (see Section 2.1, Appendix IX). Even if the statistical analysis appeared that the "univariate" approach may work in some circumstances (see Appendix IX) , the System Dynamics (SD) model itself may be based on some slightly suspect data, and so the conclusions this thesis research has drawn may not be 100% reliable due to these potential technical limitations. This thesis research suggests that the future researchers can look into the numerical-scale problems concerning risk measurement and may attempt to solve problems for the legitimate use of ordinal data in parametric statistical procedures.

Since there were no real data in terms of qualitative risk effects, many parameter values in the *SD* model were heavily relied on the interviewees (the project experts). Thus the accuracy and error of *SD* model might be greatly subject to the interviewees. For example, the *SD* model reported the result that the estimate of key output variable “construction delay percentage” was 18.63% for mean, 0.08% for standard deviation, and (18.47%, 18.78%) for a 95% confidence interval. The forecast error was approximately 0.22%, which represented a small discrepancy between the simulated and real data. This remarkable result on low estimation error was checked and analysed in Appendix X to find out why *SD* model reported a low standard deviation and low forecast error for the percentage of construction delay. As explained in Appendix X, this is because the data obtained from the interviewees set up a tight range value between “the maximum time delay effect” and “the minimum time delay effect” of a risk event on a work package. “The maximum time delay effect” and “the minimum time delay effect” are two of the key parameters that affect the output values of risk variable “construction delay”. The smaller range values between “the maximum time delay effect” and “the minimum time delay effect”, the smaller variation in the output values of “construction delay”. This interprets that the low standard deviation and low forecast error in the output values of “construction delay” are the result of tight range values between “the maximum time delay effect” and “the minimum time delay effect” provided by the interviewees. This case reflects that the risk effect values of qualitative risk factors such as “resource unavailable” and “ownership change” have to depend on the interviewees’ estimation and hence the model outcomes may greatly be constrained to reflect *SD* model’s real forecasting capacity.

To enhance the model validity, the model parameters needed to be calibrated (Lyneis, 2008) by tracing and comparing the simulation results with the real project data in the future, particularly with data concerning the operation stage which would normally be lacking in most large-scale PPP projects. As for the behaviour reproduction tests addressed in chapter 8, the researcher can only evaluate the model forecasting capability in average daily ridership in 2007 because the THSR project has only been in operation since January 2007. The related parameters to average daily ridership should be modified every applicable period to ensure that the time profile of model outcome is consistent with the reality.

Although the researcher has established that the theoretical approach has proved to be valid in building a decision support model for PPP project concessionaire selection, this theory still requires further research to assure its realistic representation. A field investigation with PPP project managers for an overview evaluation on usability in terms of technical view, economic view, organisational view, and legal view to examine whether the proposed approach is practical in concessionaire selection for the public sector would be necessary. The technical view refers to evaluate the ease to use methods and tools of the proposed theoretical approach to build a decision support model for PPP project concessionaire selection. For example, the public sectors will need to examine if they have sufficient knowledge and skills to apply system dynamics modelling, risk analysis, statistic techniques, and decision-making methods used in the proposed theoretical approach. The economic view refers to evaluate the cost efficiency to apply the proposed approach. For example, the public sector will need to examine how much and how long they can train the staff to apply the proposed approach if they don’t have sufficient knowledge and skills. The organizational view refers to the organizational commitment to apply the proposed approach. For example, the public sector will need to examine if the staff at operational level accept the new approach which is different from the approaches they used to apply and the staff at the management level support to use the proposed approach. The legal view refers to the legality to use the proposed approach. For example, the public sector will need to examine if the proposed approach is allowed by the current regulations or laws.

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Appendix I Risk Factors Collected from Literature Survey

I.1 Empirical Studies

Table I.1.1 Li (2005)'s Three Levels of Risk Factors

Risk Levels	Risk Factors	Risk Events
Macro level	Political and government policy	Unstable government
		Expropriation or nationalisation of assets
		Poor public decision-making process
		Strong political opposition/hostility
	Macroeconomic	Poor financial market
		Inflation rate volatility
		Interest rate volatility
		Influential economic events
	Legal	Legislation change
		Change in tax regulation
		Industrial regulatory change
	Social	Lack of tradition of private provision of public services
		Level of public opposition to project
	Natural	Force majeure
		Geotechnical conditions
		Weather
		Environment
Meso level	Project selection	Land Acquisition (site availability)
		Level of demand for project
	Project finance	Availability of finance
		Financial attraction of project to investors
		High finance costs
	Residual risk	Residual risks
	Design	Delay in project approvals and permits
		Design deficiency
		Unproven engineering techniques
	Construction	Construction cost overrun
		Construction time delay
		Material/labour availability
		Late design changes
		Poor quality workmanship
		Excessive contract variation
		Insolvency/default of sub-contractors or suppliers
	Operation	Operation cost overrun
		Operational revenues below expectation
		Low operating productivity
		Maintenance costs higher than expected
		Maintenance more frequent than expected
Micro level	Relationship	Organisation and co-ordination risks
		Inadequate experience in PFI/PPP
		Inadequate distribution of responsibilities and risks
		Inadequate distribution of authority in partnership
		Differences in working method and know-how between partners
		Lack of Commitment from either partner
	Thirty party	Thirty party tort liability
		Staff crises

Table I.1.2 Hodge(2004)'s Risk Categories and Risk Events

Risk Category	Risks
Finance	Securing finance
	Maintaining finance (including changes to loan conditions
	Interest Rate and tax amendments
	Tax rulings
	Price escalation in capital components
Design and development	Design suitability
	Development problems
	Testing problem
	Design and development variants
	Delivery of design
Construction	Fixed time and cost to complete
	Delivery schedule
	Planning approvals
	Environmental issues
	Disruption to existing services
	Site preparation
	Transport of asset to site
	Design and construction variations
	Industrial disputes
Operation	Asset/service performance
	Asset/service availability
	Repairs and maintenance cost variations
	Security
	Staff training
	Change to requirements
	Cost of keeping existing assets operational
	Latent defects in existing assets
	Change in demand
	Third-party revenue
Ownership	Uninsurable loss or damage to the assets
	Technology chance or obsolescence
	Legislation/regulation changes
	Public/third-party liabilities
	Force majeure
	Realisation of residual value of assets

Table I.1.3 Ghosh & Jintanapakanont (2004)'s Risk Factors Influencing Rail Projects

Risk factors
1. Accuracy of project programme
2. Errors and omissions
3. Defective design
4. Design change
5. Scope of work definition
6. Inadequate specification
7. Conflict of document
8. Material productivity and shortage
9. Construction method
10. Culture difference between consultants
11. Consultant lacks of adequate number of staff
12. Subcontractor lack of adequate number of staff
13. Contractor competence
14. Subcontractor failure
15. Coordination with subcontractors
16. Poor liaison with local authority
17. Damage to persons or property
18. Poor team communication
19. Availability of resources
20. Treatment of material removed from site
21. Site access
22. Unforeseen site condition

23. defective construction work
24. Construction delay
25. Third party delays
26. Quantity variations
27. Change in work
28. Late drawings and instructions
29. Cost of tests and samples
30. System outages
31. Equipment productivity
32. Labour productivity
33. Quality of work
34. Suitability of materials
35. Accidents
36. labour dispute and strike
37. Inflation
38. Unavailability of funds
39. Exchange rate fluctuation
40. Tender price
41. Financial failure of contractor
42. Financial failure of subcontractor
43. Economic disaster
44. Cost of legal processes
45. War
46. Act of God (Earthquake, landslide, wind, rain and flood)
47. Fire and theft
48. Subsurface conditions of geology
49. Subsurface conditions of ground water
50. Pollutions and safety rules
51. Public consultation
52. Change order negotiation
53. Delay payment on contract and extras
54. Delays in solving disputes
55. Delays in solving contractual issues
56. Permit and regulation
57. Ecological constrains
58. Environmental clearing risk
59. Infrastructures by others not provided to programme

Table I.1.4 Thomas (2003)'s Risk Category for BOT Road Projects

Project Phase	Risk category
Development phase	Pre-investment risk
	Resettlement and rehabilitation risk
	Delay in land acquisition
	Permit/approval risk
	Delay in financial closure
Construction phase	Technology risk
	Design and latent defect risk
	Completion risk
	Cost overrun risk
Operation phase	Traffic revenue risk
	Operation risk
	Demand risk
	Debt servicing risk
Project life cycle	Legal risk
	Political risk
	Partnership risk
	Regulatory risk
	Financial risk
	Environmental risk
	Physical risk
	Non-political force majeure risk

Table I.1.5 Dey (2002)'s Risk Factors for Large-scale Construction Projects

Risk factors	Risk subfactors
Technical risk	Scope change
	Technology selection
	Implementation methodology
	Equipment risk
	Material risk
	Engineering and design change
Financial & economical risk	Inflation risk
	Fund risk
	Changes in local law
	Changes in government policy
	Improper estimate
Organizational risk	Capability of owner's project group
	Contractor's capability
	Vendor's capability
	Consultant's capability
Acts of God	Calamity normal
	Calamity abnormal
Clearance risk	Environmental clearance
	Land acquisition
	Explosive clearance
	Other clearances

Table I.1.6 Mott MacDonald (2002)'s Project Risk Areas

Project risk group	Project risk areas	Project risk type description
procurement	Complexity of contract structure	Where the complexity of the contract structure is likely to result in a delay to the contract being signed or impact on works duration, costs and benefits achieved.
	Late contractor involvement in design	Where the late involvement of the contractor in the design is likely to lead to redesign or problems during construction.
	Contractor capabilities	Where the contractor's capabilities/experience of managing projects of a similar nature is likely to impact on his ability to perform the works program on schedule and/or to the required quality.
	Government guidelines	Where existing government guidelines for procurement may not provide the Client with the necessary guidance to procure adequately.
	Dispute and claims occurred	Where disputes and claims are likely to occur if no mechanisms exist to manage effectively adversarial relationships between project stakeholders.
	Information management system	Where effective information management and communication methods are essential to enable the delivery of the project.
	Other (specify)	Where other influencing factors that relate to procurement are likely to affect the project outcome.
Project specific	Design complexity	Where the complexity of design (including requirements, specifications and detailed design) is such that it needs significant management to reduce the impact on project outcomes.
	Degree of innovation	Where the degree of innovation required due to the nature of a project requires unproven methods to be used to deliver the project.
	Environmental impact	Where the nature of the project has a major impact on its adjacent area where there is a strong likelihood of objection from neighbours and the general public.

	Other (specify)	Where other project specific influencing factors are likely to affect the project outcome.
Client specific	Inadequacy of the business case	Where project scope changes are likely to occur as a result of the poor quality of requirement specifications and inadequate project scope definition.
	Large number of stakeholders	Where project scope changes are likely to occur as a result of conflicting requirements or bad co-ordination of project stakeholders.
	Funding availability	Where project delays or changes in scope are likely to occur as a result of the availability of funding (i.e. departmental budget spent or insufficient contingency funds).
	Project management team	Where the Client project management team's capabilities/experience of managing projects of a similar nature is likely to impact on the project outcome.
	Poor project intelligence	Where the quality of initial project intelligence (e.g. preliminary site investigation, user requirements surveys, etc) is likely to have a significant impact on the likelihood of the occurrence of unforeseen problems.
	Other (specify)	Where other Client specific influencing factors are likely to affect the project outcome.
Environment	Public relations	Where a high level of effort is required to address public concern about the project, which may have a significant impact on the project outcomes.
	Site Characteristics	Where the characteristics of the proposed environment for the project are highly sensitive to the project's environmental impacts.
	Permits / Consents / Approvals	Where there is a likelihood of significant delays obtaining necessary permits, consents or approvals.
	Others (specify)	Where other influencing factors that relate to the proposed environment for the project are likely to affect the project outcome.
External influences	Political	Where the project outcomes are sensitive to political influences.
	Economic	Where the project outcomes are sensitive to economic influences.
	Legislation /Relations	Where the project outcomes are sensitive to legislation and regulation changes.
	Technology	Where the project outcomes are sensitive to technological advancements.
	Others (specify)	Negative influencing factors that are external to the project that have an impact that are not identified above.

Table I.1.7 Akintoye et al (2001)'s PFI/PPP Project Risk Factors

- Site acquisition
- Delay in feasibility studies/planning approval
- Design and construction risks (i.e. cost/overruns; poor technical solution)
- Commissioning and operating risks (including maintenance)
- Occupation demand (revenue) and usage risks over time
- Obsolescence / Technology risk
- Residual value risk
- Economic risks (including: fall in revenue; financiers pulling out, etc.)
- Legislative / Regulation risks (e.g., future planning regulations, health and safety features etc.)

• Taxation risks (Change in taxes/laws) • Bid process / Complicated negotiations • Political (long time governmental support of international projects) • Corruption • Consortium structure • Local partner • Project management ability • Existing infrastructure • Raw material (supply, availability, etc.) • Financing (foreign exchange) • Force majeure • Operation and maintenance failure • Market competition • Revenue tariffs/demand change • Project performance • Foreign exchange/inflation • Financing risks

Table I.1.8 Shen et al. (2001)'s Risk List Associated with Sino-foreign Joint Ventures Typed PFI/PPP Construction Projects

(1) Financial risks
Bankruptcy of project partner
Difficult convertibility of currency
Loss due to fluctuation of interest rate
Loss due to fluctuation of currency exchange rate
Low credibility of shareholders and lenders
(2) Legal risks
Breach of contracts by other participants
Breach of contracts by project partner
Lack of enforcement of legal judgment
Loss due to insufficient law for joint ventures
Uncertainty and unfairness of court justice
(3) Management risks
Change of organization within local partner
Improper project feasibility study
Improper project planning and budgeting
Improper selection of project type
Inadequate choice of project partner
Inadequate project organization structure
Incompetence of project management team
Incomplete contract terms with partner
Increase in project management overheads
Poor relation and disputes with partner
Poor relation with government departments
Problems associated with culture difference
Project delay
(4) Market risks
Competition from other similar projects
Fall short of expected income from project use
Increase of accessory facilities price
Increase of labor costs
Increase of materials price
Increase of resettlement costs
Inadequate forecast about market demand
Local protectionism
Unfairness in tendering
(5) Policy and Political risks
Cost increase due to changes of policies
Loss incurred due to corruption and bribery
Loss incurred due to political changes
Loss due to bureaucracy for late approvals

(6) Technical risks
Technical risk
Accidents on site
Design changes
Equipment failure
Errors in design drawings
Hazards of environmental regulations
Incompetence of transportation facilities
Increase in site overheads
Industrial disputes
Local firm's incompetence and low credibility
Materials shortage
Obsoleteness of building equipment
Poor quality of procured accessory facilities
Poor quality of procured materials
Problems due to partners' different practice
Shortage in accessory facilities
Shortage in skillful workers
Shortage in supply of water, gas, and electricity
Subcontractor's low credibility
Unknown site physical conditions
Unusual weather and force majeure

Table I.1.9 Wang (2000)'s List of Risks Associated with BOT Projects in Different Infrastructure Sectors

All sectors
Force majeure risk
Political risks (change in law and regulation; revoke; expropriation)
Financial risks (inflation; interest rate; exchange rate and convertibility)
Competition risk
Environmental risk (increasing consciousness in society)
Land acquisition and compensation risk
Construction risks (cost overrun; delay; quality)
Operation risk (operator inability; output quantity and quality; production regularity)
Condition of facility
Supply risk (shortage; quality)
Offtake risk (quantity; pay in time)
Documentation/contractual risk (conflict and arbitration; applied law)
Power sector
Repayment of external debt
Restriction on imported equipment and raw materials
Fluctuating demand of power generated
Problem in bill collection
Illegal connection to transmission system (power theft)
Transmission failure
Lowered tariffs due to competition
Specification not being fulfilled, resulting in refusal of power purchase by state utility
Power plant location (inadequate transport facilities)
Environmental dispute
Fluctuation of cost and availability of fuel/coal
Construction delay
Prolonged downtime during operation
Liquidated damages or termination of Power Purchase Agreement (output and quality do not meet off-taker's requirement)
Government's restrictions on profitability (rate of return) and tariff levels
Transport Sector (Road)
Inadequate traffic volume (inadequate traffic forecasts or subsequent deviation)
Competing routes (particularly free or underpriced ones)
Restrictions on toll level and increase
Cost overruns (because of size and scope, particularly if project crosses a hilly region)
Construction delays (land acquisition; unexpected technical difficulty)
Long land acquisition period
Right-of-way disputes (e.g., archaeological mines)
Necessitating measures to minimize the impact of construction on traveling public

Delay in other projects connecting to this road
Income streams are usually in local currency (exchange rate and convertibility risk)
Transport Sector (Tunnel and Bridge)
Geological risks for immersed tunnel
Safety at work and disturbances to surface traffic in municipal areas
Health risks of compressed air
Stability of seabed for submerged tunnel
Traffic accidents and fire breakouts for tunnels during operation
Restrictions to harbor navigation and air traffic flight path for bridge
Hydrological opposition from ferry workers and fishermen
Bad weather conditions
Competition from ferries and airlines
Transport Sector (Rail)
Long land acquisition period
Complex relocation of existing utilities
Uncoordinated attempt in various districts
Controlled fare levels
Complexity of getting design approvals
Competition from road transportation
Environmental dispute
Taxation
Expensive rolling stock and control systems
Transport Sector (Airport and Port)
Competition from other airports
Regional or international trade prosperity
Tourism business prosperity
Political stability and spending pattern
Integration with other connecting facilities
Inadequate adjoining land for expansion
Throughput capacity affected by breakdown of equipment, labor disputes, and extreme weather conditions for port
Economic and trade conditions
Changes in tariff regulations and quotas
Political risk
Process plant
Take-or-pay agreement with gas producer
Leakage of pipe
Nonpayment and pilferage
Controlled tariffs
Fast changing environmental regulations for waste treatment (rising concerns and advancing technology making improvements possible)
Telecommunication
Most competitive sector
High research and development costs
Restrictions by incumbent operator for new entrants to access to established network
Addition cost and problem in integrating with existing network including technological incompatibility
Bureaucracy in licensing

- Moody (2006)'s research report recommended a methodology to model risks for PFI/PPP infrastructure project. It takes the risk factors into account, which include "project simplicity" "reasonability of construction schedule" "construction budget" "vulnerability to local" "economic conditions" "site conditions" "site access, acquisition and planning" "force majeure" "change in law" and "liquidity level."
- Cooper et al (2005)'s book "Project Risk Management Guideline" proposed the risk categories for risk allocation of PFI/PPP projects are "location" "design" "construction or acquisition" "finance" "ownership and provision of services" "disposal" "assurance of supply" "commercial" "contractual" "financial" "security" "supportability" and "regulatory."
- Nguyen and Ogunlana (2005)'s research proposed to model infrastructure projects by considering the risk factors into account, which include "project scope change" "rework" "poor quality of practice" "inadequate manpower" "breakdown of equipment and plant" "shortage of material" "improper resource allocation" "poor project performance" "unclear project objectives" "scope change" "short project deadline" "resource constraints" "ineffective resource levelling" "poor subcontractors" "technology change" "poor coordination among parties" and "unexpected site conditions."
- Mills (2001)'s study cited from Roozbeh (1995) listed the risk factors for large construction project, which include "labours and equipment productivity" "quality of work" "labour, equipment, material

availability" "safety" "defective material" "contractor competence" "inflation" "actual quantities of work" "labour disputes" "differing site conditions" "defective design" "site access/ right of way permits and ordinances" "changes in government regulations" "delay payment on contract" "changes in work" "financial failure" "change-order negotiation" "contract-delay resolution" "Acts of God" "Third-party delays" and "defensive engineering."

I.2 Official Publications

Table I.2.1 The UK Government's General Types of Risk (HM Treasury, 2003)

Types of Risk	Descriptions
Availability risk	The risk that the quantum of the service provided is less than required under a contract.
Business risk	The risk that an organisation cannot meet its business imperatives.
Construction risk	The risk that the construction of physical assets is not complete time, to budget and to specification.
Decant risk	The risk arising in accommodation projects relating to the need to decant staff/ clients from one site to another.
Demand risk	The risk that demands for a service does not match the levels planned, projected or assumed. As the demand for a service may be partially controllable by the public body concerned, the risk to the public sector may be less than that perceived by the private sector.
Design risk	The risk that design cannot deliver the services at the required performance or quality standards.
Economic risk	Where the project outcomes are sensitive to economic influences. For example, where actual inflation differs from assumed inflation rates.
Environment risk	Where the nature of the project has a major impact on its adjacent area and there is a strong likelihood of objection from the general public.
Funding risk	Where project delays or changes in scope occur as a result of the availability of funding.
Legislative risk	The risk that changes in legislation increase costs. This can be sub-divided into general risks such as changes in corporate tax rates and specific ones which may affect a particular project.
Maintenance risk	The risk that the costs of keeping the assets in good condition from budget.
Occupancy	The risk that a property will remain untenanted – a form of demand risk.
Operational risk	The risk that operating costs vary from budget, that performance standards slip or that service cannot be provided.
Planning risk	The risk that the implementation of a project fails to adhere to the terms of planning permission or that detailed planning cannot be obtained, or if obtained, can only be implemented at costs greater than in the original budget.
Policy risk	The risk of changes of policy direction not involving legislation.
Procurement risk	Where a contractor is engaged, risk can arise from the contract between the two parties, the capabilities of the contractor, and when a dispute occurs.
Project intelligence risk	Where the quality of initial project intelligence (eg preliminary site investigation) is likely to impact on the likelihood of unforeseen problems occurring.
Reputation risk	The risk that there, will be an undermining of customer/ media perception of the organisations ability to fulfil its business requirements e.g. adverse publicity concerning an operational problem.
Residual value risk	The risk relating to the uncertainty of the value of physical assets at the end of the contract.
Technology risk	The risk that changes in technology result in services being provided using non-optimal technology.
Volume risk	The risk that actual usage of the service varies from the level forecast.

The guidance for PFI/PPP project risk management (Australia Government, 2005; Partnerships Victoria, 2001), published by the Australia Government, listed common infrastructure and project risk categories as Table 5.2.2.

Table I.2.2 The Australia Government's Risk Category Checklist (Australia Government, 2005; Partnerships Victoria, 2001)

Risk Category	Description
Site risks	
Existing structure	Risk that existing structures are inadequate to support new improvements.
Site conditions	Risk that unanticipated adverse ground conditions are discovered which cause construction costs to increase and/or cause construction delays.
Approvals	Risk that necessary approvals may not be obtained or may be obtained only subject to unanticipated conditions which have adverse cost consequences or cause prolonged delay.
Environmental (1)	Risk that the project site is contaminated requiring significant expense to remediate.
Environmental (2)	Risk that prior to financial close offsite pollution has been caused from a government preferred site (any site) to adjacent land.
Environmental (3)	Risk that prior to financial close (in case of a non-government site) or after financial close (any site) offsite pollution is caused to adjacent land.
Clean-up and rehabilitation	Risk that the use of the project site over the contract term has resulted in a significant clean up or rehabilitation obligation to make the site fit for future anticipated use.
Native title	Risk of costs and delays in negotiating indigenous land use agreements where project site may be subject to native title or risk injunction and/or invalidity of approvals.
Cultural heritage	The risk of costs and delays associated with archaeological and cultural heritage discoveries.
Availability of site	Risk that tenure/access to a selected site which is not presently owned by government or private party cannot be negotiated.
Design, Construction and Commissioning risks	
Design	The risk that the design of the facility is incapable of delivering the services at anticipated cost.
Construction	The risk that events occur during construction which prevent the facility being delivered on time and on cost.
Commissioning	The risk that either the physical or the operational commissioning tests which are required to be completed for the provision of services to commence, cannot be successfully completed.
Sponsor and Financial risks	
Interest rates pre-completion	The risk that prior to completion interest rates may move adversely thereby undermining bid pricing.
Sponsor risk	The risk that the private party is unable to provide the required services or becomes insolvent or is later found to be an improper person for involvement in the provision of these services or financial demands on the private party or its sponsors exceed its or their financial capacity causing corporate failure.
Financing unavailable	The risk that when debt and/or equity are required by the private party for the project it is not available then and in the amounts and on the conditions anticipated.
Further finance	The risk that by reason of a change in law, policy or other event additional funding is needed to rebuild, alter, reequip etc the facility which cannot be obtained by the private party.
Change in ownership	The risk that a change in ownership or control of the private party results in a weakening in its financial standing or support or other detriment to the project.
Refinancing benefit	The risk (upside) that at completion or other stage in project development the project finances can be restructured to materially reduce the project's finance costs.
Tax changes	The risk that before or after completion the tax impost on the private party, its assets or on the project, will change.
Operating risks	
Inputs	The risk that required inputs cost more than anticipated, are of inadequate quality or are unavailable in required quantities.
Maintenance and Refurbishment	The risk that design and/or construction quality is inadequate resulting in higher than anticipated maintenance and refurbishment costs.
Changes in output specification outside agreed specification range	Risk that government's output requirements are changed after contract signing whether pre or post commissioning.

Operator failure	Risk that a subcontract operator may fail financially or may fail to provide contracted services to specification.
Technical obsolescence or innovation	Risk of the contracted service and its method of delivery not keeping pace, from a technological perspective, with competition and/or public requirements.
Market risks	
General economic downturn	In a user pays model, the risk of a reduction in economic activity affecting demand for the contracted service.
Competition	In a user pays model the risk of alternate suppliers of the contracted service competing for customers.
Demographic change	The risk of a demographic/socio-economic change affecting demand for contracted service.
Inflation	Risk that value of payments received during the term is eroded by inflation.
Network and Interface risks	
Withdrawal of support network	The risk that, where the facility relies on a complementary government network, that support is withdrawn or varied adversely affecting the project.
Changes in competitive network	The risk that an existing network is extended/changed/re-priced so as to increase competition for the facility.
Interface (1)	The risk that the delivery of core services in a way which is not specified/anticipated in the contract adversely affects the delivery of contracted services.
Interface (2)	The risk that the delivery of contracted services adversely affects the delivery of core services in a manner not specified/anticipated in the contract.
Industrial Relations risks	
Industrial relations and civil common	Risk of strikes, industrial action or civil commotion causing delay and cost to the project.
Legislative and Government Policy risks	
Approvals	The risk that additional approvals required during the course of the project cannot be obtained.
Changes in law/policy (1)	The risk of a change in law/policy of the State Government only, which could not be anticipated at contract signing and which is directed specifically and exclusively at the project or the services and which has adverse capital expenditure or operating cost consequences for the private party.
Changes in law/policy (2)	In some cases, the risk of a change in law/policy (at whatever level of government it occurs) which could not be anticipated at contract signing which is general (ie not project specific) in its application and which causes a marked increase in capital costs and/or has substantial operating cost consequences for the private party.
Regulation	Where there is a statutory regulator involved there are pricing or other changes imposed on the private party which do not reflect its investment expectations.
Force Majeure risks	
Force majeure	The risk that inability to meet contracted service delivery (pre or post completion) is caused by reason of force majeure events.
Asset Ownership risks	
Technical obsolescence	The risk that design life of the facility proves to be shorter than anticipated accelerating refurbishment expense.
Default and termination	Risk of 'loss' of the facility or other assets upon the premature termination of lease or other project contracts upon breach by the private party and without adequate payment.
Residual value on transfer to government	The risk that on expiry or earlier termination of the services contract the asset does not have the value originally estimated by government at which the private party agreed to transfer it to government.

Table I.2.3 The South Africa Government's Risk Categories (South Africa, 2000)

Availability risk	The possibility that the Services to be provided by the Private Party do not meet the output specifications of the Institution.
Completion risks	The possibility that the completion of the Works required for a project.
Cost over-run risk	The possibility that during the design and construction phase, the actual Project costs will exceed projected Project costs.

Design risk	The possibility that the Private Party's design may not achieve the required output specifications.
Environmental risk	The possibility of liability for losses caused by environmental damage.
Exchange rate risk	The possibility that exchange rate fluctuations will impact on the envisaged costs of imported inputs required for the construction or operations phase of the Project.
Force Majeure risks	The possibility of the occurrence of certain unexpected events that are beyond the control of the Parties.
Inflation risk	The possibility that the actual inflation rate will exceed the projected inflation rate.
Insolvency risk	The possibility of the insolvency of the Private Party.
Insurance risk	The possibility (i) that any risks that are insurable as at the Signature Date pursuant to the agreed Project Insurances later become Uninsurable or (ii) of substantial increases in the rates at which insurance premiums are calculated.
Interest rate risk	These are factors affecting the availability and cost of funds.
Latent defect risk	The possibility of loss or damage arising from latent defects in the Facilities included in the Project.
Maintenance risk	The possibility that (i) the cost of maintaining assets in the required condition may vary from the projected maintenance costs, or (ii) maintenance is not carried out.
Market, demand or volume risk	The possibility that the demand for the Services generated by a project may be less than projected.
Operating risk	Any factors (other than Force Majeure) impacting on the operating requirements of the Project.
Planning risk	The possibility that the proposed use of the Project Site in terms of the PPP Agreement and, in particular, the construction of the Facilities on the Project Site will fail to comply with any applicable laws relating to planning, land-use or building.
Political risk	The possibility of (i) Unforeseeable Conduct by the Institution or by any other government authority that materially and adversely affects the expected return on Equity, debt service or otherwise results in increased costs to the Private Party, or (ii) expropriating actions of the assets of the Private Party.
Regulatory risk	The possibility that Consents required from other government authorities will not be obtained or, if obtained, can only be implemented at a greater cost than originally projected.
Residual value risk	The risk that the Project Assets at termination or expiry of the PPP Agreement will not be in the prescribed condition for handback to the Institution.
Resource or input risk	The possibility of a failure or shortage in the supply of the inputs or resources required for the operation of a project including deficiencies in the quality of available supplies.
Subcontractor risk	The risk of subcontractor (first-tier and below) defaults or insolvency.
Tax rate change risk	The possibility that changes in applicable tax rates or new taxes may decrease the anticipated return on equity.
Technology risk	The possibility that (i) the technology inputs for the outsourced institutional function may fail to deliver the required output specifications, or (ii) technological improvements may render these technology inputs out-of-date ("technology refresh or obsolescence risk").
Utilities risk	The possibility that (i) the utilities (e.g. water, electricity or gas) required for the construction and/or operation of a project may not be available, or (ii) the project will be delayed because of delays in relation to the removal or relocation of utilities located at the Project Site.

United Nations (2000) published a guideline book on PFI/PPP infrastructure project procurement listed risk factors, which include "technical risks: implementation delays, accidents related to technical, underground or equipment failures" "delay risks" "efficiency risk due to the service management difficulties" "commercial risks: service costs, income shortfall, and so on" "financial risks: inflation, difficulty finding funds or in refinancing, interest rate change or currency rates change" "technical building risks: ground conditions, bad weather, etc" and "legal, political, force majeure risks."

European Commission (2003) published a guideline book on PFI/PPP infrastructure project procurement listed risk factors, which include “revenue risks” “choice of private partner” “construction risks” “foreign exchange risks” “regulatory/contractual risks” “political risks” “environmental/ archaeological risks” “latent defect risks” “public acceptance risks” “sustainability risks” and “hidden protectionism risks”

Appendix II Interview Survey Plan

A. Why

The interview survey will be conducted to explore the risk scenarios of THSR project. The purposes of interview survey are: first, modify the Causal Loop Diagrams that are created in Chapter 5 to ensure that the risk causal relationships can fit the likely risk scenarios of THSR project well; second, gather risk variables and parameters information to model risk cost network for THSR project.

B. Who

The interviewees are the senior members of public sector 'Bureau of High Speed Rail: BHSR' for THSR project. These informants include expertise from a cross section of disciplines and stakeholders that covers all area of interest on the 52 risks described in Chapter 5. They had ever participated in THSR project and have wide experiences on mass transit projects that are similar to THSR project, which include: project manager and project team, discipline engineers, commercial specialists, safety and environmental specialists, contract managers, etc. In addition, the financial institute 'International Commercial Bank of China (ICBC)' that provided project financing for THSR will also be interviewed for the information on financial risks. The interview organisations include:

- The 1st Division of BHSR (function: design and supervision)
- The 2nd Division of BHSR (function: civic engineering)
- The 3rd Division of BHSR (function: mechanical/electrical engineering)
- The 4th Division of BHSR (function: contract performance)
- The 5th Division of BHSR (function: land acquisition)
- The 6th Division of BHSR (function: safety and environment)
- ICBC (function: project financing)

The liaise is Mrs Chung: Email: public@nthsr1.hsr.gov.tw; Tel# 886-2-8072-3333 ext 8632. All of the above informants can be accessed through Mrs Chung.

C. How

The interview survey was conducted by Internet phone with the following procedure:

1. The interviewees were made an appointment in advance.
2. This interview was conducted by Internet Phone: 'SkypeOut'.
3. The interviewees was informed of the definition of 52 risks and the purpose of interview before interview to ensure that the interviewees have enough time to prepare for interviews and answering questions.
4. All interviews were recorded as MP3 files for evidence by software: 'Hotkey Sound Recorder'.
5. The interviewees asked for anonym.

D. When

The interview survey was conducted by Internet phone from 11th of June, 2007 to 13th of August, 2007. Each interview took 30 minutes to 50 minutes.

E. What

The plan is summarized as below:

Risk Event	The Interviewee	Name (anonym)	Date	File Name (MP3)
1. Land unavailable	5th Division of BHSR	M1	11/06/07	110607_1.mp3
2. Resources unavailable	1st, 4th Division of BHSR	M2/M3	13/06/07	130607_2.mp3
3. Performance unavailability	1st, 4th Division of BHSR	M2/M4	15/06/07	150607_3.mp3
4. Scope changes	1st, 4th Division of BHSR	M5/M4	18/06/07	180607_4.mp3
5. Defective design	1st Division of BHSR	M6	19/06/07	190607_5.mp3
6. Design changes	1st Division of BHSR	M6	19/06/07	190607_6.mp3
7. Construction cost overrun	1st Division of BHSR	M2	21/06/07	210607_7.mp3
8. Construction delay	1st Division of BHSR	M2	21/06/07	210607_8.mp3

9.	Defective construction	2nd Division of BHSR	M7	19/06/07	190607_9.mp3
10.	Construction changes	2nd , 4th Division of BHSR	M7/M4	19/06/07	190607_10.mp3
11.	Complex system interface/ integration	3rd, 4th Division of BHSR	M8/M9	25/06/07	150607_11.mp3
12.	Failed commissioning tests	1st Division of BHSR	M6	26/06/07	260607_12.mp3
13.	Low operating productivity	4th Division of BHSR	M9	27/06/07	270607_13.mp3
14.	Mis-pricing	4th Division of BHSR	M10	27/06/07	270607_14.mp3
15.	Revenue loss	4th Division of BHSR	M10	27/06/07	270607_15.mp3
16.	System breakdown	3rd Division of BHSR	M8	28/06/07	280607_16.mp3
17.	High maintenance frequency	3rd Division of BHSR	M8	28/06/07	280607_17.mp3
18.	Accidents and safety issues	6th Division of BHSR	M11	02/07/07	020707_18.mp3
19.	Price escalation	1st, 4th Division of BHSR	M12/M10	03/07/07	030707_19.mp3
20.	Complex technologies	1st, 3rd Division of BHSR	M6/M8	04/07/07	040707_20.mp3
21.	Poor cooperation/ coordination	1st Division of BHSR	M12	05/07/07	050707_21.mp3
22.	Finance unavailable	1st, 4th Division of BHSR/ ICBC	M14/M10/M13	09/07/07	090907_22.mp3
23.	Refinancing liabilities	1st, 4th Division of BHSR/ ICBC	M14/M10/M13	10/07/07	100707_23.mp3
24.	Insolvency of contractor	1st, 4th Division of BHSR	M14/M10	10/07/07	100707_24.mp3
25.	Ownership change delay	1st, 4th Division of BHSR	M14/M15	10/07/07	100707_25.mp3
26.	Tax increases	4th Division of BHSR	M16	12/07/07	120707_26.mp3
27.	Insurance increases	4th Division of BHSR	M16	12/07/07	120707_27.mp3
28.	Contractual disputes	4th Division of BHSR	M15	16/07/07	160707_28.mp3
29.	Inflexible contract arrangements	4th Division of BHSR	M15	17/07/07	170707_29.mp3
30.	Delay in contract change negotiation	4th Division of BHSR	M15	17/07/07	170707_30.mp3
31.	Contract breach	4th Division of BHSR	M15	16/07/07	160707_31.mp3
32.	Contract remedies/penalties	4th Division of BHSR	M15	16/07/07	160707_32.mp3
33.	Default of subcontractor	1st, 4th Division of BHSR	M2/M15	18/07/07	180707_33.mp3
34.	Inspection and testing delay	1st, 4th Division of BHSR	M6/M9	19/07/07	100707_34.mp3
35.	Latent defect	4th Division of BHSR	M15	23/07/07	230707_35.mp3
36.	Shorter asset life	1st, 4th Division of BHSR	M2/M4	24/07/07	240707_36.mp3
37.	Less residual values	1st, 4th Division of BHSR	M2/M4	24/07/07	240707_37.mp3
38.	Termination liabilities	1st, 4th Division of BHSR	M14/M15	16/07/07	160707_38.mp3
39.	Higher level of inflation rate	1st Division of BHSR/ ICBC	M14/M17	25/07/07	250707_39.mp3
40.	Volatility of exchange rate	1st Division of BHSR/ ICBC	M14/M17	25/07/07	250707_40.mp3
41.	Higher level of interest rate	1st Division of BHSR/ ICBC	M14/M17	25/07/07	250707_41.mp3
42.	Variability of less demand	1st, 4th Division of BHSR/ ICBC	M14/M17	26/07/07	260707_42.mp3
43.	Higher competition	1st, 4th Division of BHSR/ ICBC	M14/M17	26/07/07	260707_43.mp3
44.	Downside economic events	1st, 4th Division of BHSR/ ICBC	M14/M17	26/07/07	260707_44.mp3
45.	Political interference	1st Division of BHSR	M18	30/07/07	300707_45.mp3
46.	Unsuitable regulatory policy	1st Division of BHSR	M18	31/07/07	310707_46.mp3
47.	Approval delays	1st Division of BHSR	M18	01/08/07	010807_47.mp3
48.	Law/policy changes	1st, 4th Division of BHSR	M18/M15	02/08/07	020807_48.mp3
49.	Unforeseen site conditions	2nd Division of BHSR	M19	06/08/07	060807_49.mp3
50.	Greater environmental expectation	6th Division of BHSR	M20	08/08/07	080807_50.mp3
51.	Industrial disputes	1st Division of BHSR	M18	09/08/07	090807_51.mp3
52.	Force Majeure	1st, 6th Division of BHSR	M21/M11	13/08/07	130807_52.mp3

Appendix III SD Model Variables and Parameters

A. Parameter values of the exogenous risk variables in SD model

Exogenous Risk Variables	Project Phase	Parameter Estimates
Default of subcontractors	Construction	Default of subcontractors C= RANDOM TRIANGULAR(8.36, 24.69 , 6.71 , 18.7 , 24.69 , 1234),Units: Dmnl
Default of subcontractor	Operation	Default of suncontractors O= RANDOM TRIANGULAR(8, 25 , 6.29 , 18.76 , 25 , 1234), Units: Dmnl
Downside economic events	Construction	Downside economic events C=RANDOM NORMAL(1, 25 , 18.14 , 4 , 1234), Units: Dmnl
Downside economic events	Operation	Downside economic events O=RANDOM NORMAL(1, 25 , 16.51 , 5.75 , 1234), Units: Dmnl
Force Majeure	Construction	Force Majeure C=RANDOM NORMAL(1, 25 , 18.27 , 4.96 , 1234), Units: Dmnl
Force Majeure	Operation	Force Majeure O=RANDOM TRIANGULAR(4, 25 , 2.5 , 17.5 , 25 , 1234), Units: Dmnl
Greater environmental expectation	Construction	Greater environmental expectation C=RANDOM NORMAL(1, 25 , 15.78 , 5.3 , 1234), Units: Dmnl
Greater environmental expectation	Operation	Greater environmental expectation O=RANDOM TRIANGULAR(5, 25 , 3.37 , 17.79 , 25 , 1234), Units: Dmnl
Latent defect	Construction	Latent defect C=RANDOM NORMAL(1, 25 , 15.89 , 3.91 , 1234), Units: Dmnl
Latent defect	Operation	Latent defect O=RANDOM NORMAL(1, 25 , 17.49 , 4.03 , 1234), Units: Dmnl
Political interference	Construction	Political interference C=RANDOM TRIANGULAR(2, 25 , 1 , 14.91 , 25 , 1234), Units: Dmnl
Political interference	Operation	Political interference O=RANDOM NORMAL(1, 25 , 8 , 4.1 , 1234), Units: Dmnl
Unforeseen site conditions	Construction	Unforeseen site conditions C=RANDOM NORMAL(1, 25 , 11.89 , 3.24 , 1234), Units: Dmnl
Variability of exchange rate	Construction/ Operation	Variability of exchange rate=RANDOM NORMAL(25.16, 34.58 , 30.73 , 3.34 ,1234), Units: Dmnl
Variability of inflation rate	Construction/ Operation	Variability of inflation rate=RANDOM TRIANGULAR(0, 0.09 , 0.02 , 0.0369 , 0.07 , 1234), Units: 1/Year
Variability of interest rate	Construction/ Operation	Variability of interest rate=RANDOM TRIANGULAR(0.01, 0.13 , 0.0175 , 0.067 , 0.07 , 1234), Units: 1/Year
Variability of less demand	Construction/ Operation	Variability of less demand=RANDOM NORMAL(-0.13, 0.71 , 0.166 , 0.32 , 0), Units: Dmnl
Variability of tax rate	Construction/ Operation	Variability of tax rate=RANDOM TRIANGULAR(0.15, 0.25 , 0.15 , 0.18 , 0.25 , 1234), Units: Dmnl
Equity fraction	Construction/ Operation	Equity fraction=0.3, Units: Dmnl

B. Parameter values of other variables in SD model
(There is a partial list for variable equations only)

"% Construction delay"[Proposal]=IF THEN ELSE(Time<=Actual construction completion time[Proposal], Construction delay[Proposal]/Scheduled total construction time, 0)Units: Dmnl

"% risk transfer"[Proposal]=0, 0.901, 0.812, 0.732, 0.602, Units: Dmnl

Accidents and safety issues[Proposal]=IF THEN ELSE(Time>VMAX(Risk adjusted construction completion time[workpackage!,Proposal]), 5.93+0.2*Force Majeure[Proposal]+0.253*Defective construction[Proposal]+0.104*"Complex system interface/integration"[Proposal]+0.0971*Resources unavailable[Proposal], 1)Units: Dmnl

Actual construction completion time[Proposal]=VMAX(Risk adjusted construction completion time[workpackage!,Proposal])Units: Year

Actual total construction time=VMAX(Risk adjusted construction completion time[workpackage!,Proposal!])-VMIN(Risk adjusted construction start time[workpackage!])Units: Year

Adjusted bidding cost of DEE control scheme[Base case]=Bidding cost of DEE control scheme[Base case]Adjusted bidding cost of DEE control scheme[Bid A]= Bidding cost of DEE control scheme[Base case]*(1-(Fraction of DEE risk transfer C[Bid A]+Fraction of DEE risk transfer O[Bid A])/2)+Bidding cost of DEE control scheme[Bid A]

Adjusted bidding cost of DEE control scheme[BidB]=Bidding cost of DEE control scheme[Base case]*(1-(Fraction of DEE risk transfer C[BidB]+Fraction of DEE risk transfer O[BidB])/2)+Bidding cost of DEE control scheme[BidB]

Adjusted bidding cost of DEE control scheme[BidC]=Bidding cost of DEE control scheme[Base case]*(1-(Fraction of DEE risk transfer C [BidC]+Fraction of DEE risk transfer O[BidC])/2)+Bidding cost of DEE control scheme[BidC]
Adjusted bidding cost of DEE control scheme[Bid D]=Bidding cost of DEE control scheme[Base case]*(1-(Fraction of DEE risk transfer C[Bid D]+Fraction of DEE risk transfer O[Bid D])/2)+Bidding cost of DEE control scheme[Bid D]Units: NT$

Adjusted bidding cost of DOS control scheme[Base case]=Bidding cost of DOS control scheme[Base case]

Adjusted bidding cost of DOS control scheme[Bid A]=Bidding cost of DOS control scheme[Base case]*(1-(Fraction of DOS risk transfer C [Bid A]+Fraction of DOS risk transfer O[Bid A])/2)+Bidding cost of DOS control scheme[Bid A]
Adjusted bidding cost of DOS control scheme[BidB]=Bidding cost of DOS control scheme[Base case]*(1-(Fraction of DOS risk transfer C[BidB]+Fraction of DOS risk transfer O[BidB])/2)+Bidding cost of DOS control scheme[BidB]

Adjusted bidding cost of DOS control scheme[BidC]=   Bidding cost of DOS control scheme[Base case]*(1-(Fraction of DOS risk transfer C[BidC]+Fraction of DOS risk transfer O[BidC])/2)+Bidding cost of DOS control scheme[BidC]

Adjusted bidding cost of DOS control scheme[Bid D]= Bidding cost of DOS control scheme[Base case]*(1-(Fraction of DOS risk transfer C[Bid D]+Fraction of DOS risk transfer O[Bid D])/2)+Bidding cost of DOS control scheme[Bid D]Units: NT$

Adjusted bidding cost of FM control scheme[Base case]=Bidding cost of FM control scheme[Base case]
Adjusted bidding cost of FM control scheme[Bid A]=Bidding cost of FM control scheme[Base case]*(1-(Fraction of FM risk transfer C[Bid A]+Fraction of FM risk transfer O[Bid A])/2)+Bidding cost of FM control scheme[Bid A]

Adjusted bidding cost of FM control scheme[BidB]=Bidding cost of FM control scheme[Base case]*(1-(Fraction of FM risk transfer C
[BidB]+Fraction of FM risk transfer O[BidB])/2)+Bidding cost of FM control scheme[BidB]
Adjusted bidding cost of FM control scheme[BidC]=Bidding cost of FM control scheme[Base case]*(1-(Fraction of FM risk transfer C[BidC]+Fraction of FM risk transfer O[BidC])/2)+Bidding cost of FM control scheme[BidC]

Adjusted bidding cost of FM control scheme[Bid D]=Bidding cost of FM control scheme[Base case]*(1-(Fraction of FM risk transfer C[Bid D]+Fraction of FM risk transfer O[Bid D])/2)+Bidding cost of FM control scheme[Bid D]Units: NT$

Adjusted bidding cost of GEE control scheme[Base case]=Bidding cost of GEE control scheme[Base case]

Adjusted bidding cost of GEE control scheme[Bid A]=Bidding cost of GEE control scheme[Base case]*(1-(Fraction of GEE risk transfer C[Bid A]+Fraction of GEE risk transfer O[Bid A])/2)+Bidding cost of GEE control scheme[Bid A]

Adjusted bidding cost of GEE control scheme[BidB]=Bidding cost of GEE control scheme[Base case]*(1-(Fraction of GEE risk transfer C [BidB]+Fraction of GEE risk transfer O[BidB])/2)+Bidding cost of GEE control scheme[BidB]

Adjusted bidding cost of GEE control scheme[BidC]=Bidding cost of GEE control scheme[Base case]*(1-(Fraction of GEE risk transfer C [BidC]+Fraction of GEE risk transfer O[BidC])/2)+Bidding cost of GEE control scheme[BidC]

Adjusted bidding cost of GEE control scheme[Bid D]=Bidding cost of GEE control scheme[Base case]*(1-(Fraction of GEE risk transfer C[Bid D]+Fraction of GEE risk transfer O[Bid D])/2)+Bidding cost of GEE control scheme[Bid D]Units: NT$

Adjusted bidding cost of LT control scheme[Base case]=Bidding cost of LT control scheme[Base case]

Adjusted bidding cost of LT control scheme[Bid A]=Bidding cost of LT control scheme[Base case]*(1-(Fraction of LT risk transfer C[Bid A]+Fraction of LT risk transfer O[Bid A])/2)+Bidding cost of LT control scheme[Bid A]

Adjusted bidding cost of LT control scheme[BidB]=Bidding cost of LT control scheme[Base case]*(1-(Fraction of LT risk transfer C[BidB]+Fraction of LT risk transfer O[BidB])/2)+Bidding cost of LT control scheme[BidB]

Adjusted bidding cost of LT control scheme[BidC]=Bidding cost of LT control scheme[Base case]*(1-(Fraction of LT risk transfer C[BidC]+Fraction of LT risk transfer O[BidC])/2)+Bidding cost of LT control scheme[BidC]

Adjusted bidding cost of LT control scheme[Bid D]=Bidding cost of LT control scheme[Base case]*(1-(Fraction of LT risk transfer C[Bid D]+Fraction of LT risk transfer O[Bid D])/2)+Bidding cost of LT control scheme[Bid D]Units: NT$

Adjusted bidding cost of PI control scheme[Base case]=Bidding cost of PI control scheme[Base case]

Adjusted bidding cost of PI control scheme[Bid A]=Bidding cost of PI control scheme[Base case]*(1-(Fraction of PI risk transfer C[Bid A]+Fraction of PI risk transfer O[Bid A])/2)+Bidding cost of PI control scheme[Bid A]

Adjusted bidding cost of PI control scheme[BidB]=Bidding cost of PI control scheme[Base case]*(1-(Fraction of PI risk transfer C[BidB]+Fraction of PI risk transfer O[BidB])/2)+Bidding cost of PI control scheme[BidB]

Adjusted bidding cost of PI control scheme[BidC]=Bidding cost of PI control scheme[Base case]*(1-(Fraction of PI risk transfer C[BidC]+Fraction of PI risk transfer O[BidC])/2)+Bidding cost of PI control scheme[BidC]

Adjusted bidding cost of PI control scheme[Bid D]=Bidding cost of PI control scheme[Base case]*(1-(Fraction of PI risk transfer C[Bid D]+Fraction of PI risk transfer O[Bid D])/2)+Bidding cost of PI control scheme[Bid D]Units: NT$

Appendix IV Questionnaire Survey Plan and Risk Meausurement Mechanism

A. Questionnaire survey plan

1. Why

The questionnaire survey will be conducted to measure risk effects. The purposes of questionnaire survey are: first, quantify risk effects by project experts; second, consistently scale the expected risk effect for each risk event; third, quantify the interrelationships between risk variables and infer the probability distribution for the input risk variables of a risk cost network modelling by statistic analysis.

2. Who

The main target respondents are the senior members of public sector 'Bureau of High Speed Rail: BHSR' for THSR project. These respondents include expertise from a cross section of disciplines and stakeholders that covers all area of interest on the risk events for THSR project described in Chapter 6. They had ever participated in THSR project and have wide experiences on mass transit projects that are similar to THSR project, which include: project manager and project team, discipline engineers, commercial specialists, safety and environmental specialists, contract managers, etc. In addition, the financial institute 'International Commercial Bank of China (ICBC)' that provided project financing for THSR is also one of the target respondents. The organisations for questionnaire survey include:

- The 1st Division of BHSR (function: design and supervision)
- The 2nd Division of BHSR (function: civic engineering)
- The 3rd Division of BHSR (function: mechanical/electrical engineering)
- The 4th Division of BHSR (function: contract performance)
- The 5th Division of BHSR (function: land acquisition)
- The 6th Division of BHSR (function: safety and environment)
- ICBC (function: project financing)

The liaise and coordinator is Mrs Chung/BHSR: Email: public@nthsr1.hsr.gov.tw; Tel# 886-2-8072-3333 ext 8632, who agreed to assist the researcher to dispatch questionnaires to the members of the above organizations and to collect them back to the researcher.

3. How

The questionnaire survey was conducted by the following procedure:

1. The questionnaire will be sent out to the liaise and coordinator, Mrs Chung/BHSR. She will print out the questionnaire and dispatch about 60-70 copies of questionnaire to the respondents.
2. The liaise and coordinator, Mrs Chung/BHSR will collect the questionnaires back by the deadline of survey period, and then send them back to the researcher by airmail.
3. The questionnaire is designed with 'Questionnaire Instructions' before starting to answer questions. The liaise and coordinator, Mrs Chung/BHSR, would also help the respondents with how to answer the question. Moreover, the researcher leaves email and Skype contacts for question inquiry.
4. Without a clear standardised-definition, the sampled data for risk effect gathered from respondents would be inconsistent so that it would likely to mislead data interpretation. To reduce ambiguity and inconsistency, which is the 'measurement error' in statistical term that means the discrepancy between the respondents' response mean and the sample true mean (Groves et al., 2004), the Table 1 'The Reference Matrix for Rating Risk Effects', Table 2 'The Definition of Measure Dimensions for Risk Likelihood and Impact', and Table 3 'The Definition of Risk Events' are attached to the questionnaire so that the respondents would have clear definitions to complete the questionnaire.
5. There are 34 risk variables listed in questionnaire for rating the expected risk effects.
6. To meet a meaningful statistically large-sample condition (Anderson et al., 2002), 30-35 valid samples are expected to be returned for the research. The respondents who have working experience more than 5 years in a transit project are senior staff in public sector BHSR so that it is reasonable to think they can make more sensible decision than the junior staff that have working experience less than 3 years to estimate THSR project risks. If the research can gather more than 30 samples from the respondents who have more than 5-year working experience, then the samples collected from the respondents who have working experience less than 3 years will be screened out of analysis.

4. When

The questionnaire survey will be conducted from 12th of Nov, 2007 to 30th of Nov, 2007. Each respondent was given 2 weeks to complete the questionnaire by 25th of Nov. An additional 1 week will be given to those respondents who have not responded within the survey period.

5. What

The questionnaire is designed as below.

Part A: The Questionnaire Instructions

- This form would enable us to consistently measure and quantify the expected risk effect for Taiwan High Speed Rail project.
- 1 to 25 rating scale is used to estimate risk effects.
- Please refer to the attached Table 1: 'The Reference Matrix for Rating Risk Effect, which is used to guide the respondents to rate risk effect. The expected risk effect is defined by the 'Impact' and 'Likelihood' of a risk event. There are 5 dimensions for Impact (the vertical dimension of matrix) and Likelihood (the horizontal dimension of matrix) respectively, which is categorised as 'Very Low' 'Low' 'Medium' 'High' and 'Very High.' For example, if a risk event is perceived to have 'Very High' impact and 'Medium' likelihood, then two dimensions are intersected at '21'. That is the risk effect for a specific risk event is 21.
- The 5-dimension for Impact and Likelihood is defined as Table 2.
- The definition for each risk event is listed in Table 3.
- Please refer to the attached Table 1-3, basing on your own perception of a risk effect on the THSR project, answer each question listed in Part B. Please check a proper rating for risk effect of a risk event.
- If you have any question about this questionnaire, please feel free to contact the researcher at email: jang_steve@yahoo.com or Skype: jang_steve.

Part B: The Questions

- ***Your background***

Please provide the following information about yourself:

1. Organisation in which you service:
   ☐ The 1st Division of BHSR (function: design and supervision)
   ☐ The 2nd Division of BHSR (function: civic engineering)
   ☐ The 3rd Division of BHSR (function: mechanical/electrical engineering)
   ☐ The 4th Division of BHSR (function: contract performance)
   ☐ The 5th Division of BHSR (function: land acquisition)
   ☐ The 6th Division of BHSR (function: safety and environment)
   ☐ ICBC (function: project financing)

2. What is your job position:
   ☐ Senior manager
   ☐ Manager
   ☐ Senior engineer
   ☐ Engineer
   ☐ Other; please specify:

3. Number of years of working experience in a mass transit project including Taiwan High Speed Rail project:
   ☐ Less than 3 years
   ☐ 3 years to 5 years
   ☐ More than 5 years

- ***Rating risk effects***

1. Basing on the definitions described in the attached Table 1-3, what is the expected risk effect (1-25) of the risk event ‘***land unavailable***’ at Construction phase?

I	Construction Phase				
VH	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)
H	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)
M	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)
L	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)
VL	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)
L	VL	L	M	H	VH

2. Basing on the definitions described in the attached Table 1-3, what is the expected risk effect (1-25) of the risk event ‘***resource unavailable***’ at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	VH
H	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	H
M	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	M
L	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	L
VL	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	VL
L	VL	L	M	H	VH	VL	L	M	H	VH	L

3. Basing on the definitions described in the attached Table 1-3, what is the expected risk effect (1-25) of the risk event ‘***scope change***’ at Construction phase and Operation?

I	Construction Phase					Operation Phase					I
VH	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	VH
H	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	H
M	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	M
L	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	L
VL	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	VL
L	VL	L	M	H	VH	VL	L	M	H	VH	L

4. Basing on the definitions described in the attached Table 1-3, what is the expected risk effect (1-25) of the risk event ‘***defective design***’ at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	VH
H	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	H
M	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	M
L	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	L
VL	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	VL
L	VL	L	M	H	VH	VL	L	M	H	VH	L

5. Basing on the definitions described in the attached Table 1-3, what is the expected risk effect (1-25) of the risk event ‘***design changes***’ at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	VH
H	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	H
M	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	M
L	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	L
VL	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	VL
L	VL	L	M	H	VH	VL	L	M	H	VH	L

6. Basing on the definitions described in the attached Table 1-3, what is the expected risk effect (1-25) of the risk event '***defective construction***' at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	VH
H	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	H
M	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	M
L	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	L
VL	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	VL
L	VL	L	M	H	VH	VL	L	M	H	VH	L

7. Basing on the definitions described in the attached Table 1-3, what is the expected risk effect (1-25)of the risk event '***construction changes***' at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	VH
H	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	H
M	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	M
L	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	L
VL	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	VL
L	VL	L	M	H	VH	VL	L	M	H	VH	L

8. Basing on the definitions described in the attached Table 1-3, what is the expected risk effect (1-25) of the risk event '***complex system interface/integration***' at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	VH
H	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	H
M	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	M
L	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	L
VL	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	VL
L	VL	L	M	H	VH	VL	L	M	H	VH	L

9. Basing on the definitions described in the attached Table 1-3, what is the expected risk effect (1-25) of the risk event '***failed commissioning tests***' at Construction phase?

I	Construction Phase				
VH	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)
H	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)
M	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)
L	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)
VL	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)
L	VL	L	M	H	VH

10. Basing on the definitions described in the attached Table 1-3, what is the expected risk effect (1-25) of the risk event '***low operating productivity***' at Operation phase?

Operation Phase					I
(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	VH
(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	H
(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	M
(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	L
(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	VL
VL	L	M	H	VH	L

11. Basing on the definitions described in the attached Table 1-3, what is the expected risk effect (1-25) of the risk event '***system breakdown***' at Operation phase?

Operation Phase					I
(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	VH
(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	H
(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	M
(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	L
(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	VL
VL	L	M	H	VH	L

12. Basing on the definitions described in the attached Table 1-3, what is the expected risk effect (1-25) of the risk event '***high maintenance frequency***' at Operation phase?

Operation Phase					I
(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	VH
(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	H
(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	M
(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	L
(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	VL
VL	L	M	H	VH	L

13. Basing on the definitions described in the attached Table 1-3, what is the expected risk effect (1-25) of the risk event '***accidents and safety issues***' at Operation phase?

Operation Phase					I
(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	VH
(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	H
(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	M
(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	L
(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	VL
VL	L	M	H	VH	L

14. Basing on the definitions described in the attached Table 1-3, what is the expected risk effect (1-25) of the risk event '***complex technologies***' at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	VH
H	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	H
M	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	M
L	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	L
VL	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	VL
L	VL	L	M	H	VH	VL	L	M	H	VH	L

15. Basing on the definitions described in the attached Table 1-3, what is the expected risk effect (1-25) of the risk event '***poor cooperation/coordination***' at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	VH
H	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	H
M	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	M
L	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	L
VL	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	VL
L	VL	L	M	H	VH	VL	L	M	H	VH	L

16. Basing on the definitions described in the attached Table 1-3, what is the expected risk effect (1-25) of the risk event '***finance unavailable***' at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	VH
H	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	H
M	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	M
L	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	L
VL	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	VL
L	VL	L	M	H	VH	VL	L	M	H	VH	L

17. Basing on the definitions described in the attached Table 1-3, what is the expected risk effect (1-25) of the risk event '***insolvency of contractor***' at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	VH
H	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	H
M	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	M
L	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	L
VL	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	VL
L	VL	L	M	H	VH	VL	L	M	H	VH	L

18. Basing on the definitions described in the attached Table 1-3, what is the expected risk effect (1-25)t of the risk event '***ownership change delay***' at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	VH
H	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	H
M	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	M
L	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	L
VL	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	VL
L	VL	L	M	H	VH	VL	L	M	H	VH	L

19. Basing on the definitions described in the attached Table 1-3, what is the expected risk effect (1-25) of the risk event '***contractual disputes***' at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	VH
H	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	H
M	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	M
L	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	L
VL	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	VL
L	VL	L	M	H	VH	VL	L	M	H	VH	L

20. Basing on the definitions described in the attached Table 1-3, what is the expected risk effect (1-25) of the risk event '***inflexible contract arrangement***' at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	VH
H	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	H
M	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	M
L	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	L
VL	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	VL
L	VL	L	M	H	VH	VL	L	M	H	VH	L

21. Basing on the definitions described in the attached Table 1-3, what is the expected risk effect (1-25) of the risk event '***delay in contract change negotiation***' at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	(☐ 17	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	VH
H	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	H
M	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	M
L	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	L
VL	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	VL
L	VL	L	M	H	VH	VL	L	M	H	VH	L

22. Basing on the definitions described in the attached Table 1-3, what is the expected risk effect (1-25) of the risk event '***contract breach***' at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	VH
H	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	H
M	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	M
L	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	L
VL	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	VL
L	VL	L	M	H	VH	VL	L	M	H	VH	L

23. Basing on the definitions described in the attached Table 1-3, what is the expected risk effect (1-25) of the risk event '***default of subcontractor***' at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	VH
H	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	H
M	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 17)	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	M
L	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	L
VL	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	VL
L	VL	L	M	H	VH	VL	L	M	H	VH	L

24. Basing on the definitions described in the attached Table 1-3, what is the expected risk effect (1-25) of the risk event '***latent defect***' at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	VH
H	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	H
M	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	M
L	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	L
VL	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	VL
L	VL	L	M	H	VH	VL	L	M	H	VH	L

25. Basing on the definitions described in the attached Table 1-3, what is the expected risk effect (1-25) of the risk event '***shorter asset life***' at Operation phase?

Operation Phase					I
(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	VH
(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	H
(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	M
(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	L
(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	VL
VL	L	M	H	VH	L

26. Basing on the definitions described in the attached Table 1-3, what is the expected risk effect (1-25) of the risk event ‘***downside economic events***’ at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	VH
H	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	H
M	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	M
L	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	L
VL	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	VL
L	VL	L	M	H	VH	VL	L	M	H	VH	L

27. Basing on the definitions described in the attached Table 1-3, what is the expected risk effect (1-25) of the risk event ‘***political interference***’ at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	VH
H	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	H
M	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	M
L	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	L
VL	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	VL
L	VL	L	M	H	VH	VL	L	M	H	VH	L

28. Basing on the definitions described in the attached Table 1-3, what is the expected risk effect (1-25) of the risk event ‘***unsuitable regulatory policy***’ at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	VH
H	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	H
M	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	M
L	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	L
VL	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	VL
L	VL	L	M	H	VH	VL	L	M	H	VH	L

29. Basing on the definitions described in the attached Table 1-3, what is the expected risk effect (1-25) of the risk event ‘***approval delay***’ at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	VH
H	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	H
M	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	M
L	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	L
VL	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	VL
L	VL	L	M	H	VH	VL	L	M	H	VH	L

30. Basing on the definitions described in the attached Table 1-3, what is the expected risk effect (1-25) of the risk event ‘***law/policy changes***’ at Construction phase and Operation phase)?

I	Construction Phase					Operation Phase					I
VH	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	VH
H	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	H
M	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	M
L	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	L
VL	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	VL
L	VL	L	M	H	VH	VL	L	M	H	VH	L

31. Basing on the definitions described in the attached Table 1-3, what is the expected risk effect (1-25)of the risk event '***unforeseen site conditions***' at Construction phase?

I	Construction Phase				
VH	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)
H	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)
M	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)
L	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)
VL	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)
L	VL	L	M	H	VH

32. Basing on the definitions described in the attached Table 1-3, what is the expected risk effect (1-25) of the risk event '***greater environmental expectation***' at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	VH
H	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	H
M	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	M
L	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	L
VL	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	VL
L	VL	L	M	H	VH	VL	L	M	H	VH	L

33. Basing on the definitions described in the attached Table 1-3, what is the expected risk effect (1-25) of the risk event '***industrial disputes***' at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	VH
H	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	H
M	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	M
L	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	L
VL	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	VL
L	VL	L	M	H	VH	VL	L	M	H	VH	L

34. Basing on the definitions described in the attached Table 1-3, what is the expected risk effect (1-25) of the risk event '***Force Majeure***' at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	(☐ 17)	(☐ 19)	(☐ 22)	(☐ 24)	(☐ 25)	VH
H	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	(☐ 15)	(☐ 18)	(☐ 20)	(☐ 21)	(☐ 23)	H
M	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	(☐ 9)	(☐ 12)	(☐ 13)	(☐ 14)	(☐ 16)	M
L	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	(☐ 3)	(☐ 6)	(☐ 8)	(☐ 10)	(☐ 11)	L
VL	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	(☐ 1)	(☐ 2)	(☐ 4)	(☐ 5)	(☐ 7)	VL
L	VL	L	M	H	VH	VL	L	M	H	VH	L

Table 1 The Reference Matrix for Rating Risk Effect

IMPACT (I) \ LIKELIHOOD (L)	Very Low (VL)	Low (L)	Medium (M)	High (H)	Very High (VH)
Very High (VH)	17	19	22	24	25
High (H)	15	18	20	21	23
Medium (M)	9	12	13	14	16
Low (L)	3	6	8	10	11
Very Low (VL)	1	2	4	5	7

Table 2 The Definition of Measure Dimensions for Risk Likelihood and Impact

Dimensions	Likelihood	Impact
Very High	Is expected to occur	It would cause major cost overrun; schedule would be hopelessly lost with no chance of recovery; performance degradation is such that the system or facility is unusable.
High	Will probably occur in most instances.	It would cause the budgeted cost estimates increased substantially; major slippage to delivery milestones; performance degradation has substantial impact on outcome and would severely degrade capability if not corrected.
Medium	Might occur at some time.	It would cause budgeted cost estimates increased noticeably and may be manageable within current contingency; some slippage to delivery milestones; performance degradation has noticeable effect on outcome and may be at the limit of acceptability.
Low	May occur but only in exceptional circumstances.	It would cause budgeted cost estimates increased slightly; minor slippage to delivery milestones; minor reduction in performance degradation but tolerable.
Very Low	Not likely to occur.	Budgeted cost estimates won't exceed; no overall change to delivery milestones; negligible impact on performance anticipated; reduction in performance degradation but tolerable.

Table 3 The Definition of Risk Events

Risk Event	Definition
1. Land unavailable	The term 'land unavailable' refers to the risk of costs and delays arising from acquiring lands for infrastructure construction.
2. Resources unavailable	The term 'resources unavailable' refers to the possibility that the quantity or quality of the material resources such as equipment, facilities or materials, etc., the manpower resources such as manager, engineers, etc., and the energy resources such as water, power, gas, etc., cannot meet contract requirements so that they are unavailable for construction and/or operation.
3. Performance unavailable	The term 'performance unavailable' refers to the possibility that the performance of asset are delayed or disrupted to deliver services set up in the output specifications.
4. Scope changes	The term 'scope changes' refer to the risk that the originally agreed scope of work definition is changed after contracting signing whether pre or post commissioning, which will lead to additional costs and time delay.
5. Defective design	The term 'defective design' refers to the risk that the design of facility does not achieve the required output specifications.
6. Design changes	The term 'design changes' refers to the risk that the changes of originally agreed design or the correction of the defective design lead to additional costs and time delay.
7. Defective construction	The term "defective construction" refers to the equipment, system or facility cannot meet the construction standards and requirements.
8. Construction changes	The term 'construction changes' refers to the equipment, system or infrastructure need to be remedied or reworked due to construction defects or design changes.
9. Complex system interface/integration	The 'complex system interface/integration' refers to the designed and constructed infrastructure is unable to interface with or incompatible with other public systems, which may need the structural changes to design and construction work. As a result, it leads to the substantial cost overrun and delivery delay at construction phase. Even though it is able to interface with or compatible with the other public sector systems, it may lead to large upgrade and maintenance costs at operation phase.
10. Failed commissioning tests	The 'failed commissioning tests' refers to the risk that either the physical or the operational commissioning tests which are required to be completed for the provision of services to commence, cannot be successfully completed or acceptable by the agreed date.
11. Low operating productivity	The 'low operating productivity' refers to the risk that the system operating productivity is lower than the output specifications.
12. System breakdown	The 'system breakdown' refers to the possibility that the system or facility cannot work, which leads to unexpected costs and additional time for services delivery.
13. High maintenance frequency	The 'high maintenance frequency' refers to the risk that the additional cost and time delay to deliver services because the mean-time-between-repairs cannot meet the service output requirements.
14. Accidents and safety issues	The 'accidents and safety issues' refers to the risk that the loss and time delay to deliver services due to the frequent accidents and safety issues which cannot meet the service output requirements.
15. Complex technologies	The 'complex technologies' refers to the risks that the selected technology used for engineering or services is technically complex or expensive to maintain, or market volatility results in early obsolescence, or not innovated enough to keeping pace with competition and/or public requirements.
16. Poor cooperation and coordination	The 'poor cooperation and coordination' refers to the risk that the cooperation and coordination within a party and among different industrial parties including public party, private party and third parties cannot work well over contracting periods, which may lead to inefficient project performance and time delay at construction and operation phase.
17. Insolvency of contractor	The 'insolvency of contractor' refers to the possibility of the insolvency of private party that it is unable to provide the required services.
18. Ownership change delay	The 'ownership change delay' refers to the risk that a change in ownership would need additional time that would result in project performance delay.
19. contractual disputes	The 'contractual disputes' refers to the risk of time delay and additional costs to solve contractual disputes.
20. Inflexible contract arrangement	The 'inflexible contract arrangement' refers to the risk of time delay and additional costs to change the contract contents due to inflexible contract

	change mechanism.
21. Delay in contract change negotiation	The 'delay in contract change negotiation' refers to the risk of time delay to negotiate and arrange contract changes between the government authority and project contractor.
22. Contract break	The 'contract break' refers to the risk of time delay and additional costs arising from being failed in meeting contract requirements.
23. Default of subcontractors	The 'default of subcontractors' refers to the risk of subcontractors/suppliers or service providers go out of business or encounter difficulties in supplying the contracted services to specification through the required life of the capability due to insolvency or incapability, which leads to the construction risks or operation risks.
24. Latent defects	The 'latent defects' refers to the possibility of loss or damage arising from latent defects within existing infrastructure that infringe the patents held by the third parties.
25. Shorter asset life	The 'shorter asset life' refers to the risk that design life of the facility proves to be shorter than the planned, which lead to additional cost of upgrade.
26. Downside economic events	The 'downside economic events' refers to the possibility that the demand for the services generated by a project may be less than projected due to the impact of specific downside economic events, which results in revenue below projections.
27. Political interference	The 'political interference' refers to the possibility of unforeseeable conduct by the political parties that materially and adversely affect the public decision-making process or project implementation.
28. Unsuitable regulatory policy	The 'unsuitable regulatory policy' refers to the possibility that the public regulatory policies do not reflect project investment expectations or do not reflect the public interests.
29. Approve delays	The 'approve delays' refers to the delays to obtain the consents from each the government authorities. If obtained, the additional cost and time are required.
30. Low/policy changes	The 'low/policy changes' refers to the risk of a change in law/policy will lead to the additional cost and time to comply with the change.
31. Unforeseen site conditions	The 'unforeseen site conditions' refers to the unanticipated adverse site conditions such as unusual surface condition of geology and ground water are discovered, which will lead to additional construction time and cost.
32. Greater environmental expectation	The 'greater environmental expectation' refers to the possibility of greater environmental protection expectation on air, water and noise at the level which is greater than that of original environmental regulations and contract requirements.
33. Industrial disputes	The 'industrial disputes' refers to the risk of strikes, industrial action, civil commotion, or public protests causing delay and cost to the project.
34. Force Majeure	The 'Force Majeure' refers to the possibility of occurrence of naturally unexpected events like earthquake, storm, flood, etc. or man-made events like war, and fire that are beyond the control of both public and private parties which may affect the construction or operation of the project.

Part C: The Results

There were 43 questionnaires in total received by the 14th of December 2007, which includes 13 copies from those respondents who have working experience more than 5 years; 24 copies from those who have working experience between 3 years to 5 years; 6 copies from those who have working experience less than 3 years. As stated above, the samples obtained from those who have working experience less than 3 years will be screened out. Therefore, there are 37 valid samples as the Table 4 for construction phase and Table 5 for operation phase.

Table 4 The Sample Data for the Expected Risk Effect on Construction Phase

greater environmental expectation	default of subcontractor	latent defect	downside economic events	political interference	unforeseen site conditions	Force Majeure
12	17	18	11	5	6	21
15	20	24	22	20	12	14
12	22	20	9	12	7	19
16	21	10	19	17	14	20
13	23	16	11	21	12	21
16	19	12	19	15	13	22
23	19	19	17	22	18	19
17	21	13	17	19	11	22
17	18	13	18	13	12	24
24	17	16	16	16	17	17
19	20	12	23	8	14	18
23	24	17	15	11	14	21
15	16	11	16	18	14	17
14	24	14	13	22	12	19
20	18	13	20	23	11	23
22	16	19	20	20	15	16
13	10	11	24	10	13	24
22	21	7	18	10	13	16
25	18	15	18	18	8	23
20	15	21	16	20	15	11
10	25	9	12	6	16	13
14	22	17	19	9	15	20
15	21	14	22	8	11	25
18	23	21	14	19	19	20
8	22	14	21	15	12	23
21	23	15	20	14	4	13
9	23	16	20	17	13	20
21	13	17	17	14	11	16
19	23	14	22	2	10	14
11	20	23	23	12	8	22
18	24	15	25	23	10	11
6	14	18	14	13	10	24
4	24	21	21	11	9	3
11	11	20	22	25	10	18
18	25	17	24	15	9	24
7	22	18	15	16	13	15
16	19	18	18	17	9	8

Table 5 The Sample Data for the Expected Risk Effect on Operation Phase

Force Majeure	default of subcontractor	latent defect	downside economic events	political interference	greater environmental expectation
20	23	20	21	5	10
19	16	15	21	9	19
23	15	24	21	10	7
17	24	14	23	4	21
21	25	22	13	3	16
20	16	19	12	7	22
23	24	22	13	5	20
11	18	10	18	2	19
25	19	12	22	10	24
16	21	15	14	16	19
21	15	15	14	8	13
18	17	15	11	2	18
19	24	20	16	18	15
24	8	12	24	9	15
14	18	16	15	11	24
23	12	8	22	4	24
19	10	17	16	11	23
22	22	18	17	12	22
12	21	13	8	6	22
12	13	17	24	13	23
9	22	14	24	8	23
4	23	16	12	11	20
24	23	18	15	3	13
22	21	23	10	5	18
22	13	18	6	8	14
17	11	19	20	7	21
14	18	23	9	14	12
15	20	20	2	4	11
21	22	21	18	6	25
7	19	19	19	7	20
18	20	21	20	6	14
13	19	20	25	1	16
24	22	17	19	9	21
16	17	21	7	12	16
18	14	12	23	7	5
17	17	16	19	8	17
15	20	25	18	15	17

B. Risk measurement mechanism

The researcher proposed a "univariate" mechanism that it used a risk matrix for the conversion of the 2 dimensional measures of likelihood and impact into a single measure of risk with 1 to 25 ordinal numerical scales. There are two-dimension categorical data found in 'Impact' and 'Likelihood' in the risk matrix. The vertical dimension is Impact, which is categorized from *Very Low* (VL) to *Very High* (VH). The horizontal dimension is Likelihood, which is categorized from *Very Low* (VL) to (VH), too. Combining impact and likelihood data, there are 25 qualitative scales (categorical data) used to define and describe the risk effect shown in Table 1. These are then transformed into ordinal numerical scales for use as indicators to rate relative risk effect in the questionnaire survey.

The thesis research employed the method as advocated by Cooper et al. (2005) to transform 25 qualitative scales to 25 ordinal numerical scales:

(1) Cooper et al. (2005) defined the risk factor (RF*)* from 0 (*low*) to 1*(high*) which reflect the likelihood of a risk arising and the severity of its impact. One of ways to calculate risk factors is formula of the product of the likelihood and consequence measures:

$$RF=P*C$$

Where P = risk likelihood measure, on a scale of 0 to 1;
Where C = consequence measure, on a scale of 0 to 1.

(2) To represent the risk characteristics of Taiwan High Speed Rail project, the qualitative likelihood and impact scales should be converted to suitable numerical scales to calculate RF. After consulting with some of the project experts in BHSR, 1-9 and 5-1000 were used to respectively weigh qualitative likelihood and impact. As shown in Table 6, the qualitative likelihood scales from VL to VH are converted to 1-9 ordinal points. The product formula shown in (1) has one significant disadvantage that high impact but low likelihood may make it unwise to be allocated low risk factors (Cooper et al., 2005). For example, a catastrophic earthquake is a rare occurrence in Taiwan. But once it happens, it would have serious impact on the Taiwan High Speed Rail. Hence, to reduce this risk, a large range of scale with 5-1000 ordinal points was used to convert qualitative impact scales from VL to VH. The higher level of impact scales such as VH and H will have more weighted numerical points. For consistently comparative results, the numerical scales were normalized to a scale of 0 to 1 (Goodwin & Wright, 2004).

(3) With the product of normalized impact and likelihood scales, the 25 RF values for 25 qualitative scales in the 5 x 5 risk matrix were calculated as shown in Table 6.

(4) Based on the ranking of RF values, the 25 qualitative scales (categorical data) were thus transformed into 1-25 ordinal numerical scales (ordinal data) as shown in Table 7. If there is a tie, then following the logic described in (2) that the higher level of impact scales would have more weight so would have higher ranks is helpful.

(5) As a result, the procedure from (1) to (4) is exactly the logic for how the two-dimension categorical data were converted to a one-dimension ordinal data as shown in Table 1.

Table 6 RF Values in the Risk Matrix30

Normalized	Numerical	**Impact**	**RF**					
0.5479452	1000	**VH**	0.0228311	0.045662	0.1141553	0.1598174	0.205479	
0.3835616	700	**H**	0.0159817	0.031963	0.0799087	0.1118721	0.143836	
0.0547945	100	**M**	0.0022831	0.004566	0.0114155	0.0159817	0.020548	
0.0109589	20	**L**	0.0004566	0.000913	0.0022831	0.0031963	0.00411	
0.0027397	5	**VL**	0.0001142	0.000228	0.0005708	0.0007991	0.001027	
1	**1825**		**VL**	**L**	**M**	**H**	**VH**	**Likelihood**
		Numerical	1	2	5	7	9	24
		Normalized	**0.0416667**	**0.083333**	**0.2083333**	**0.2916667**	**0.375**	**1**

Table 7 Converting the Descriptive Scales to the Ordinal Numeric Scales3

Descriptive scales (Impact, Likelihood)	RF	Ordinal numerical scales
(VH,VH)	0.2054	25
(VH,H)	0.1598	24
(H,VH)	0.1438	23
(H,H)	0.1141	22
(VH,M)	0.1118	21
(H,M)	0.0799	20
(VH,L)	0.0456	19
(H,L)	0.0319	18
(VH,VL)	0.0228	17
(M,VH)	0.0205	16
(H,VL)	0.0159	15
(M,H)	0.0159	14
(M,M)	0.0114	13
(M,L)	0.0045	12
(L,VH)	0.0041	11
(L,H)	0.0031	10
(M,VL)	0.0022	9
(L,M)	0.0022	8
(VL,VH)	0.001	7
(L,L)	0.0009	6
(VL,H)	0.0007	5
(VL,M)	0.0005	4
(L,VL)	0.0004	3
(VL,L)	0.0002	2
(VL,VL)	0.0001	1

Appendix V The Analysis of CLD

V1. Land unavailable

The term, *land unavailable*, refers to the risk costs and delays arising from acquiring lands for infrastructure construction. As shown in Figure V1, the land unavailable risk event would cause construction delay due to the fact that there is no land available on which to start building an infrastructure (Hodge, 2004; Lu, 2004; The Work Bank, 1999). The construction delay would be likely to further cause the construction cost overrun risk event since the extra costs were incurred during maintenance of the purchased materials and equipment and paying for manpower during the construction time delay. Furthermore, the construction cost overrun risk event could possibly lead to finance unavailable risk event due to the risk of running out of money and having to borrow more money from other financial institutes. Consequentially, the unavailability of land would create a vicious circle (the positive loop 1) of more resources unavailable, more construction delays and more cost overruns. The construction delay also leads to the performance unavailable risk that the infrastructure will not be available for operation, thus resulting in revenue loss. In general, land unavailable risk would cause dynamic feedback effects on construction cost overruns during the construction phase and also on revenue loss during the operation phase respectively.

The land unavailable risk would likely be triggered by the industrial disputes risk event that would result should residents protest against the unsatisfied land acquisition costs or the environment and ecology impact (Hodge, 2004; Lu, 2004; The Work Bank, 1999).

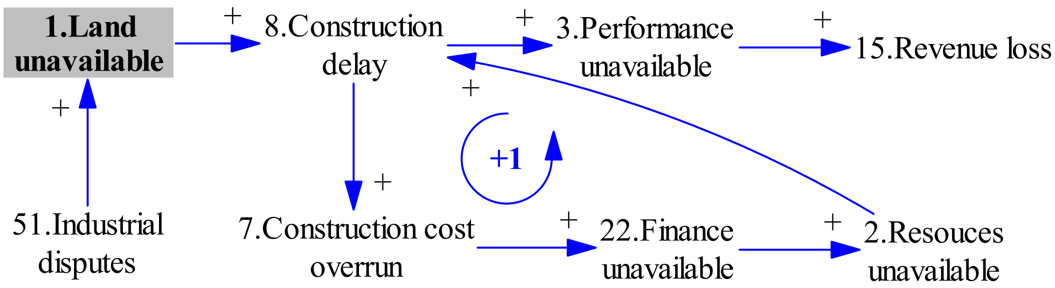


Figure V1 Causal Loop Diagram for 'Land Unavailable' Risk Event

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. as a BOOT contract for the City Link road infrastructure project in Melbourne. It was one of the Australia's largest public BOOT infrastructure projects, costing AUD$2.1 billion. Due to delays for land available by the agreed date, the government authority was liable for costs associated with those delays incurred by project contractor, Transurban, (Hodge, 2004). In addition, Lu (2004) in the Yangtze Three Gorges Project (China) indicated that this lead to delays in project progress due to expensive land acquisition and difficult resident relocation. The Work Bank's report (Work Bank, 1999) also reflected that the PPP contract for the Bangkok Second Stage Expressway had the same problem in that the government authority transferred the land too late to the project contractor, Bangkok Expressway Company Limited (BECL) due to the land acquisition difficulties.

V2. Resources unavailable

The term, resources unavailable, refers to the possibility that the quantity or quality of the material resources of equipment, facilities or materials, and the like, the manpower resources such as manager, engineers, and the like, and the energy resources such as water, power, gas, and the like cannot meet contract requirements, and therefore are unavailable for construction and/or operation.

As shown in Figure V2, the resources unavailable risk event would cause construction delays due to inadequate quantity and quality of manpower, materials and equipment for building infrastructure (NAO, 2004a; Work Bank, 1999). The construction delays would likely cause construction cost overruns risk event since the extra costs were incurred while maintaining the purchased materials, equipment and paying for the recruited manpower during the construction time delay. Furthermore, the construction cost overrun risk would possibly result in the finance unavailable risk due to expenditure of money borrowed from the financial institutes. This would likely cause the event of resources unavailable due to insufficient funds for manpower, materials and equipment required to build infrastructure. Consequently, it would create a vicious circle (the positive loop 1) to cause more risk in construction delay and construction cost overrun. The construction delay would also result in performance unavailable because the infrastructure would not be ready to deliver its services. This would lead to revenue loss, with not enough credit to repay the debt, which will result in financial unavailable. Consequently, it would create a vicious circle (the positive loop 2) to cause yet again more risk in resources unavailable so that performance unavailable resulting in more revenue loss. At the operation stage, the resources unavailable risk event would directly cause low operating productivity event due to inadequate quantity and quality of manpower, materials and equipment which are required to deliver its services efficiently (NAO, 2004a; PAC, 2005b). It would lead to revenue loss which would cause financial unavailable again, which will create a vicious circle (the positive loop 3) to cause more risk in resource unavailable which leads to more low operating productivity and then more revenue loss. The low operating productivity would also directly cause performance unavailable since the adequate quantity and quality of manpower, materials and equipment is not available to operate the whole infrastructure. It would create a vicious circle (the positive loop 4) to cause revenue loss which leads to financial unavailable and more risk in resource unavailable. Finally, the resources unavailable risk event would result in dynamic feedback effects on construction cost overrun during construction phase and revenue losses during operation phase respectively.

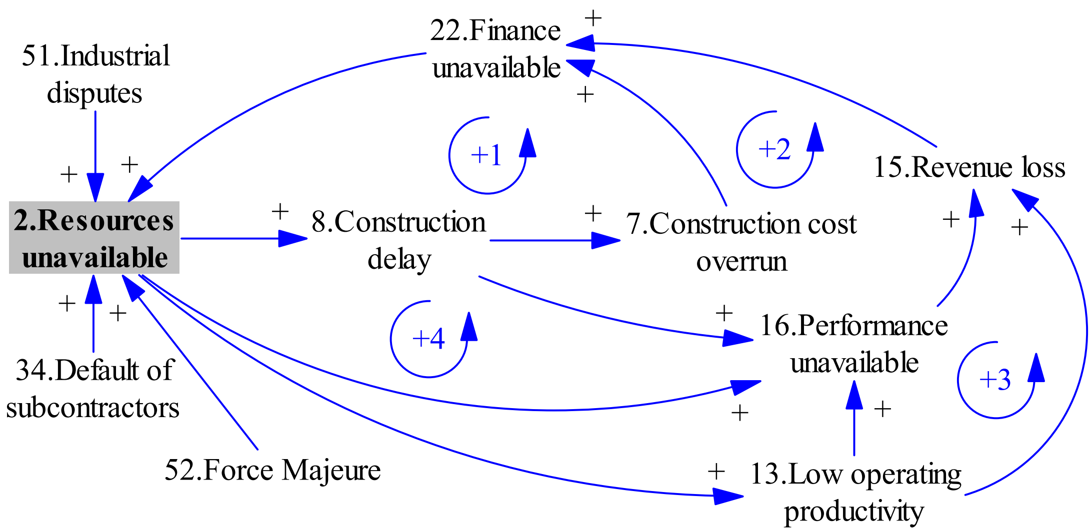


Figure V2 Causal Loop Diagram for 'Resources Unavailable' Risk Event

The resources unavailable risk event would be likely to be triggered by the default of subcontractors risk events that the subcontractors are incapable of supplying materials, equipment, and manpower to build or operate the infrastructure (Hodge, 2004; NAO, 2006). The financial unavailable risk event is when the project contractor has insufficient capital to purchase materials, equipment or manpower required to build infrastructure (PAC, 2006a). The industrial disputes risk events include strikes, industrial action, civil commotion, or public protests, which would cause materials, equipment, and manpower that cannot be supplied in time (EC, 2003). The Force Majeure risk events like earthquake, storm, flood, war, and fire, etc. make supply for materials, equipment or manpower unavailable (EC, 2002; Grey, 2004).

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for the cases, the UK National Audio Office's report (NAO, 2004a) on the London Underground indicated that they are unclear for both of the PPP project operation contractor, LUL, and infrastructure construction contractors, Infracos, to sustain and develop staff skilled to run PPP contract for the Tube network. In a report, the members of the UK Public Account Committee (PAC) for PFI criticized the fact that the professional skills for PFI contract management were not sustained for the operational phase due to unnecessary staff changes (PAC, 2005b). In addition, the Work Bank officials reported that staff changes were problematic in that there was not enough skilled personnel to deal with the PPP contract for the Bangkok Elevated Road and Track System (Work Bank, 1999). Lu (2004) indicated in a case study on BOT contract for the Labin B Power Plant (China) that the government officials took the materials unavailable risk to guarantee the fuel supply. Furthermore, the PFI contract for the BBC's White City 2 Development indicated that the space and technical capacity at White City 2 were under-utilized because experienced staff with professional skills were not utilized (PAC, 2006b).

V3. Performance unavailable

The term performance unavailable refers to the possibility that asset performance is delayed or disrupted to deliver services outlined in the output specifications. As shown in Figure V3, the performance unavailable risk event would delay or disrupt the services so that the operating contractor cannot meet the contract performance requirements, resulting in a contract breach (Hodge, 2004; PAC, 2005a). This would cause a contract remedies/penalties risk event in which the operating contractor must pay for the penalties and problems fixing costs according to contract terms and conditions (PAC, 2005a). The greater the cost for fixing a problem, the greater the loss for services. In addition, performance unavailable event would likely cause the contract disputes risk event that would cause contracting parties to argue over who should be held accountable for defective issues (Hodge, 2004). The more contract disputes exist between parties, the more contract remedies/penalties are incurred to settle the disputes. Therefore, the contract remedies/penalties risk event arising from contract break or contract disputes would lead to revenue loss risk event. Moreover, the performance unavailable would directly cause revenue loss because the infrastructure cannot deliver its services (Hodge, 2004). The cumulative revenue loss would likely cause the financial unavailable risk resulting in the lack of adequate credits by the contractor to pay debt. This would likely cause the insolvency of contractor risk event so that the contractor was unable to provide the services. Consequently, this would lead to a performance unavailable event again. This would create a vicious circle (the positive loop 1.)

Furthermore, the performance unavailable event would cause a contract breach risk event when the operating parties could not provide services to meet the contract requirements. This event would lead to termination liability for which the operating parties pay according to the contract terms and conditions (Work Bank, 1999). This would result in revenue loss risk event and then financial unavailable. Consequently, these events create a vicious cycle (the positive loop 2) at performance unavailable risk again. As stated above, the financial unavailable risk event would likely result in resources unavailable because the project contractor would not have enough capital to purchase materials, equipment or manpower that are required to operate the infrastructure. This would also create a vicious circle (the positive loop 3) at performance unavailable risk. In general, the resources unavailable risk event would result in dynamic risk feedback effects on revenue loss during the operation phase.

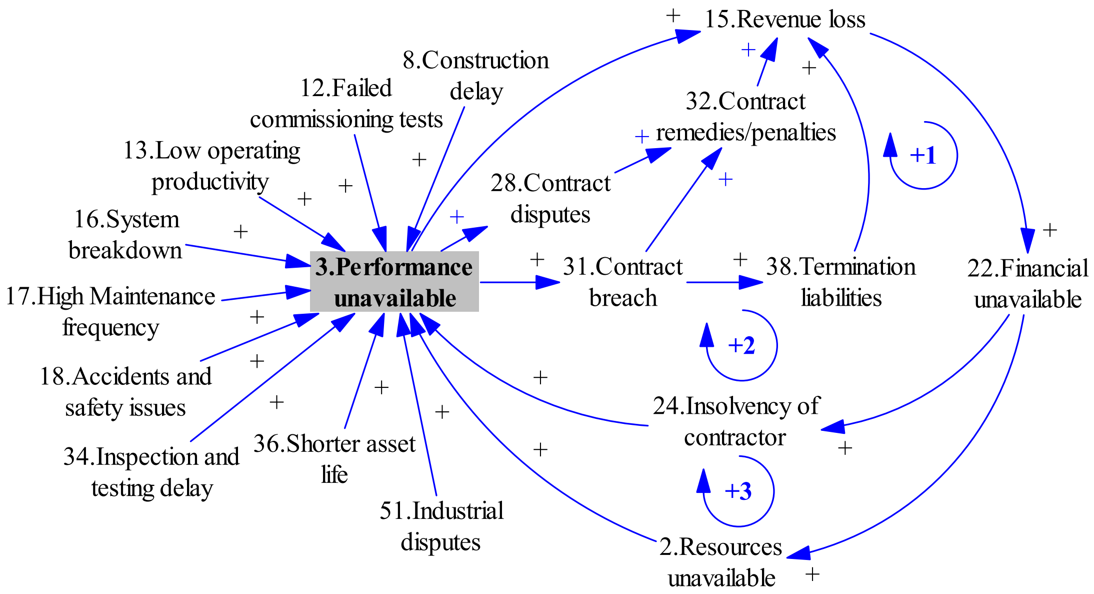


Figure V3 Cause Loop Diagram for 'Performance Unavailable' Risk Event

The performance unavailable risk event would be likely to be triggered by several risk events such as the resource unavailable event (NAO, 2004a; PAC, 2005b; Work Bank, 1999) that the materials, equipment, and manpower of the contractor cannot meet the operation requirements for infrastructure; the construction delay event (Ghosh & Jintanapakanont, 2004; Hodge, 2004; Work Bank); failed commissioning tests, and inspection and testing delay events (Ghosh & Jintanapakanont) in which infrastructure is inoperable; and low operating productivity (EC, 2004c). System breakdown (Hodge), high maintenance frequency (Ghosh & Jintanapakanont) and accidents and safety issues (EC, 2002; NAO, 2004a) lead to the infrastructure that cannot be operated under normal conditions so that the contractor performance cannot meet the contract requirements; insolvency of contractor events occur (Ghosh & Jintanapakanont) which result in bankruptcy and the incapability to operate the infrastructure. Shorter asset life (EC, 2002; NAO, 2004a) occurs when the infrastructure is disposed of and thereby contracts can no longer deliver services. Industrial disputes (EC, 2003; Ghosh & Jintanapakanont) occur when strikes, industrial action, civil commotion, or public protests result in the inability to supply materials, equipment, and manpower to operate the infrastructure.

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. The members of the European Commission reported (EC, 2002) on the London Underground and indicated both the PPP project operation contractor, LUL, and infrastructure construction contractors, Infracos, should assume the responsibility to make the railway infrastructure available and in working condition. The members of the UK Public Accounts Committee criticized the government authority for not terminating the contract with the PFI project service contractor, LUL, when the LUL officials failed to deliver the project and broke the contract with London Underground (PAC, 2005a). Moreover, Hodge (2004) indicated in the Melbourne City Link case study that the project contractor, Transurban, initiated an AUD$37 million claim against the government authority for less demand and subsequent financial loss due to contract breach.

V4. Scope changes

The term scope changes refers to the probability that the originally agreed upon scope of work outlined at the contract agreement has been changed after contracting signing, either pre- or post-commissioning. This event leads to additional costs and time delays in a project.

As shown in Figure V4, the scope changes risk event would naturally cause design changes and construction changes risks (Ghosh & Jintanapakanont, 2004) thus leading to further to construction delays. At the construction stage, the construction delay would likely lead to construction cost overruns (PAC, 2006a) due to the extra costs incurred in maintaining materials and equipment, and paying for manpower during the delay. This event would lead to the financial unavailable risk event resulting in bankruptcy. The construction party would likely reduce scope changes due to inadequate funds being available for the originally agreed scope of work definition. This would create a vicious cycle (the positive loop 1) to increase risk in scope changes, which would cause more risks in construction delays and construction cost overruns. At the construction stage, scope changes would also directly cause delay in contract change negotiation risk events (NAO, 2004a; PAC, 2003c) in which the parties involved in the design and construction take time to negotiate an agreement for scope changes. All of these risk events would be likely to cause further construction delay risk events, consequently creating a vicious cycle (the positive loop 2) to make more risk in scope changes.

Furthermore, the financial unavailable would lead to resources unavailable due to a lack of funds to recruit manpower, and purchase materials and equipment for construction, therefore causing construction delays. This also would create a vicious cycle (the positive loop 3) and increase risk in construction delays. On the other hand, at the operation stage the construction delays would cause performance unavailable events so that the asset performance would be delayed or disrupted in the delivery of services until after completing the construction changes. This would lead to increased risk in revenue loss, causing more risk in financial unavailable. As a result, the operation party would likely ask to reduce scope changes due to money shortage in order to deliver the originally agreed scope of services. Consequently, this too would create a vicious cycle (the positive loop 4) to cause yet again more risk in scope changes.

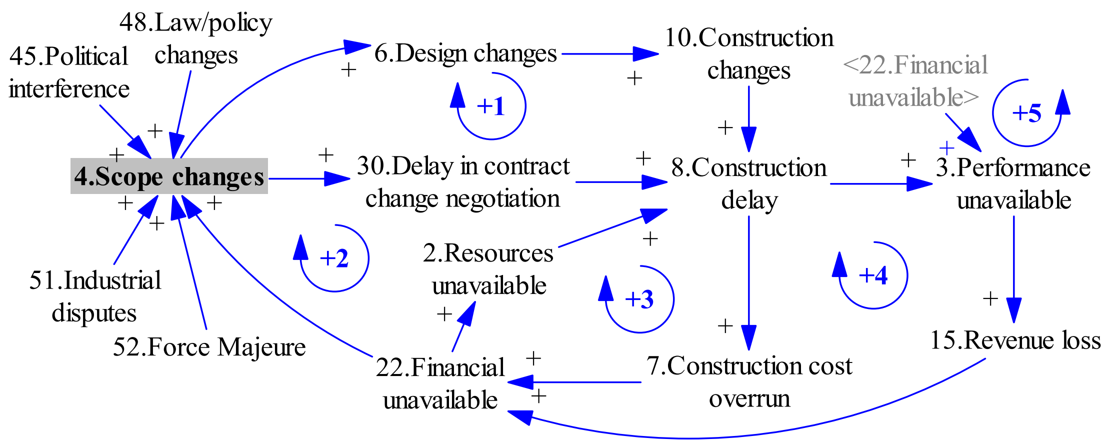


Figure V4 Cause Loop Diagram for 'Scope Changes' Risk Event

Furthermore, as stated above, the financial unavailable event would likely lead to the resources unavailable event due to insufficient capital to recruit manpower and purchase materials and equipment for performance. This too would create a vicious cycle (the positive loop 5) to cause yet again more risk in performance unavailable and more risk in revenue loss. In general, the scope changes risk event would result in dynamic feedback effects on construction cost overruns during construction phase and revenue losses during operation phase, respectively.

The scope changes risk event would likely be triggered by several risk events such as: (a) the financial unavailable event (PAC, 2006a) in which the contractors would have inadequate funds to deliver the originally agreed scope of services as outlined in the output specification; (b) law/policy changes (EC, 2002) in which the output specification would be changed to follow the government authorities policy changes; (c) political interference (EC, 2004d) in that the output specification originally set up in the PPP contract might be against the political benefits with certain political implications; (d) industrial disputes (EC, 2003) indicating that the output specification originally set up in PPP contract may be controversial and therefore forced to change by public protests; (d) Force Majeure (Lu, 2004) in which the uncontrolled events such as natural and unforeseen man-made events would make the scope of output specification changed.

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for the case, it would happen in Channel Tunnel Rail Link. The members of the UK Public Account Committee (PAC) reported that the Section 2 of Link will open in 2007, but that the costs will exceed budget mainly due to changes to the works (PAC, 2006a). In addition, Ghosh & Jintanapakanont (2004) in their case study in the Thailand Underground Rail Project demonstrated that the scope changes for work definition is the most important factor in project delivery.

V5. Defective design

The term "defective design" refers to the probability that the design of facility does not achieve the required output specifications.

As shown in Figure V5, the defective design risk event would cause defective construction at the construction stage since construction depends on design. Then, the defective construction would incur contract remedies/penalties risk to fix defective issues, which would further result in design changes and construction changes. (Hodge, 2004; Lu, 2004) The more construction changes occur, the more construction delays occur.

As described, the extra costs incurred in maintaining the existing materials and equipment, purchasing new materials and equipment and paying for recruited manpower during the construction time delay lead to construction cost overruns which likely lead to the finance unavailable event due to running out of money for construction. This would result in resources unavailable event and increased risk in defective design since the construction parties would not have adequate money to employ qualified, skillful design engineers. Consequently, this would create a vicious cycle (the positive loop 1) causing increased risk in defective design, and more risk in construction delay and construction cost overrun. Moreover, at the operating stage, the defective construction would also cause the performance unavailable event because the asset might not be available to deliver services. It would lead to a contract remedies/penalties risk to fix defective issues, which would further result in design changes and construction changes. As described above, the more construction changes exist, the more construction delays occur. It would lead to performance unavailable events because the infrastructure would not be ready to deliver services. Therefore, this would create a vicious circle (the positive loop 2) causing increased risk in construction delays, and more risks in performance unavailable events.

At operation stage, the performance unavailable event due to defective construction would be likely to cause the contract disputes risk event so that contract parties argue about who should be responsible for defective issues. The more contract disputes occur, the more contract remedies/penalties would incur to settle the disputes. All of the contract remedies/penalties actions arising from contract breach and contract disputes would lead to revenue loss, resulting in insufficient credit to repay the debt and would result in the financial unavailable event. This would cause resources to be available and performance unavailable because the operating party has inadequate funds to acquire materials, equipment and manpower from the suppliers in order to deliver service. Consequently it would create a vicious circle (the positive loop 3) with increased risk in performance unavailable events and more risk in revenue loss. Generally, the defective design risk event would result in a dynamic feedback effect on construction cost overruns during the construction phase and revenue losses during the operation phase, respectively.

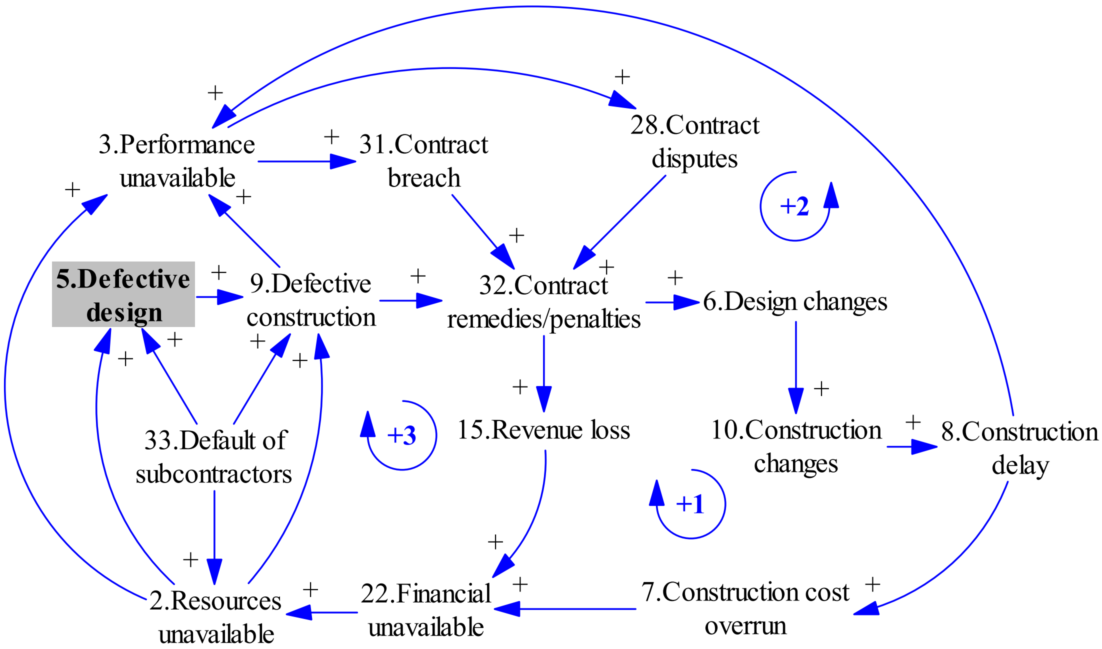


Figure V5 Cause Loop Diagram for 'Defective Design' Risk Event

The defective design risk event would be likely be triggered by the default of subcontractors (Hodge, 2004), meaning that it cannot meet contract specification due to insolvency or incapability of design subcontractors. Resources unavailable events occur when the designer cannot meet contract specification because of insufficiently qualified manpower (Lu, 2004; NAO, 2004a; PAC, 2005b; PAC, 2006b).

This risk has been described in Table 4.1.1 and 4.1.2. Hodge (2004) indicated that relative to the Melbourne City Link a major consortium subcontractor, TOVJ, initiated litigation against the project consortium, Transurban, alleging flaws in the design of two faulty City Link tunnels.

V6. Design changes

The term design changes refers to the possibility that the changes of originally agreed design or the correction of the defective design lead to additional costs and time delay.

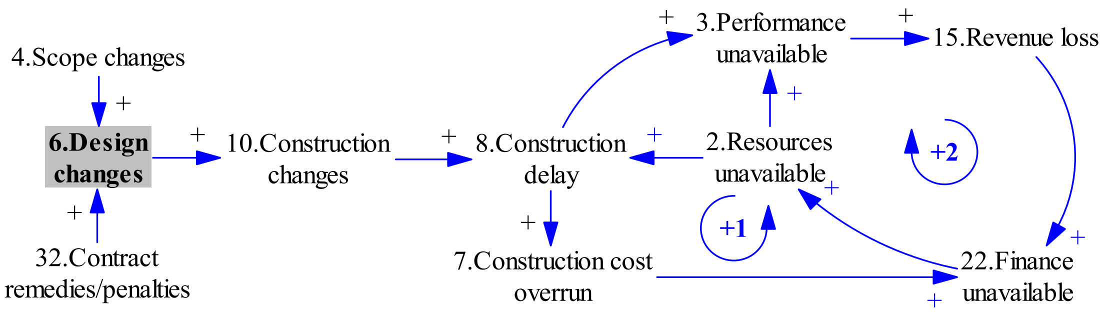


Figure V6 Cause Loop Diagram for 'Design Changes' Risk Event

As described above, the Figure V6 shows that the design changes risk event would cause construction change events (PAC, 2006b) since the construction depends on the design. The more construction changes occur, the more construction delays would occur. The construction delays would lead to construction cost overruns at the construction stage, which would likely lead to finance unavailable events due to lack of money for construction. It would result in more risks in resources unavailable events and more risk in construction delays since the construction parties would not have adequate funds for employment. Again, this would create a vicious circle (the positive loop 1) and cause more risk in construction delay, and more construction cost overruns. This would also lead to performance unavailable event as the infrastructure would not be ready to deliver its services, resulting in revenue loss. Revenue loss would lead to financial unavailable events since there would not be enough credit to repay the debt. Furthermore, as previously described, the financial unavailable event would likely lead to a resources unavailable event because there would be inadequate amounts of money for the required tasks and resources. Consequently, it would create a vicious circle (the positive loop 2) and cause increased risk in performance unavailable events and more risk in revenue loss. In general, the design changes would cause dynamic feedback effects on construction cost overruns during construction phase and revenue losses during operation phase, respectively.

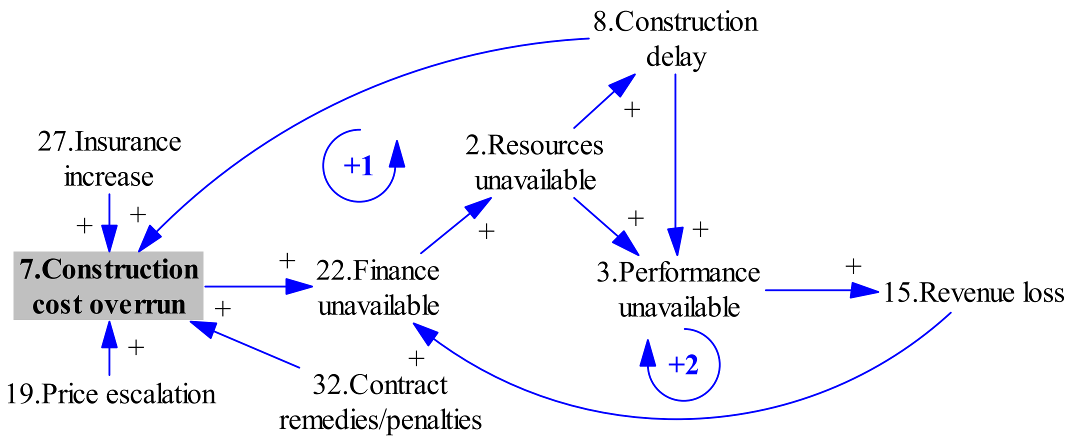
The design changes risk event would possibly be triggered by the risk events such as: (a) scope changes (PAC, 2006a) which result when design or construction parameters need to be changed to meet the new scope requirements; and (b) contract remedies/penalties (Hodge, 2004; PAC, 2006b) because the remedies for poor performance failed to meet output specifications.

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As in the PFI contract for the BBCs White City 2 Development, the members of the UK Public Account Committee (PAC) criticized the fact that £60 million was needed for additional costs (an increase of 29%) due to the design changes. Introducing variations after contracting inevitably increase risk costs (PAC, 2006b). In addition, Hodge (2004) indicated that the tunnel in the Melbourne City Link project needed to be redesigned after experts discovered it had defective construction; this led to delays in the tunnel opening. Furthermore, the Ghosh and Jintanapakanont (2004) reflected in their case study of the Thailand Underground Rail Project that design change is one of the most important factors regarding project delivery.

V7. Construction cost overrun

The term construction cost overrun refers to the possibility that the infrastructure is incapable of delivering within the budget. As shown in Figure V7, the construction cost overrun risk event would possibly lead to finance unavailable events due to inadequate capital availability for construction (Flyvbjerg et al., 2003; Reilly, 2005). This would likely lead to resources unavailable events in which there was not enough money to purchase materials and equipment, or to recruit skilful manpower for infrastructure. These events would result in construction delays in the construction phase and then construction cost overruns due to the need for purchasing new materials and equipment and paying for recruited manpower during the construction time delay. This creates a vicious circle (the positive loop 1) causing more risk in resources unavailable events, and more construction delays and cost overruns.

On the other hand, the construction delays would also cause performance unavailable events because the infrastructure might not be ready to deliver services. It would also lead to revenue loss since there would be insufficient credit to repay the debt, resulting in financial unavailable events. Consequently, this would create a vicious cycle (the positive loop 2) causing more risk in resources unavailable events resulting in more construction delays and performance unavailable events which would lead to more revenue loss.



<u>FigureV7 Cause Loop Diagram for 'Construction Cost Overrun' Risk Event</u>

The construction cost overrun event is often triggered by risk events such as: (a) construction delays resulting in extra costs incurred during the construction time delay; and (b) price escalation which is the unexpected increase in the labor costs, materials and equipments used for infrastructure construction (Hodge, 2004). Contract remedies/penalties is defined as the extra costs for remedies for defective construction which had failed to meet contract requirements (Hodge). Insurance increase occurs when the agreed project insurances substantially increases during the construction stage (Lu, 2004).

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. Many researchers have found (Flyvbjerg et al., 2003; Reilly, 2005) that in 9 out of 10 transport infrastructure projects, costs are underestimated resulting in cost overruns. For rail projects, actual costs are on average 45% higher than estimated costs (standard deviation =38). For all project types, the actual costs are 28% higher than the estimated costs (standard deviation = 39). Cost underestimation and cost overruns across 20 nations and 5 continents appear to be a global phenomenon that has not decreased over the past 70 years. For example, in the Boston, Massachusetts artery/tunnel project in the US, there is 196% of cost overruns; 110% of cost overruns exist for Great Belt rail tunnel in Denmark, 100% of cost overruns exist for Shinkansen Joetsu rail line in Japan; and 80% cost overruns exist for Channel tunnel in the UK and France, respectively.

V8. Construction delay

The term construction delay refers to the possibility that the officials of the facility are incapable of delivering on time. As discussed, Figure V8 shows that the construction delay risk events would likely cause construction cost overrun risk events because of the extra costs incurred during the construction time delay. Then, the construction cost overrun risk event would lead to a finance unavailable event due to lack of capital. This event then leads to resources unavailable events because of inadequate funds for materials and manpower for infrastructure construction. A construction delay would result. Again, the vicious circle would occur (the positive loop 1) and cause more risk in construction delay and more risk in construction cost overruns.

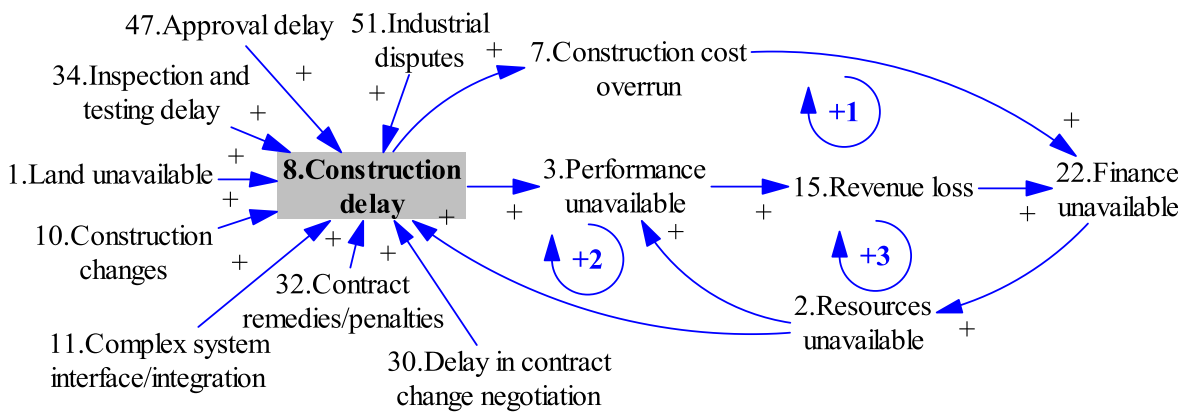


Figure V8 Cause Loop Diagram for 'Construction Delay' Risk Event

On the other hand, the construction delay events would also cause performance unavailable events since the infrastructure would not be ready to deliver its services. This would lead to revenue loss based on bad credit issues which will result in financial unavailable events. Consequently, the positive loop 2 would cause yet again more risk in construction delays so that more performance unavailable events would result in more revenue loss. Furthermore, at the operating stage, the resources unavailable event would directly cause performance unavailable events due to the lack of materials or manpower for infrastructure performance. Positive loop 3 would cause increased risk in revenue loss. In general, the construction delay risk event would result in dynamic feedback effects on construction cost overruns during construction phase and revenue losses during the operation phase.

The construction delay would be likely to be triggered by the risk events such as: (a) land unavailable events (Hodge, 2004; Lu, 2004; Work Bank, 1999) which is when the land cannot be acquired on time for infrastructure construction; (b) resources unavailable events (NAO, 2004a; Work Bank) created when the required materials, equipments and manpower are not ready for construction; (c) construction changes (Hodge) which occur when additional time is needed to complete construction; (d) complex system interface/integration(PAC, 2005a) which is a likely delay in design and construction work since the designed and constructed infrastructure is incompatible with other public systems; (e) delays in contract change negotiation (Hodge; NAO, 2004b; PAC, 2003c) which is the additional time needed to reach an agreement between parties for construction changes; (f) contract remedies/penalties (EC, 2002; Ghosh & Jintanapakanont, 2004; Hodge) when time is needed to remedy construction problems in order to meet contract requirements; (g) inspection/testing delays (Ghosh & Jintanapakanont) when there is a delay in project commissioning because of additional time needed to passing inspection and testing; (h) approval delay occurs when the permits or licenses needed to proceed with construction as scheduled are delayed in processing; (i) industrial disputes (EC, 2003; Hodge) cause the time delay due to strikes, industrial action, civil commotion or public protests.

These risks have been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. Hodge (2004) indicated the government authority was to pay for construction delays due to delays arising from land acquisition and industrial disputes in the Melbourne City Link project. Moreover, Ghosh and Jintanapakanont (2004) reflected on the Thailand Underground Rail Project that construction delay was one of the most important factors leading to project delivery delay.

V9. Defective construction

The term defective construction refers to the situation in which the equipment, system or facility cannot meet the construction standards and requirements. As shown in Figure V9, the defective construction would cause failed commission tests (Hodge, 2004) at the end of construction stage that the facilities cannot pass the operating tests. This results in a contract remedies/penalties risk to fix defect issues which would result in design changes and construction changes. The more construction changes, the more construction delays would occur. As described above, the extra costs incurred in maintaining the existing materials and equipment, purchasing new materials and equipment and paying for recruited manpower during the construction time delay would lead to construction cost overruns.

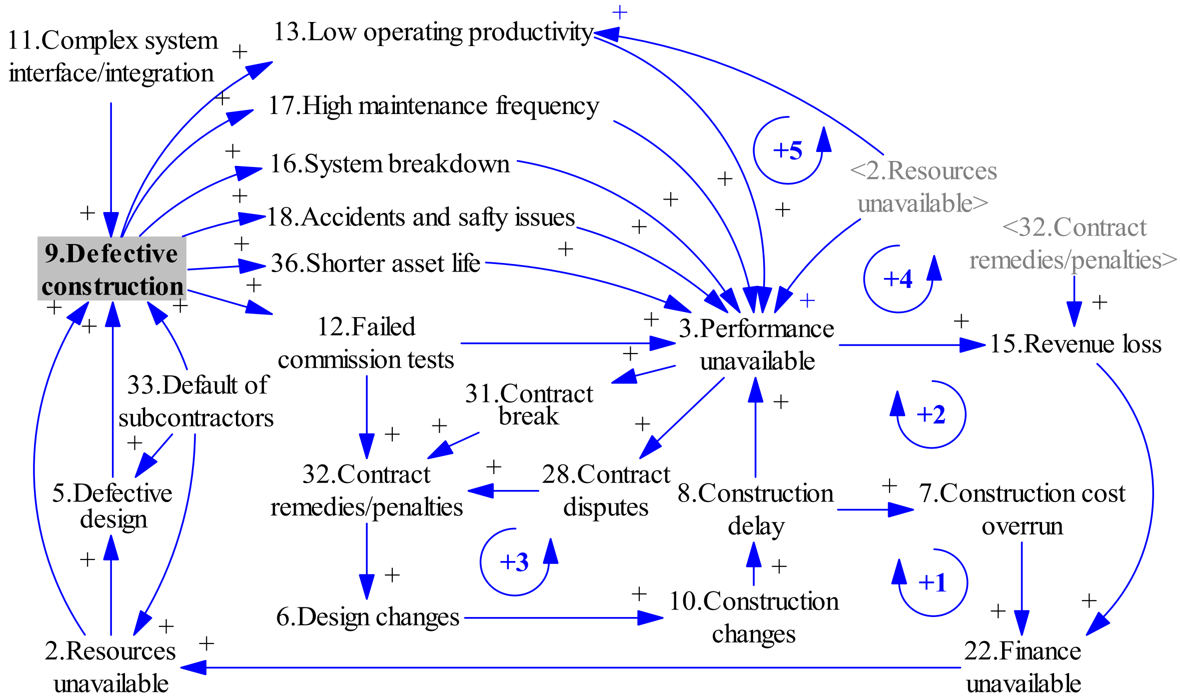


Figure V9 Cause Loop Diagram for "Defective Construction" Risk Event

This fact would likely cause finance unavailable events due to lack of money for construction. This would further result in more risk in resources unavailable events which would likely cause more risk in defective design and more risk in defective construction since the construction parties may lack money. Consequently, this would create a vicious circle (the positive loop 1) causing more risk in defective construction, more risk in construction delay and construction cost overruns.

On the other hand, the defective construction would possibly cause a series of risk events at the operation stage such as: (a) low operating productivity (EC, 2004a; Ghosh & Jintanapakanont, 2004) which exists when system operating productivity is lower than the output specification that was setup in the contract requirements; (b) high maintenance frequency (Ghosh & Jintanapakanont) which occurs when the maintenance frequency is higher than expected so that the system cannot deliver service as required; (c) system breakdown (Hodge, 2004) when that system would completely fail to deliver services; (d) accidents and safety issues (Hodge) which occur when the system cannot be operated as safely as the contract required; (d) shorter asset life (EC, 2002; NAO, 2004a) occurs when the system has a shorter life than the expected time set up in the contract output specifications. All of these would lead to performance unavailable events in which the infrastructure is not able to deliver services as required in the contract output specifications. The more performance unavailable events occur, the more revenue loss occurs as well. This fact would be likely to cause financial unavailable events which would result in more risk in resources unavailable events in which the contract parties do not have adequate money to employ the required materials, equipment and manpower from suppliers to deliver services. Consequently, this creates a vicious circle (the positive loop 2) causing more risk in defective construction. In addition, performance unavailable events would lead to contract breaches that result in infrastructure performance inability to meet contract requirements. This would necessitate construction remedies/penalties risk events to fix defect issues. This would likely cause contract disputes risk events in which contract parties argue with each other relative to who should be responsible for defect issues. The more contract disputes occur, the more contract remedies/penalties costs would incur to settle the disputes. The contract remedies/penalties would result in design changes and construction changes yet again thus causing more risk in construction delay. Consequently, this again creates the vicious circle (the positive loop 3) causing more risk in performance unavailable events and more risk in revenue loss.

Furthermore, the resources unavailable events would create two vicious circles (the positive loop 4 and loop 5) causing more risk in performance unavailable events and low operating productivity respectively since there would not be adequate money to secure the required materials, equipment and manpower from suppliers to deliver service. In general, the defective construction risk event would result in dynamic feedback effects on construction cost overrun during construction phase and revenue losses during operation phase respectively.

The defective construction events would be likely to be triggered by the following situations: (a) the defective design event (Hodge, 2004) in which the design created cannot meet output specifications; (b) default of subcontractors (EC, 2002; Hodge, 2004; NAO, 2006; PAC, 2002a) so that the construction provider cannot meet contract requirements because the subcontractors are incapable or insolvent; (c) resources unavailable event (Lu, 2004; NAO, 2004a; PAC, 2002a, 2006b; Work Bank, 1999) such that the quantity and quality of the materials, equipment, and manpower required for construction are inadequate; (d) complex system interface/integration (PAC, 2002a; PAC, 2005a) in which the constructed system is difficult to interface with or incompatible with other public systems.

This type of risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. Hodge (2004) indicated relative to the Melbourne City Link project that a major consortium subcontractor, TOVJ, needed to pay the project contractor, Transurban AUD$153.6 millions to settle a dispute over delays and traffic problems caused by faulty construction.

V10. Construction changes

The term construction changes refers to the possibility that the equipment, system or infrastructure need to be remedied or rework due to construction defects or design changes. As described, Figure V10 shows that the construction changes would cause construction delay events because the extra time would be needed to remedy construction. The more construction changes occur, the more construction delays would result. The construction delays would lead to construction cost overruns at the construction stage which would likely lead to finance unavailable events due to lack of money for construction completion. This would result in more risk in resources unavailable events and more risk in construction delays since the construction parties would not have sufficient monies to employ qualified and skilled construction manpower. Consequently, this would create a vicious circle (the positive loop 1) and cause more risk in construction delays and more risk in construction cost overruns. This would also lead to performance unavailable events that preclude the delivery of the infrastructure for services. This would result in revenue loss which causes finance unavailable events since there would not be enough credit available to repay the debt. Furthermore, the financial unavailable event would likely to lead to resources unavailable events because there would not be enough money to recruit manpower, purchase materials and equipment for performance completion. Again, this would create a vicious circle (the positive loop 2) causing more risk in performance unavailable events and more risk in revenue losses. In general, the construction changes would result in dynamic feedback effects on construction cost overruns during the construction phase and revenue losses during operation phase, respectively.

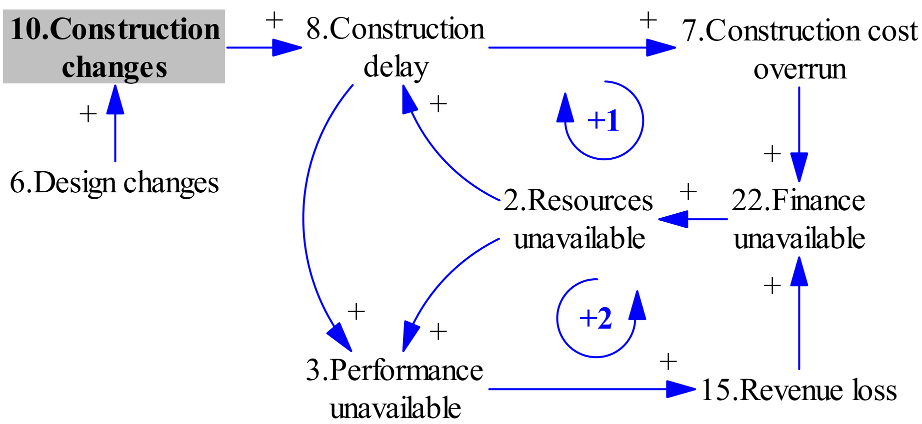


Figure V10 Cause Loop Diagram for 'Construction Changes' Risk Event

Construction changes would be likely to be triggered by design changes (Ghosh & Jintanapakanont, 2004; Hodge, 2004; PAC, 2006b; Work Bank, 1999) because the construction depends on design. This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. Hodge (2004) indicated relative to the Melbourne City Link case study that the operation of the southern section of City Link was delayed a year due to work remedies needed for tunnel cracking and leaking.

V11. Complex system interface/integration

The complex system interface/integration refers to the probability that the designed and constructed infrastructure is unable to interface with or incompatible with other public systems. This might necessitate the need for major changes for design and construction work. As a result, this leads to the substantial cost overruns and delivery delays in construction phase. Even though a project may be able to interface with or be compatible with the other public sector systems, this interface may lead to large upgrade and maintenance costs in the project operation phase.

As shown in Figure V11, the complex system interface/integration would likely cause defective construction because the constructed system may be difficult to interface with or may be incompatible with other public systems (PAC, 2002a, 2005a). Then further consequences arise as a result of defective construction as described above in Section (9) Defective construction. In general, the complex system interface/integration risk event would result in dynamic feedback effects on construction cost overruns during the construction phase and revenue losses during the operation phase.

The complex system interface/integration would likely be triggered by the complex/innovative technology when applied technology is not able to solve the system interface/integration issues (NAO, 2006).

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. This type of risk has occurred in the London Underground. The members of the UK Public Account Committee (PAC) reported that because of interface issues, the Central line modernization and the Jubilee line extension of London Underground were both substantially over budget and the contractors did not deliver the improvements envisaged at the commencement of the projects. The London Underground PPP projects involved complex interface across the entire network of the current systems. Such issues can create the potential risk costs associated with logistical complexities in managing and maintaining many interfaces between the new assets and old assets, and a significant level of difficulties in integrating asset varieties such as signals, tracks and trains across the 11 lines in the London Underground network (PAC, 2005a).

One of the other cases the researcher examined was the Airwaves project which had high risk events in complex system interface/integration aspects. A key requirement for this PPP project was the need for interoperability of new radio networks across different emergency services like fire service and the ambulance service (PAC, 2002a).

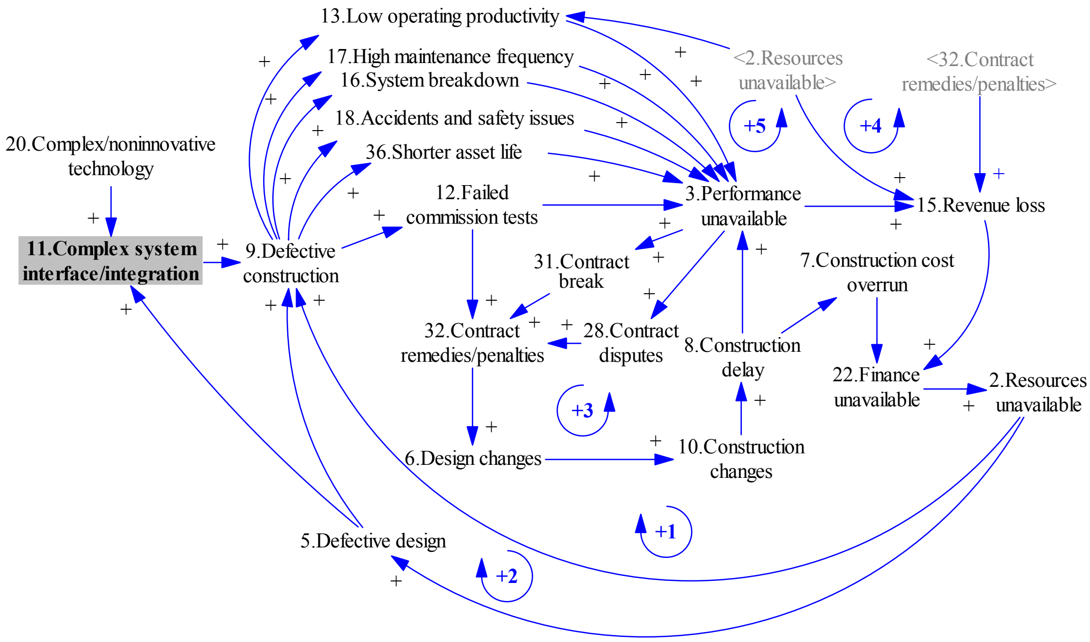


Figure V11 Cause Loop Diagram for 'Complex System Interface / Integration' Risk Event

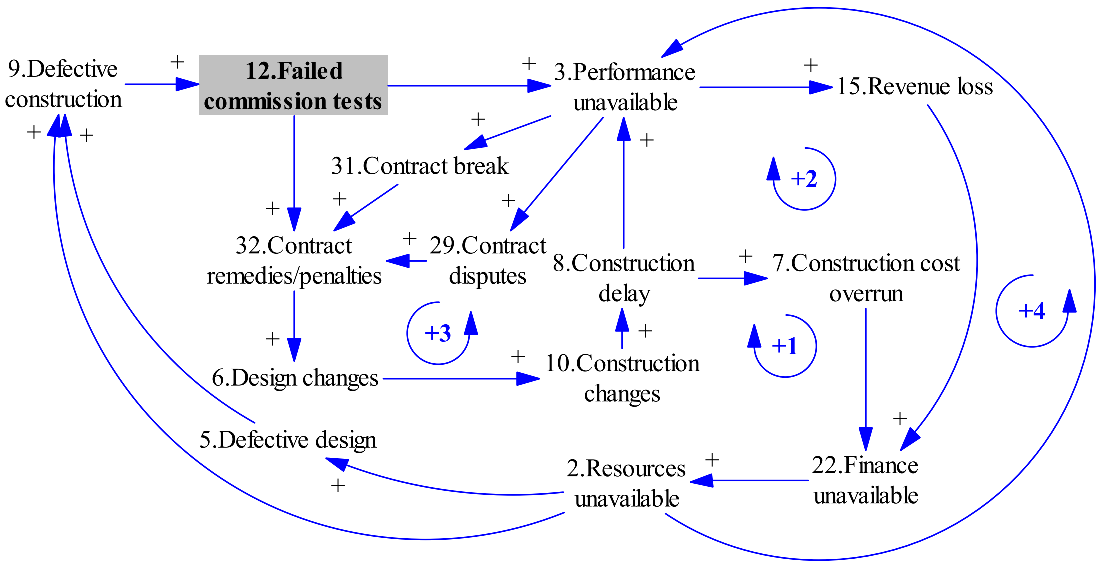


Figure V12 Cause Loop Diagram for 'Failed Commission Tests' Risk Event

V12. Failed commissioning tests

The failed commissioning tests refers to the possibility that the operational commissioning tests which are required to be completed before starting services cannot be successfully completed or acceptable by the agreed date. As shown in Figure V12, the failed commissioning tests arise when officials at facilities cannot pass the operating tests arising from defective construction risks because the built infrastructure could not meet the contract requirements.

This would lead contract remedies/penalties risks in order to correct defective issues (Hodge, 2004) thus resulting in design changes and construction changes. The more construction changes occur, the more construction delays result. As described, the extra costs incurred in maintaining the existing materials and equipment, purchasing new materials and equipment and paying for recruited manpower during the construction time delay would lead to construction cost overruns which would likely lead to finance unavailable events due to lack of money for final construction. This would result in more risk in resources unavailable events likely leading to more risk in defective design and more risk in defective construction since the construction parties would not have adequate money to employ qualified and skilled design and construction engineers. Consequently, this would create a vicious circle (the positive loop 1) causing more risk in defective construction and more risk in failed commissioning tests.

The failed commissioning tests would lead to performance unavailable events which cause the inability of the infrastructure to deliver services as required in the contract output specifications (Hodge, 2004). The more performance unavailable occurs, the more revenue loss results. This would likely lead to financial unavailable events resulting in more risk of resources unavailable events as the contract parties do not have adequate money to employ the required materials, equipment and manpower from suppliers to deliver services. Consequently, this would create a vicious circle (the positive loop 2) causing more risk of defective construction and then more risk of failed commission tests. In addition, performance unavailable events would lead to contract breach so that infrastructure performance cannot meet contract requirements. It would then be necessary for officials to invoke construction remedies/penalties in order to fix defect issues.

This would also cause contract disputes risk events as the contract parties argue with each other for whom should be take responsibility for defect issues. The more contract disputes occur, the more contract remedies/penalties would incur to settle the disputes. The contract remedies/penalties would result in design changes and construction changes which would cause more risk in construction delays. Consequently, this would create a vicious circle (the positive loop 3) causing more risk in performance unavailable events and more risk in revenue loss.

Furthermore, the resources unavailable events would create a vicious circle (the positive loop 4) causing more risk in performance unavailable events since there would not be adequate money to employ the required materials, equipment and manpower from suppliers to deliver services. In general, the failed commissioning tests would cause dynamic feedback effects on construction cost overruns during the construction phase and revenue losses during operation phase.

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. Hodge (2004), in the Melbourne City Link, indicated that the tunnel opening was delayed due to the testing problems relative to state-of-the-art electronic technology.

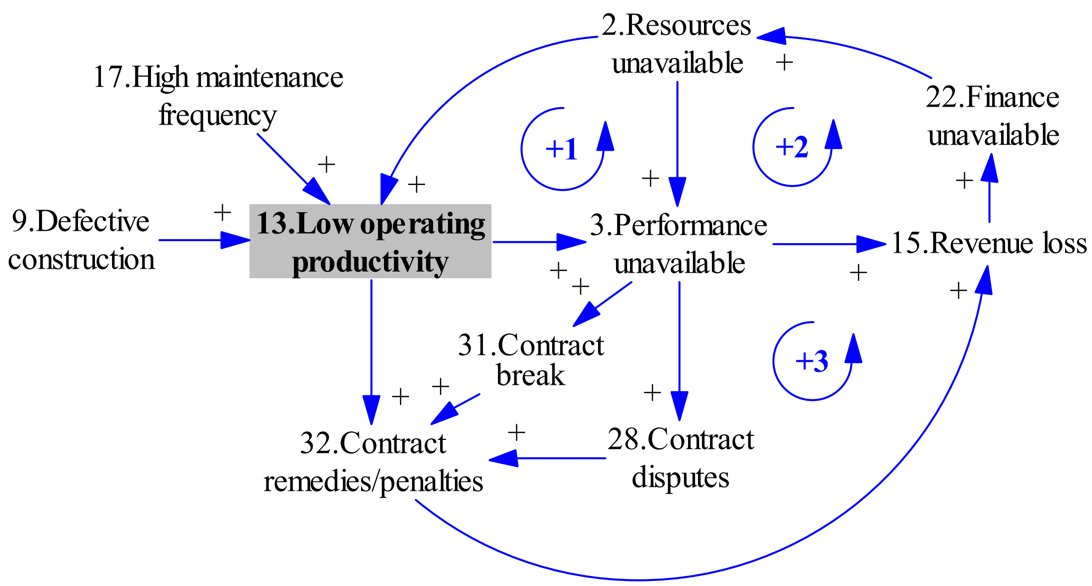


Figure V13 Cause Loop Diagram for 'Low operating productivity' Risk Event

V13. Low operating productivity

Low operating productivity refers to the possibility that the system operating productivity is lower than the output specifications.

As shown in Figure V13, the low operating productivity would lead to performance unavailable events which cause the infrastructure not to be able to deliver services as required in the contract output specification (EC, 2004a; Ghosh & Jintanapakanont, 2004). The more performance unavailable events occur, the more revenue losses result. This would cause financial unavailable events which would result in more risk of resources unavailable events in which the contract parties do not have adequate money to employ the required materials, equipment and manpower from suppliers to deliver services. Consequently, this would create a vicious circle (the positive loop 1) causing more risk of low operating productivity and then more risk of performance unavailable events.

In addition, the resources unavailable events would create a vicious circle (the positive loop 2) causing more risk of performance unavailable events since there would not be adequate money to employ the required materials, equipment and manpower from suppliers to deliver services. Furthermore, performance unavailable events would lead to contract breaches as the infrastructure performance party cannot meet contract requirements. This would make it necessary for contract remedies/penalties to be invoked to fix defective issues. This would likely cause contract disputes risk events in which the contract parties argue with each other in order to determine who should take responsibility for defective issues. The more contract disputes occur, the more contract remedies/penalties incur in order to settle the disputes. The contract remedies/penalties would result in revenue losses which would cause more risk of finance unavailable events. Consequently, this would create a vicious circle (the positive loop 3) causing more risk performance unavailable events and more risk of revenue loss. In general, the low operating productivity risk events would result in dynamic feedback effects on revenue loss during the operation phase.

The low operating productivity would be likely to be triggered by such events as: (a) the defective construction as the contracted infrastructure cannot deliver the services as required in the PPP contract (EC, 2004a; Ghosh & Jintanapakanont, 2004); (b) the resources unavailable events occurring that affect the quantity and quality of the materials, equipment and manpower required for operations that make them inadequate (NAO, 2004a; PAC, 2005b); (c) high frequency of maintenance events caused by the constructed system needing to be maintained in a higher frequency than expected resulting in the inability to deliver services as required.

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As shown in European Committees case studies (EC, 2004b) on the Karvina sewerage in the Czech Republic, the operational efficiency of this PPP project was much lower than output specification that were established in the contract. In addition, the Ghosh and Jintanapakanont (2004) reflected that the low operating productivity had significant impact on services delivered for the Thailand underground rail project

V14. Mis-pricing

Mis-pricing is defined as the possibility that the service prices are regulated incorrectly which will lead to revenue losses. As shown in Figure V14, mis-pricing would lead to revenue losses when the service fees are not regulated correctly (EC, 2004b). This would likely cause financial unavailable events which would result in more risk of resources unavailable events so that the contract parties do not have adequate money to employ the required materials, equipment and manpower from suppliers to deliver the required services. Consequently, this creates a vicious circle (the positive loop 1) causing more risk of revenue loss.

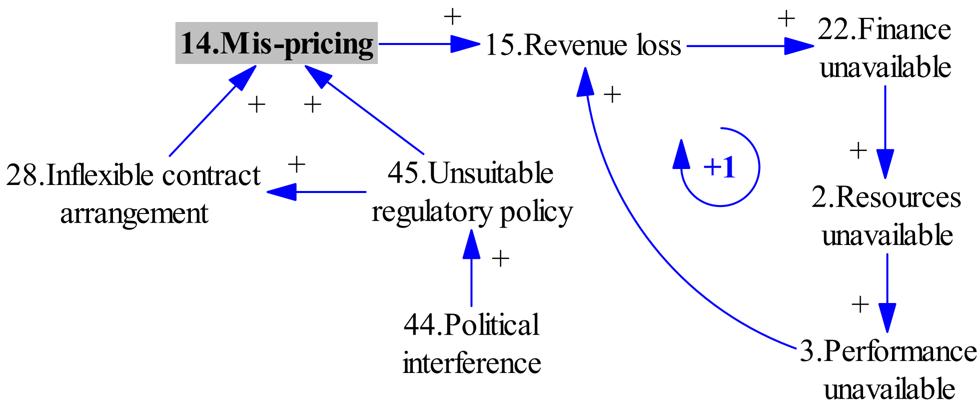


Figure V14 Cause Loop Diagram for 'Mis-pricing' Risk Event

Mis-pricing would likely be triggered by the following events: (a) unsuitable regulatory policies in which the government authorities do not allow the project pricing cap to vary according to the actual market demand variants over the long-term of the project (EC, 2004b); (b) inflexible contract arrangements such as fixed-cost contracts which do not allow price caps to be changed as needed. (NAO, 2004b; PAC, 2003c).

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As shown in the European Committees case studies on the ASA and Rethmann project in Hungary, this PPP solid waste management project officials need to collect service fees from the population and the subcontractors (EC, 2004b). The committee members indicated that the mis-pricing would lead to potential revenue losses. In addition, relative to the RWE Entsorgung in Bulgaria, another PPP solid waste management project, officials indicated that the fee for project services was often a political question in municipal council debates. As a result, the approved fee for project services was not sufficient to cover the expenses, and the project contractor faced uncertainty in the future revenues (EC, 2004b).

V15. Revenue losses

The complex system interface/integration would likely be triggered by the complex/innovative technology when applied technology is not able to solve the system interface/integration issues (NAO, 2006).

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. This type of risk has occurred in the London Underground. The members of the UK Public Account Committee (PAC) reported that because of interface issues, the Central line modernization and the Jubilee line extension of London Underground were both substantially over budget and the contractors did not deliver the improvements envisaged at the commencement of the projects. The London Underground PPP projects involved complex interface across the entire network of the current systems. Such issues can create the potential risk costs associated with logistical complexities in managing and maintaining many interfaces between the new assets and old assets, and a significant level of difficulties in integrating asset varieties such as signals, tracks and trains across the 11 lines in the London Underground network (PAC, 2005a).

One of the other cases the researcher examined was the Airwaves project which had high risk events in complex system interface/integration aspects. A key requirement for this PPP project was the need for interoperability of new radio networks across different emergency services like fire service and the ambulance service (PAC, 2002a).

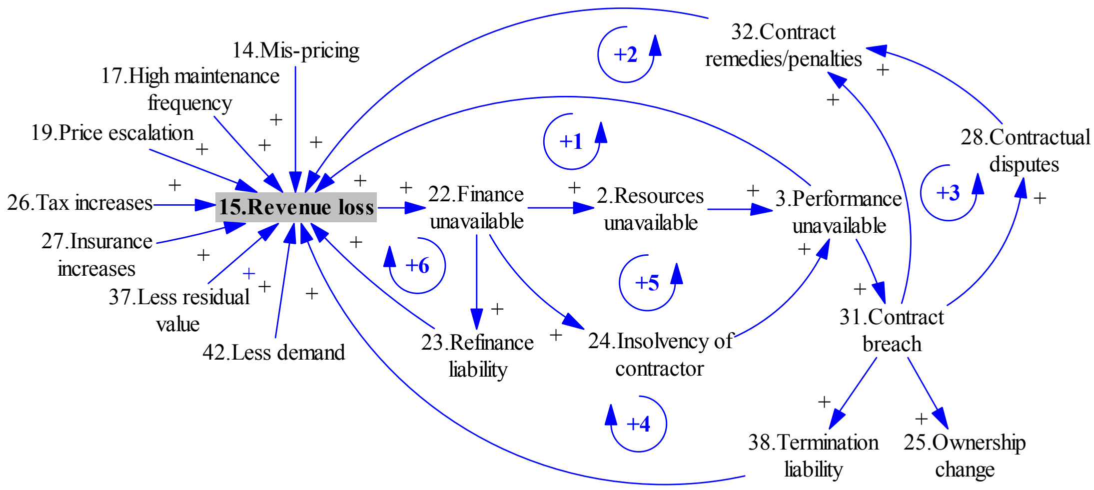


Figure V15 Cause Loop Diagram for 'Revenue Losses' Risk Event

In addition, performance unavailable events would lead to contract breaches as infrastructure performance contractors cannot meet contract requirements. It would be necessary for officials to invoke contract remedies/penalties with additional costs in order to fix defective issues. This also would create a vicious circle (the positive loop 2) causing more risk of revenue loss. The contract breach would also be likely to cause contract disputes risk events in which contracted parties argue each other to determine who should take responsibility for defect issues. The more contract disputes occur, the more contract remedies/penalties would incur to settle the disputes. Consequently, this would create a vicious circle (the positive loop 3) causing more risk of revenue losses. Moreover, if the contract defects could not be remedied, the contract breach would also likely cause a termination liability risk event resulting in compensation being paid for contract termination. This would also create a vicious circle (the positive loop 4) causing more risk of revenue losses. Additionally, the finance unavailable events would likely cause insolvency of contractor resulting in the inability of that contractor to provide the required services. Consequently, this would create a vicious circle (the positive loop 5) causing more risk in performance unavailable and more risk in revenue losses again. In addition, if refinance is necessary, the finance unavailable events would likely cause refinance liability concerns thus increasing public sector costs. Again, this would create a vicious circle (the positive loop 6) causing more risk of revenue losses again. In general, the revenue losses would be reinforced through dynamic feedback effects during the operation phase of the project.

The revenue losses would likely be triggered by the following issues: (a) mis-pricing when service fees are not regulated correctly by officials (EC, 2004b); (b) high frequency maintenance issues resulting in higher than expected maintenance costs (Ghosh & Jintanapakanont, 2004); (c) price escalation issues when the labor, material and equipment costs for infrastructure operations are increased (EC, 2002; Lu, 2004); (d) tax increases and insurance increases occurring when the project is taxed and insured more than expected (Lu, 2004); (e) less demand for the services generated by a project than expected (PAC, 2003c, 2006a); (f) less residual value so that the infrastructure life value is less than contractual requirement (EC, 2002; NAO, 2004a); (g) performance unavailable events occur in which the infrastructure cannot deliver the required services (Hodge, 2004); (h) contract remedies/penalties (EC, 2002; Hodge) in which the additional costs are used to address issues arising from contractual breaches and contractual disputes; (i) termination liability compensation which must be paid for contract termination (Work Bank, 1999); (j) refinance liability that increased costs for the public sector due to project refinancing requirements (Work Bank).

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. The members of the UK Public Account Committee (PAC) reflected that the channel tunnel rail link project (the Link) lost revenues due to less demand for the use of the completed project (PAC, 2006a). Hodge (2004) indicated that the Melbourne city link project lost revenues due to defective design and construction. Members of the European Committees indicated the ASA and Rethmann project in Hungary lost revenues due to mis-pricing (EC, 2004b).

V16. System breakdown

The 'system breakdown' refers to the possibility that the system or facility cannot work, which leads to unexpected costs and additional time for services delivery.

As shown in Figure V16, the 'system breakdown' that the built facilities cannot work arisen from 'defective construction' would lead to 'performance unavailable' that the infrastructure is not able to deliver services (Ghosh & Jintanapakanont, 2004; Hodge, 2004). As the previous description, the more 'performance unavailable' is, the more 'revenue loss' would be. This would likely lead to 'financial unavailable' which would result in more risk in 'resources unavailable' that the contract parties has no adequate money to employ the required materials, equipment and skilled manpower from suppliers to deliver services. Consequentially, it would create a vicious circle (the positive loop 1) to cause more risk in 'defective construction' and then more risk in 'system breakdown', and a vicious circle (the positive loop 2) to cause more risk in 'performance unavailable' and then more risk in 'revenue loss' as well. The 'system breakdown' would also lead to take 'contract remedies/penalties' risk and then more risk in 'revenue loss' since the additional costs have to pay for the punishment that the services don't meet contract requirement. Consequentially, it would create a vicious circle (the positive loop 3) to join the positive loop 2 to cause more risk in 'performance unavailable' and then more risk in 'revenue loss.' In addition, it'll be necessary to take 'contract remedies/penalties' risk to fix defective issues, which would result in 'design changes' and 'construction changes' which would cause more risk in 'construction delay.' The 'construction delay' would lead to 'performance unavailable' since the infrastructure cannot deliver services until its problems are fixed. Consequentially it would create a vicious circle (the positive loop 4) to cause more risk in 'performance unavailable' and more risk in 'revenue loss' again. As sated above, the 'performance unavailable' would also be likely to cause 'contract disputes' risk event that contract parties argue each other for whom should be take responsibility for defective issues. The more 'contract disputes' are, the more 'contract remedies/penalties' would incur to settle the disputes. Consequentially, it would create a vicious circle (the positive loop 5) to join the positive loop 3 to cause more risk in 'performance unavailable' and then more risk in 'revenue loss.' In general, the 'system break' risk event would result in compounding consequences on 'revenue loss' through these five feedback dynamics over the operation phase.

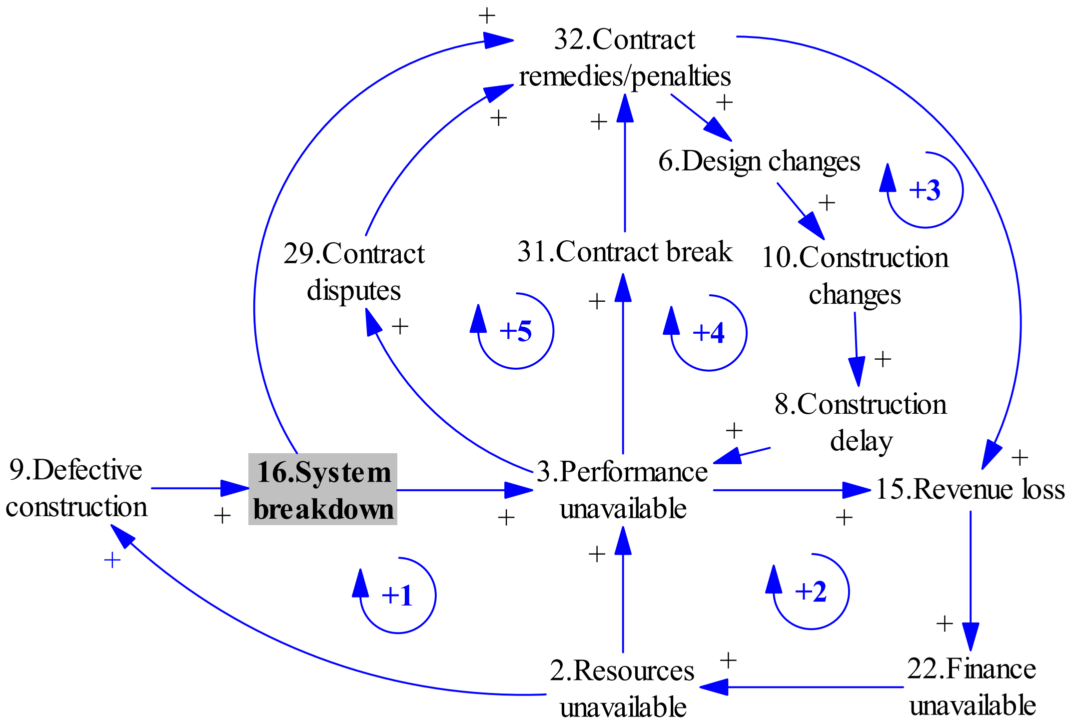


Figure V16 Cause Loop Diagram for 'System Breakdown' Risk Event

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for the cases, Hodge (2004)'s case study in the Melbourne City Link indicated that the tunnel was closed due to the defective construction on cracking and leaking. In addition, the Ghosh & Jintanapakanont (2004)' case study in the Thailand Underground Rail Project reflected that the system breakdown has significant impact on services delivery.

V17. High maintenance frequency

The "high maintenance frequency" refers to the risk that the additional cost and time delay to deliver services because the mean-time-between-repairs cannot meet the service output requirements.

As shown in Figure V17, the 'high maintenance frequency' would directly lead to 'low operating productivity' since the infrastructure cannot deliver services when it is under maintenance. It would further result in positive loop 1, 2, and 3 as described in '#13 Low operating productivity.' Moreover, 'high maintenance frequency' would also directly cause 'revenue loss' due to the maintenance costs are more than expected. In general, the 'high maintenance frequency' risk event would result in compounding consequences on 'revenue loss' through these three feedback dynamics over the operation phase.

The 'high maintenance frequency' would be likely to be triggered by the 'defective construction' that the system which is built cannot be maintained as required in the PPP contract (Hodge, 2004); 'complex system interface/integration' that the system which is built is difficult to interface with or incompatible with other public systems so that it makes low operating efficiency (PAC, 2002a; PAC, 2005a).

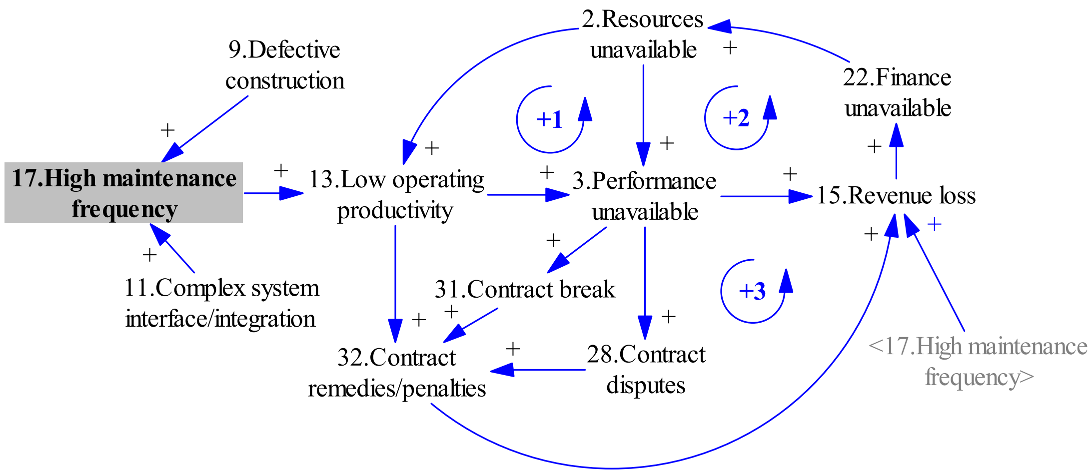


Figure 4.2 (17) Cause Loop Diagram for 'High Maintenance Frequency' Risk Event

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. In addition, the Ghosh & Jintanapakanont (2004)' case study in the Thailand Underground Rail Project reflected that the high maintenance frequency has significant impact on services delivery.

V18. Accidents and safety issues

The 'accidents and safety issues' refers to the risk that the loss and time delay to deliver services due to the frequent accidents and safety issues which cannot meet the service output requirements.

As shown in Figure V18, the 'accidents and safety' would lead to 'performance unavailable' that the infrastructure is not able to deliver services as the contract requirements (Ghosh & Jintanapakanont, 2004). It would further result in positive loop 1, 2, and 3 as described in '#13 Low operating productivity.' In general, the 'accidents and safety issues' risk event would result in compounding consequences on 'revenue loss' respectively through these three feedback dynamics over the operation phase.

The 'accidents and safety' would be likely to be triggered by the 'defective construction' that the infrastructure is defective (Hodge, 2004); 'resources unavailable' that the quantity and quality of the materials, equipment, and manpower required for operate are inadequate; 'complex system interface/integration' that the system which is built cannot interface with or incompatible with other systems well (EC, 2002; NAO, 2004a); 'Force Majeure' that the naturally unexpected events or man-made events are beyond the control of both public and private parties which would likely affect the safety of system (Ghosh & Jintanapakanont, 2004).

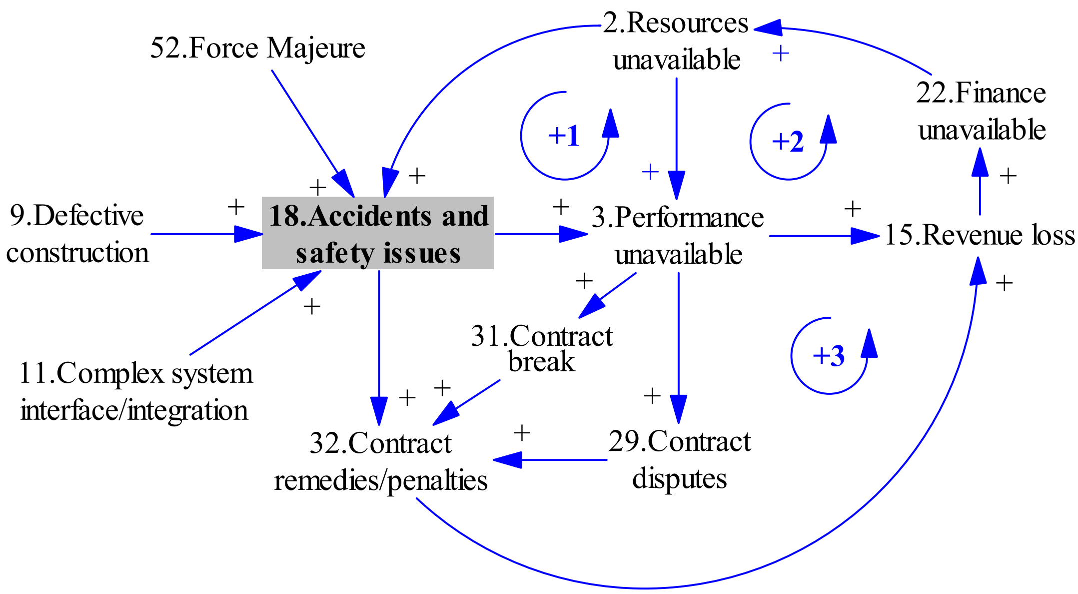


Figure V18 Cause Loop Diagram for 'High Maintenance Frequency' Risk Event

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for the cases, the European Commission's report (EC, 2002) and the National Audit Office's report (NAO, 2004a) on the London Underground indicated the Underground has potential safe issues that the PPP infrastructure contractors, Infrocos, must inspect and maintain asset in a way that meets safety standards set out in contract. In addition, the Ghosh & Jintanapakanont (2004)' case study in the Thailand Underground Rail Project reflected that the accident is one of the biggest risks that this project need to be controlled and dealt to ensure provide a safe transport system.

V19. Price escalation

The 'price escalation' refers to the possibility that the labour, material and equipment costs for infrastructure construction and operation are unexpectedly increased.

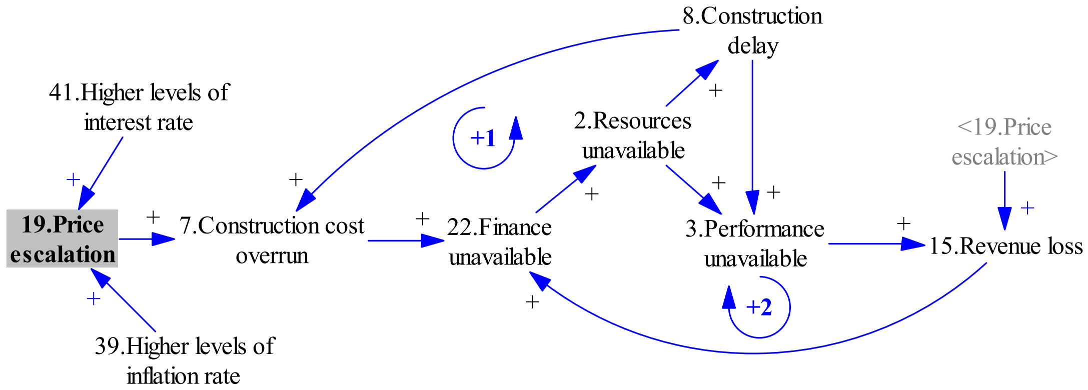


Figure V19 Cause Loop Diagram for 'Price Escalation' Risk Event

As shown in Figure V19, at the construction stage the 'price escalation' risk event would lead to the 'construction cost overrun' since the labor material and equipment costs for infrastructure construction are increased (Hodge, 2004). The 'construction cost overrun' would possibly lead to 'finance unavailable' due to running out of capital needed for construction. This would likely further lead to 'resources unavailable' that there is no adequate money to purchase materials and equipment or to recruit skilful manpower for infrastructure. It would result in 'construction delay' at construction and then 'construction cost overrun' that extra costs incurred in maintaining the existing materials and equipment, purchasing new materials and equipment, and paying for recruited manpower during the construction time delay. Consequentially it would create a vicious circle (the positive loop 1) to cause more risk in 'resources unavailable', more 'construction delay' and 'construction cost overrun'. On the other hand, at operation stage the 'construction delay' would also cause 'performance unavailable', from which the infrastructure won't be ready to deliver its services. It would lead to 'revenue loss' so that there's not enough credit to repay the debt which will result in 'financial unavailable.' Consequentially it would create a vicious circle (the positive loop 2) to cause yet again more risk in 'resources unavailable' so that more 'construction delay' and 'performance unavailable' resulting in more 'revenue loss.' Moreover, the 'price escalation' would directly lead to the 'revenue loss' since the labor, material and equipment costs for infrastructure operations are increased (EC, 2002; Lu, 2004), which would create the positive loop 2 as well to result in more risk in 'revenue loss.' In general, the 'price escalation' risk event would result in compounding consequences on 'construction cost overrun' and 'revenue loss' respectively through these two feedback dynamics over the construction and operation phase.

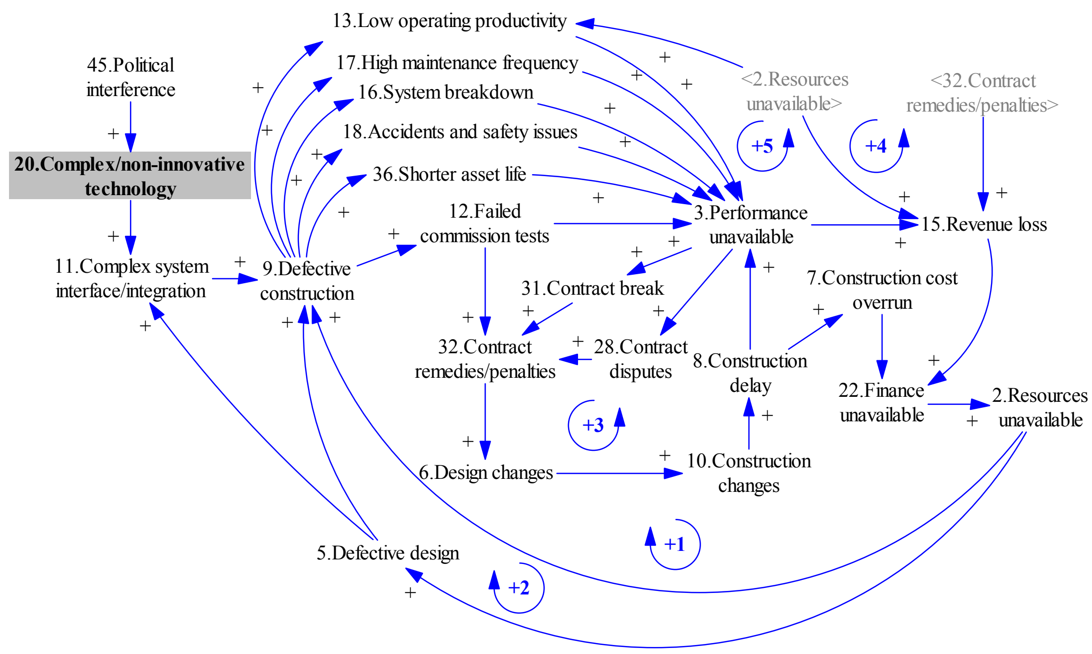
The 'price escalation' would be likely to be triggered by the risk events such as 'higher levels of inflation rate' and "higher levels of interest rate" that would make cost increased for manpower, material and equipment (EC, 2002; Lu, 2004).

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for the cases, the European Commission's report (EC, 2002) indicated that the infrastructure companies, Infracos, should take the risks of changes in the projected costs due to inflation or other factors. In addition, as shown in Lu (2004)'s case study, in 1992 China government deregulated the prices of major building materials, i.e. still reinforcing bars, cement and timber, etc., which led to the costs of labour, materials and equipments used for infrastructure projects were soared.

V20. Complex/non-innovative technology

The 'complex/non-innovative technology' refers to the risks that the selected technology used for engineering or services is technically complex or expensive to maintain, or market volatility results in early obsolescence, or not innovated enough to keeping pace with competition and/or public requirements.

As shown in Figure V20, the 'complex/non-innovative technology' would be likely to cause 'complex system interface/integration' risk event because the applied technology is not only able to solve but to create the system interface/integration issues (NAO, 2006). The 'complex system interface/integration' would further be likely to cause 'defective construction' because the system which is built is possibly difficult to interface with or incompatible with other public systems. Then the further consequences arisen from 'defective construction' is the same as described above in Section (9) Defective construction and (11) Complex system interface/integration. In general, the 'complex/non-innovative technology' risk event would result in compounding consequences on 'construction cost overrun' and 'revenue loss' respectively through these five feedback dynamics over the construction and operation phase.



FigureV20 Cause Loop Diagram for 'Complex/Non-innovative Technology' Risk Event

The 'complex/non-innovative technology' would be likely to be triggered by the 'political interference' that the public authority would make a decision under the political pressure to choose technically complex, expensive to maintain, or market volatility results in early obsolescence, or not innovated enough to keeping pace with competition and/or public requirements (EC, 2004b).

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for the case, for example, the PPP project for Airwaves, UK has such a risk. As described above, this project needs a very high degree of interoperability between different forces throughout the UK. However, the wide range of systems for high degree of interoperability is likely to present additional problems in the future by being more complex to maintain and upgrade as technology continues to develop (PAC, 2002a).

Moreover, as occurred in PFI contract for the National Physical Laboratory, the project contractor could not meet the highly-complex technical challenging requirements and then fail to deliver the required performance. Consequently it would lead to contract default and termination (NAO, 2006).

V21. Poor cooperation/coordination

The 'poor cooperation and coordination' refers to the risk that the cooperation and coordination within a party and among different industrial parties including public party, private party and third parties cannot work well over contracting periods, which may lead to inefficient project performance and time delay at construction and operation phase.

As shown in Figure V21, at the construction stage, the 'poor cooperation and coordination' risk event would lead to 'construction delay' because the public party, private party and third parties cannot work well over contracting periods, which may lead to inefficient project performance and time delay (EC, 2002; Lu, 2004). The 'construction delay' would likely lead to 'construction cost overrun' due to the extra costs that are likely to incur in maintaining the purchased materials, equipment and paying for recruited manpower during the construction time delay, which lead to 'financial unavailable' that run out of money for construction. As stated above, the 'financial unavailable' would lead to 'resources unavailable' due to no enough money to recruit manpower and purchase materials and equipment for construction, which would therefore cause 'construction delay.' Consequently, this would create a vicious circle (the positive loop 1) to make more risk in 'construction delay.' Moreover, the 'construction delay' would also lead to 'performance unavailable' that the infrastructure won't be ready to deliver its services, which would result in 'revenue loss.' 'Revenue loss' would lead to 'financial unavailable' since there's no enough credit to repay the debt. Furthermore, as previous description, the 'financial unavailable' would likely lead to 'resources unavailable' due to no enough money to recruit manpower and purchase materials and equipment for performance. Consequentially it would create a vicious circle (the positive loop 2) to cause more risk in 'performance unavailable' and more risk in 'revenue loss.' In addition, the 'performance unavailable' arisen from 'construction delay' would be likely easy to cause 'contract disputes' risk that contract parties argue each other for whom should be take responsibility for delay in operating. The more 'contract disputes' are, the more 'contract remedies/penalties' would incur to settle the disputes. This would result in 'construction cost overrun', which consequentially join positive loop 1 to make more risk in 'construction delay' and then more risk in 'performance unavailable' On the other hand, the 'poor cooperation and coordination' would directly lead to 'performance unavailable' (EC, 2002; Lu, 2004) which would cause 'contract break' which would lead to 'contract remedies/penalties' actions which result in more 'revenue loss.' Consequentially it join positive loop 2 to make more risk in 'performance unavailable' and then more risk in 'revenue loss.' In general, the 'poor cooperation and coordination' risk event would result in compounding consequences on 'construction cost overrun' and 'revenue loss' respectively through these three feedback dynamics over the construction and operation phase.

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for case, the European Commission's report (EC, 2002) on the London Underground criticized that the operating company, LUL, must cooperate with the infrastructure companies, Infrascos, one another in performing services under the PPP contract as a key objective. If LUL fails to do so, Infraco can claim compensation for costs and relief from performance. In addition, as shown in Lu (2004)'s case study on the Yangtz River Three Gorges, the join ventures project has coordination difficulties among different parties.

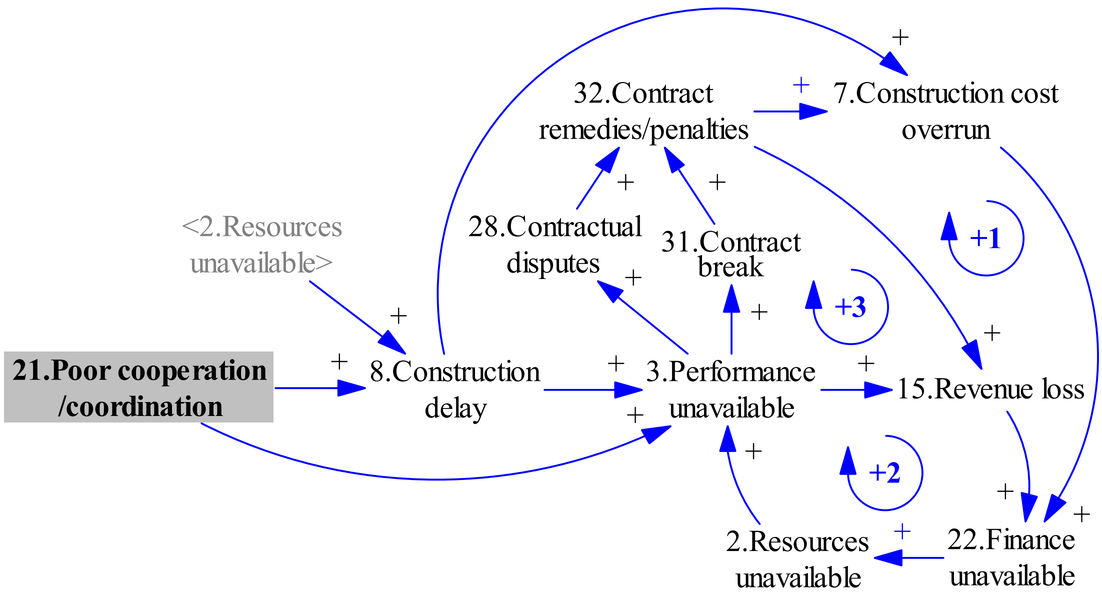


Figure V21 Cause Loop Diagram for 'Complex/Non-innovative Technology' Risk Event

V22. Finance unavailable

The "finance unavailable" refers to the risk that when debt and/or equity required by the project are not available on the amounts and on the conditions anticipated to performing project.

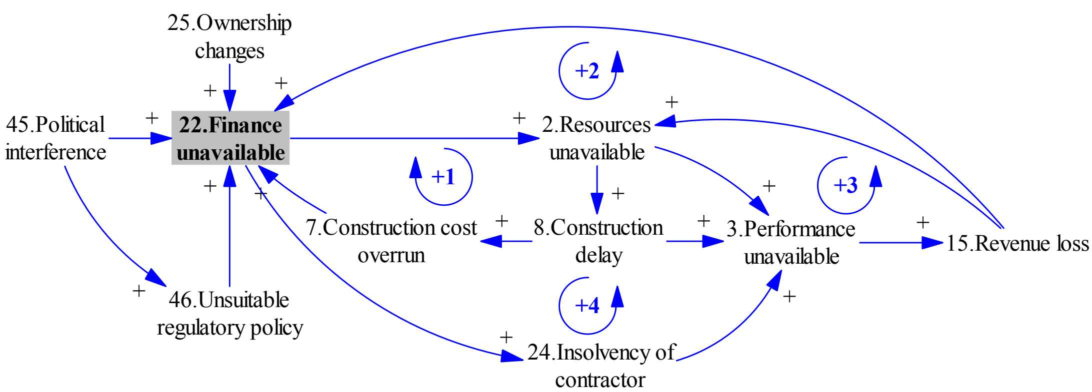


Figure V22 Cause Loop Diagram for 'Finance Unavailable' Risk Event

As shown in Figure V22, the 'finance unavailable' risk event would cause 'resources unavailable' due to no enough money to employ manpower, materials and equipment that are required to build and operate infrastructure (PAC, 2006a). At the construction stage, the 'resources unavailable' would cause 'construction delay' due to inadequate quantity and quality of manpower, materials and equipment that are available to build infrastructure, which would be likely further the cause of 'construction cost overrun' since the extra costs were incurred in maintaining the purchased materials, equipment and paying for recruited manpower during the construction time delay. Furthermore, the 'construction cost overrun' risk would possibly lead to 'finance unavailable' due to running out of money borrowed from the financial institutes. Consequentially it would create a vicious circle (the positive loop 1) to cause more risk in 'finance unavailable' and then more risk in 'construction cost overrun. The 'construction delay' would also cause 'performance unavailable', from which the infrastructure won't be ready to deliver its services. It would lead to 'revenue loss' so that there's not enough credit to repay the debt, which will result in 'financial unavailable.' Consequentially it would create a vicious circle (the positive loop 2) to cause yet again more risk in 'resources unavailable' so that more 'construction delay' and 'performance unavailable' resulting in more 'revenue loss.' At the operation stage, the 'resources unavailable' risk event would directly cause 'performance unavailable' due to inadequate quantity and quality of manpower, materials and equipment which are required to deliver its services efficiently. It would lead to 'revenue loss' and further 'financial unavailable' again, which will create a vicious circle (the positive loop 3) to cause more risk in 'resource unavailable' which leads to more 'performance unavailable' and then more 'revenue loss'. Furthermore, the 'finance unavailable' would also directly cause 'insolvency of contractor' that the contractor is completely unable to provide the service any longer due to financial difficulty, which would further lead to 'performance unavailable' again (PAC, 2001). Consequentially, it would create a vicious circle (the positive loop 4) to cause 'revenue loss' which would result in more risk in 'financial unavailable.' In general, the 'financial unavailable' risk event would result in compounding consequences on 'construction cost overrun' and 'revenue loss' respectively through these four feedback dynamics over the construction and operation phases.

The 'finance unavailable' risk event would be likely to be triggered by the 'ownership changes' (PAC, 2006a) that would result in a weakening in its financial standing or support or other detriment to the project because there would be a great time delay to contract a new owner with financial support to deliver services; 'unsuitable regulatory policy' and 'political interference' (Lu, 2004; PAC, 2003c) that the financial difficulties arisen from that the government authorities allow a low equity-debt ratio of project financing but the political imperatives make an inflexible pricing cap for service delivery conflicting with the principles of market regulation; 'construction cost overrun' that the party runs out of capital needed for construction (Flyvbjerg et al., 2003; Reilly, 2005); 'revenue loss' that the party runs out of capital needed for operation (PAC, 2003c).

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for the case of this risk, for example, it may happen in Channel Tunnel Rail Link. The UK Public Account Committee (PAC) warned that the future demand for the Link project is less than the projected leads to the weaker financial capability of the project contractor, LCR, to repay the construction costs, especially when LCR has not adequate equity capital to reflect the high level of commercial risks and sustain the project performance. As the result, the government authority, Department for Transport (TfT), had to provide more and more financial support at taxpayer's costs. The PAC suggested that in considering such major projects in future, the government authorities need to satisfy themselves that there is reasonable consistency between the degree of risk transfer and the extent of investors' equity stake in the project (PAC, 2006a).

Another case is PPP project for National Air Traffic Services (NATS), UK. The project contractor, NATS, faced financial crisis on downturn in income due to less demand than expected in the air traffic volume. The government authority tried to relax the price cap on NATS to share this risk between NATS, its investors, and its customers. However, before such a solution is negotiated, NATS is unable to access the commercial funds it required to invest in new capacity (PAC, 2003c).

V23. Refinance liabilities

The "refinance liabilities" refers to the risk that at completion or other stage in project development the project finances can be restructured to materially reduce the private sector's finance costs and lead to increase the public sector's liabilities.

As shown in Figure V23, the 'refinance liability' risk event would cause 'construction cost overrun' at construction stage and 'revenue loss' at operation stage respectively since the public sector needs to take risk costs in refinance liability arisen from the refinancing benefits of the private sector (NAO, 2005; PAC, 2006c; PAC, 2006b). Then the 'construction cost overrun' and 'revenue loss' would be likely to create two vicious circle (positive loop 1 and 2) to make more risk in 'finance unavailable' which would likely take more risk in 'refinance liability.' In general, the 'financial unavailable' risk event would result in compounding consequences on 'construction cost overrun' and 'revenue loss' respectively through these two feedback dynamics over the construction and operation phase.

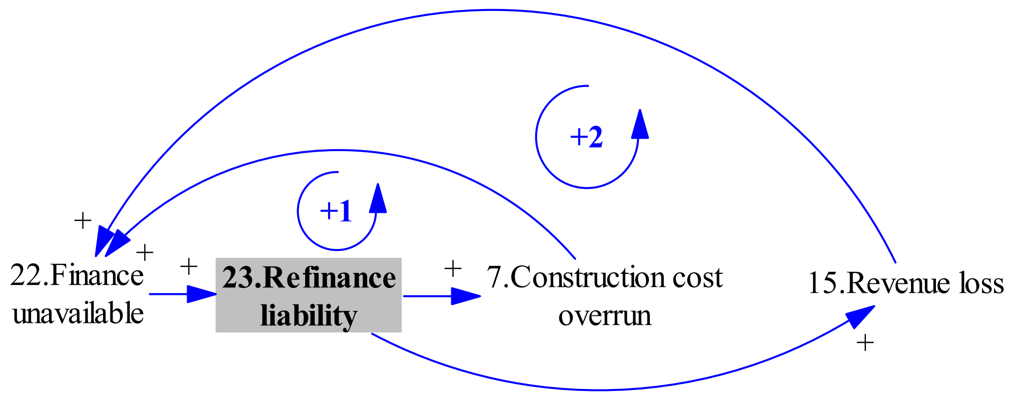


Figure V23 Cause Loop Diagram for 'Refinance Liability' Risk Event

The 'refinance liability' risk event would be likely to be triggered by the 'finance unavailable' that the project contractor needs to gain new finance support due to being incapability to pay debt (NAO, 2004b; PAC, 2003c).

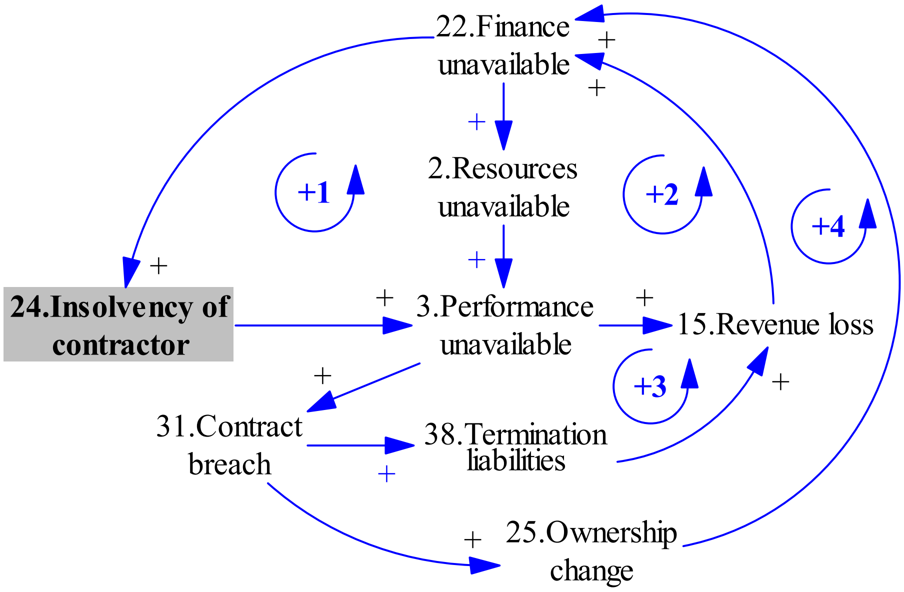
This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. One of the cases for this risk is PPP project for National Airport Traffic Services (NATS). The UK Public Account Committee (PAC) reported that the unsuitable regulatory policy of government authority didn't require a strong financial structure for the PPP project bidders, which led to the financial risks that the project contractor, NATS, has no insufficient equity capital to deal with adverse event like less revenue due to less demand on international air traffic volume (PAC, 2003c). To solve this problem, it is necessary to make re-financing for NATS to have a much more robust financial capability, enabling it to make further vital investment to expand the capacity of air traffic control to meet future growth and limit delays. However, to obtain this solution, it required concessions from shareholders and financial institutions to ensure this solution was a realistic option, which took much time and immense challenge (NAO, 2004b). The UK National Audit Office warned that "the decision on how to take the refinancing gains should always be based on value for money considerations but there may also be accounting and financing issues for public authorities to consider.(NAO, 2005)"

In addition, the BBC NEWS reported on 15th of January, 2007 (BBC NEWS, 2007) that the Paris Commercial court has approved for a major debt restructuring plan to cut the operator's debt to £2.84bn ($5.6bn) from £6.2bn. The Link operator, Euro-tunnel, has been struggling after running up debts building the tunnel.

Moreover, as occurred in the Norfolk and Norwich PFI Hospital project, the UK Public Account Committee (PAC) criticized that the project contractor, Octagon, took much gains to boost its investment return from the project refinancing, but the government authority, the Trust, could be left with liabilities now include not just the cost of the hospital but all the additional borrowings of Octagon (PAC, 2006c). The other cases like the PFI contract for the BBC's White City 2 Development (PAC, 2006b) and PFI contract for the Darent Valley Hospital (NAO, 2005) have the same risk on refinance liabilities caused by refinance benefits of the private sector.

V24. Insolvency of contractor

The "insolvency of contractor" refers to the possibility of the insolvency of private party that it is unable to provide the required services.



<u>Figure V24 Cause Loop Diagram for 'Insolvency of Contractor' Risk Event</u>

As shown in Figure V24, the 'insolvency of contractor' would cause 'performance unavailable' since the operating party is completely not able to deliver services any longer due to financial difficulty (Ghosh & Jintanapakanont, 2004; PAC, 2001). As previous prescriptions, the 'performance unavailable' would likely to lead to 'revenue loss' because the infrastructure is not ready to operate, which would further result in 'financial unavailable.' Consequentially it would create a vicious circle (the positive loop 1) to cause more risk in 'insolvency of contractor.' Moreover, the 'financial unavailable' would also lead to 'resources unavailable' that the contract parties has no adequate money to employ the required materials, equipment and manpower from suppliers to deliver services. Consequentially, it would create a vicious circle (the positive loop 2) to cause more risk in 'finance unavailable' which causes in more risk in 'resources unavailable' and then more risk in 'performance unavailable.' On the other hand, 'performance unavailable' would lead to 'contract break' that the operate party cannot fulfill the contract of its obligation to deliver services any longer due to insolvency. This would be likely to cause 'termination liability' that the compensation has to be paid for contract termination, which would consequentially create a vicious circle (the positive loop 3) to cause more risk in 'revenue loss' which would join the positive loop 2 to lead to more risk in 'finance unavailable' and thus more risk in 'contract break' again. In addition, 'contract break' would also lead to 'ownership change' since the original operate party cannot fulfill the contract of its obligation to deliver services any longer, which would consequentially create another vicious circle (the positive loop 4) to cause more risk in 'finance unavailable' because there would be a great time delay to contract a new owner with financial support to deliver services. The positive loop 4 would join the positive loop 3 to reinforce more risk in 'finance unavailable' and thus more risk in 'performance unavailable.' In general, the 'insolvency of contractor' risk event would result in compounding consequences on 'revenue loss' through these four feedback dynamics over the operation phase.

The 'insolvency of contractor' would be likely to be triggered by 'finance unavailable' that the operating contractor cannot deliver the required services any longer due to financial difficulties (PAC, 2001).

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As occurred in PFI contract for the Royal Armouries Museums in Leeds, the UK Public Account Committee (PAC) criticized that when the project contractor, RAI, faced with the possible insolvency and the consequent disruption to operations, the government authority didn't use the full strength of its commercial position as well as their legal rights to get the best possible solution for the taxpayer (PAC, 2001).

In addition, as Ghosh & Jintanapakanont (2004)' case study in the Thailand Underground Rail Project, the delay due to the financial difficulties with contractors is one of the most important components for project delivery delay.

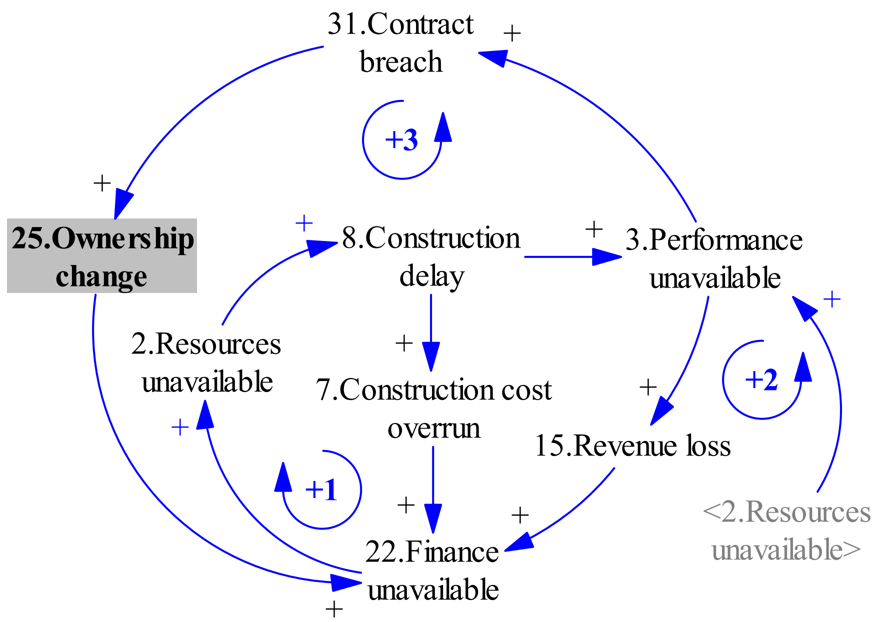
V25. Ownership change

The 'ownership change' refers to the risk that a change in ownership would result in a weakening in its financial standing or support or other detriment to the project.

As shown in Figure V25, the 'ownership change' would be likely to cause 'finance unavailable' (PAC, 2006a) since there would be a great time delay to contract a new owner with financial support to deliver services, which would further lead to 'resources unavailable.' As stated in (2) Resources unavailable, at the construction stage, the 'resources unavailable' would be likely to create a vicious circle (the positive loop 1) to cause more risk in 'construction delay', more risk in 'construction cost overrun', and more risk in 'finance unavailable.' Moreover, the 'construction delay' would also cause 'performance unavailable', from which the infrastructure won't be ready to deliver its services. It would lead to 'revenue loss' so that there's not enough credit to repay the debt, which will result in 'financial unavailable.' Consequentially it would create a vicious circle (the positive loop 2) to cause yet again more risk in 'resources unavailable' so that more 'performance unavailable' resulting in more 'revenue loss' resulting in more 'finance unavailable.' On the other hand the 'performance unavailable' would be also likely lead to 'contract breach' since operating party cannot deliver its services, which would create another vicious circle (the positive loop 3) to cause more risk in 'ownership change.' In general, the 'ownership change' risk event would result in compounding consequences on 'construction cost overrun' and 'revenue loss' respectively through these three feedback dynamics over the construction and operation phases.

The 'ownership change' would be likely to be triggered by 'contract break' that the operating contractor cannot deliver the services as contract requirements (Hodge, 2004).

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for the case, it may happen in Channel Tunnel Rail Link. The UK Public Account Committee (PAC) warned that the current project contractor, LCR, may not able to hold the ownership of the Link project to provide services in the future due to financial problems on the uncertainties such as less revenues and construction overrun. Any future changes to the ownership of LCR will need to protect the interests of the taxpayer (PAC, 2006a).



<u>Figure V25 Cause Loop Diagram for 'Ownership Change' Risk Event</u>

V26. Tax increases

The 'tax increases' refers to the risk that tax is increased before or after completion, which will affect the project financial performance.

As shown in Figure V26, the 'tax increases' would directly cause 'revenue loss' (Lu, 2004) since the project service revenue is taxed more than the expected, which would further lead to 'finance unavailable' because the operate party has no enough credits to pay debt. It would further cause 'resource unavailable' that the operate party has no adequate money to employ the required materials, equipment and manpower from suppliers to deliver services, which would likely lead to 'performance unavailable.' Consequentially, it would create a vicious circle (the positive loop 1) to cause more risk in 'revenue loss' so that more 'finance unavailable' resulting in more 'resource loss', and more 'performance unavailable' resulting in more risk in 'revenue loss.' In general, the 'tax increases' risk event would result in compounding consequences on 'revenue overrun' through this feedback dynamics over the operation phases.

The 'tax increases' would be likely to be triggered by 'law/policy changes' that the government authority increases tax rate more than expected (Lu, 2004).

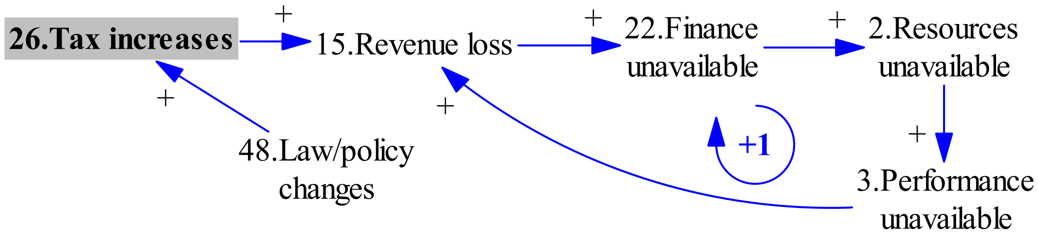


Figure V26 Cause Loop Diagram for 'Tax Increase' Risk Event

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for the case, Lu (2004)'s case study on Xiaolangdi Project on Yellow River (China) indicated both domestic and foreign contractors for this project were required to pay the taxes at increased rates because China government implemented a tax reform after signing contract.

V27. Insurance increases

The 'insurance increase' refers to the possibility that the agreed project insurances become insurable or substantially increases in the rates at which insurance premiums are calculated.

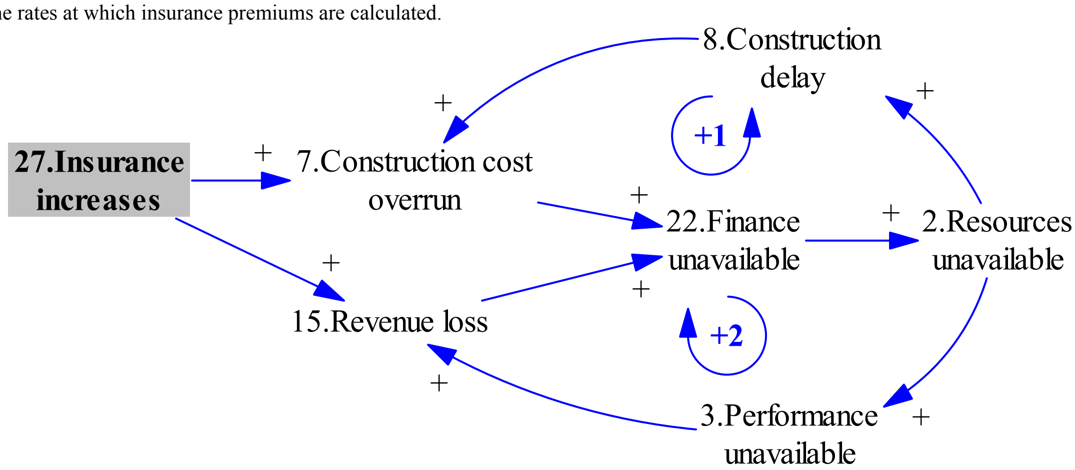


Figure V27 Cause Loop Diagram for 'Insurance Increases' Risk Event

As shown in Figure V27, the 'insurance increases' would directly cause 'construction cost overrun' (Lu, 2004) at construction stage and 'revenue loss' at operate stage respectively, which would further lead to 'finance unavailable' because the operate party has no enough credits to pay debt. As previously stated, this would further cause 'resources unavailable' that the contractors have no adequate money to employ the required materials, equipment and manpower from suppliers to deliver services, and then further cause 'construction delay' at the construction stage and 'performance unavailable' at operation stage respectively. These would create two vicious circles (positive loop 1 and 2) to cause more risk in 'construction cost overrun' and 'revenue loss' respectively. In general, the 'insurance increase' risk event would result in compounding consequences on 'construction cost overrun' and 'revenue loss' respectively through these two feedback dynamics over the construction and operation phases.

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for the case, Lu (2004)'s case study on BOT contract for the Laibin B Power Plant indicated that the project contract shall take risk at insurance increases for cargo transportation, third party liability, property loss, etc.

V28. Contractual disputes

The 'contractual disputes' refers to the risk of time delay and additional costs to solve contractual disputes.

As shown in Figure V28, the 'contractual disputes' would be likely to directly cause 'contract remedies/penalties' (Hodge, 2004) which would be likely to further cause 'construction cost overrun' at construction stage and 'revenue loss' at operating stage respectively since the additional costs are needed to settle the disputes. As previously stated, both of 'construction cost overrun' and 'revenue loss' would be likely lead to 'finance unavailable' due to running out of credits available to pay debt, which would be likely to result in 'resource unavailable' that the contractors has no adequate money to employ the required materials, equipment and manpower from suppliers to deliver services. Consequentially, it would create two vicious circles: the positive loop 1 would cause more risk in 'construction delay' which would cause more risk in 'construction cost overrun' at construction stage, and the positive loop 2 would cause more risk in 'performance unavailable' which would cause more risk in 'revenue loss' at operation stage. Moreover, the 'contract remedies/penalties' would directly cause 'construction delay' because it is necessary to take the additional time to solve disputes. This would cause 'construction cost overrun' to reinforce the positive loop 1 to make more risk in 'construction cost overrun', and cause 'performance unavailable' to reinforce the positive loop 2 to make more risk in 'revenue loss.' Furthermore, as the previous description, 'performance unavailable' would lead to 'contract break' that infrastructure performance cannot meet contract requirements and then it'll be necessary to take 'construction remedies/penalties' risk to fix defective issues. Consequentially, it would create a vicious circle (the positive loop 3) to cause more risk in 'construction delay' which would cause more risk in 'revenue loss' yet again. In general, the 'contractual disputes' risk event would result in compounding consequences on 'construction cost overrun' and 'revenue loss' respectively through these three feedback dynamics over the construction and operation phases.

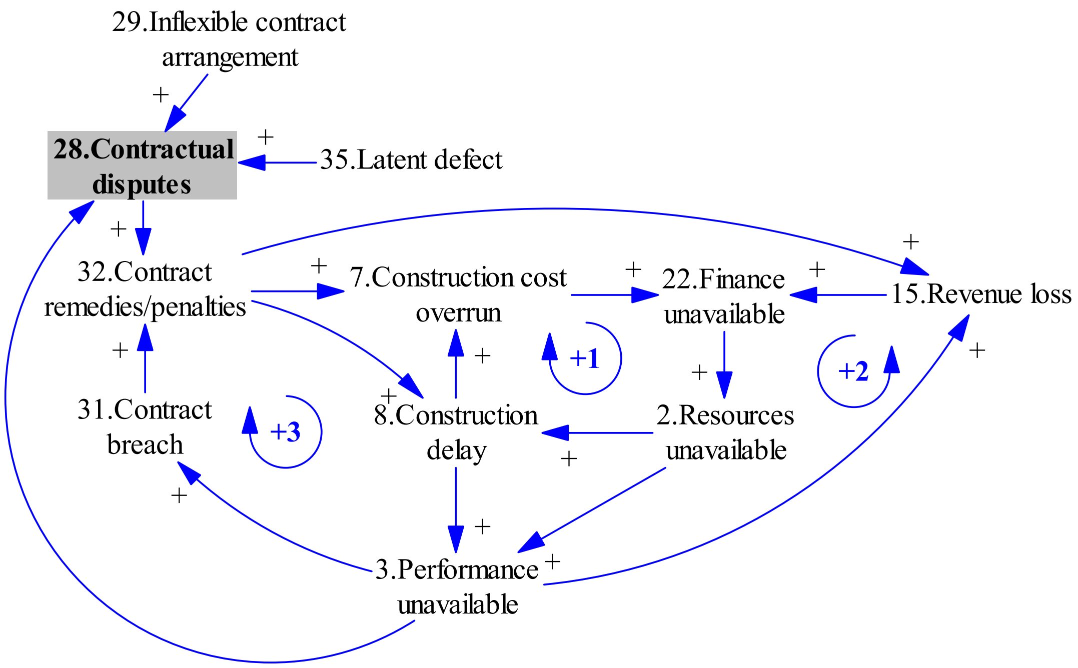


Figure V28 Cause Loop Diagram for 'Contractual Disputes' Risk Event

The 'contractual disputes' would be likely to be triggered by 'performance unavailable' that the contract parties argue each other for whom should be take responsibility for defective issues which result in performance failure (Hodge, 2004); 'inflexible contract arrangement' that the PPP contract lacks a change mechanism to incorporate appropriate arrangements for dealing with the necessary variants of long-term project life and enough room for innovation (EC, 2004b); 'latent defect' that the contractual claims would be likely to be arisen from the technologies that the project contractors employ to build and perform the existing infrastructure have been infringed the third-party patents (EC, 2002).

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for the cases, the Hodge (2004)'s case study on the Melbourne City Link indicated that the project contractor, Transurban, initiated an AUD$37 million claim against the government authority for compensation for financial loss due to contract breach. Moreover, the project subcontractor, TOJV, initiated litigation against the project contractor for negligence in the design of two City Link tunnels. The Ghosh & Jintanapakanont (2004)' case study on the Thailand Underground Rail Project also reflected that the contractual issues and disputes was the fundamental risk in project management .

V29. Inflexible contract arrangement

The 'inflexible contract changes' refers to the risk of time delay and additional costs to change the contract contents due to inflexible contract change mechanism.

As shown in Figure V29, the 'inflexible contract arrangement' would be likely to directly cause 'contractual disputes' (EC, 2004b), which would cause 'contract remedies/penalties' since the additional time and costs are needed to settle the disputes. As previously stated in (28) Contractual disputes, consequently the 'inflexible contract arrangement' would result in compounding consequences on 'construction cost overrun' and 'revenue loss' respectively through three feedback dynamics (the positive loops 1, 2, and 3) over the construction and operation phases respectively. Moreover, the 'inflexible contract arrangement' would be likely to directly cause 'delay in contract change negotiation' (Ghosh & Jintanapakanont, 2004; PAC, 2003c), which is described in "#30 Delay in contract change negotiation." Furthermore, the 'inflexible contract arrangement' would be likely to directly cause 'mis-pricing' because the inflexible contract change mechanism like the fixed-cost contract that didn't allow the service price cap to change according to the actual market demand variants in the long-term project life so that the project contractor is unable to deliver services due to financial difficulties (NAO, 2004b; PAC, 2003c). In general, the 'inflexible contract changes' risk event would result in compounding consequences on 'construction cost overrun' and 'revenue loss' respectively through these three feedback dynamics over the construction and operation phases.

The 'inflexible contract changes' would be likely to be triggered by 'unsuitable regulatory policy' because traditionally the public sector like tightly defined contract documents without flexible change mechanism so not prone to different interpretations (Lu, 2004; PAC, 2003c).

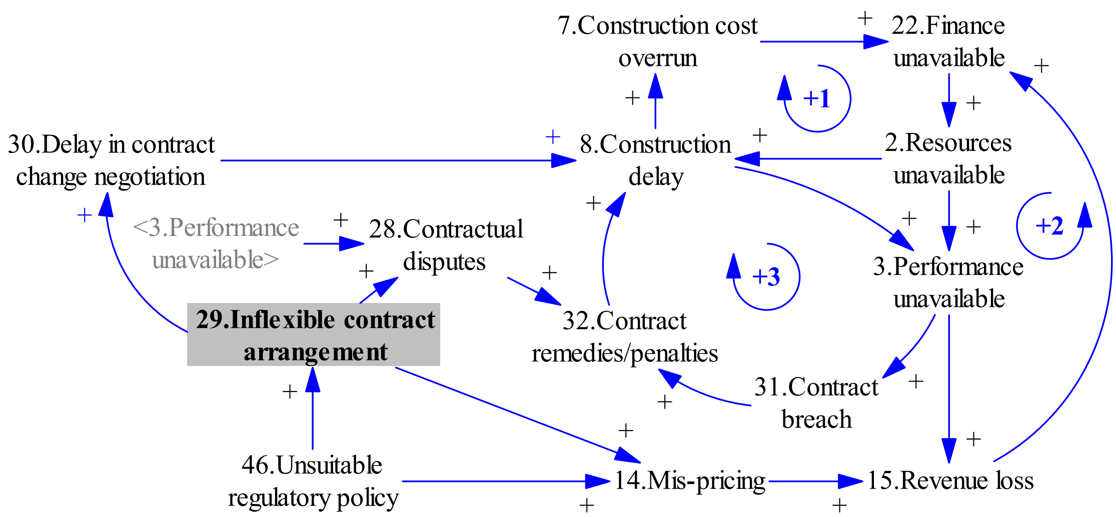


Figure V29 Cause Loop Diagram for 'Inflexible Contract Arrangement' Risk Event

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. In addition, as the case of PPP project for National Air Traffic Services (NATS), UK described above, the project contractor, NATS, faced financial difficulties due to less demand than expected in the air traffic volume, especially the government authority didn't allow the price cap to vary according to the amount of traffic and inflation rate. As a result, it took time and cost to reach an agreement and contract change to relax the price cap on NATS (PAC, 2003c). The National Audit Office of UK suggested that "where capital intensive businesses like NATS, that are particularly exposed to international shocks, are to have to their prices regulated, automatic mechanisms to share the risk of volume change with customers should be considered (NAO, 2004b)."

In addition, the lack of flexibility for the long-term PFI contract for the Redevelopment of MOD Main Building would need additional costs to meet future requirements that are genuinely uncertain (PAC, 2003b). As described above, European Committee's case studies (EC, 2004b) on the Nessebar "Golden Bug" Landfill project indicated this PPP project was easy to cause disputes and unable to solve disputes due to lacking flexible contract mechanism.

V30. Delay in contract change negotiation

The 'delay in contract change negotiation' refers to the risk of time delay to negotiate and arrange contract changes between the government authority and project contractor.

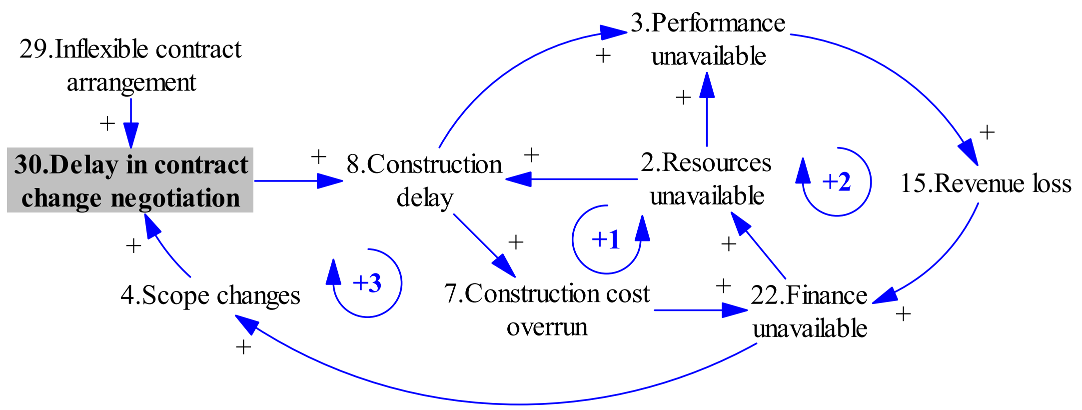


Figure V30 Cause Loop Diagram for 'Delay in Contract Change Negotiation' Risk Event

As shown in Figure V30, the 'delay in contract change negotiation' would be likely to directly cause 'construction delay' (Hodge, 2004; NAO, 2004b; PAC, 2003c) at construction stage and performance unavailable' at operating stage as well since the construction work and operation service cannot be started until reaching a change agreement between the parties. As stated above, consequently at the construction stage, the 'construction delay' would create a vicious circle (the positive loop 1) to cause more risk in 'construction cost overrun' which would cause more risk in 'finance unavailable' which would lead to more risk in 'resources unavailable' which would result in 'construction delay' and more risk in 'construction cost overrun' again yet. On the other hand, consequently at operation stage, the 'performance unavailable' would create another vicious circle (the positive loop 2) to cause more risk in 'revenue loss' which would cause more risk in 'finance unavailable' which would lead to more risk in 'resources unavailable' which result in more risk in 'performance unavailable' and more risk in 'revenue loss' again yet. Moreover, the 'finance unavailable' would be likely to cause that the construction party would likely to ask for more 'scope changes' due to no adequate money for the originally agreed scope of work definition set up in output specification. This would further cause 'delay in contract change negotiation' that the parties who involve the design and construction need to take time for negotiation to reach a change agreement. Consequently it would create a vicious circle (the positive loop 3) to make more risk in 'delay in contract change negotiation' and more risk in 'construction cost overrun' and more risk in 'revenue loss.' In general, the 'delay in contract change negotiation' risk event would result in compounding consequences on 'construction cost overrun' and 'revenue loss' respectively through these four feedback dynamics over the construction and operation phases.

The 'delay in contract change negotiation' would be likely to be triggered by 'scope changes' (NAO, 2004a) that described as above, and ''inflexible contract arrangement' that the contract documents lack flexible change mechanism to room contract changes (Ghosh & Jintanapakanont, 2004; PAC, 2003c).

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for the cases, the National Audit Office's report (NAO, 2004a) on the London Underground indicated that it would be complex to negotiate with the PPP infrastructure contractors, Infrocos, to change the service scope out of the originally agreed one in the contract due to the project operating company LUL changing its requirements. In addition, concerning the PPP project for National Airport Traffic Services (NATS), there were time delays to reach an agreement and contract change to relax the price cap varied according to the air traffic volume and inflation for project contractor, NATS (PAC, 2003c). In addition, the Ghosh & Jintanapakanont (2004)' case study in the Thailand Underground Rail Project reflected that contract change negotiation is one of the contractual issues to delay service delivery.

V31. Contract breach

The 'contract break' refers to the risk of time delay and additional costs arising from being failed in meeting contract requirements.

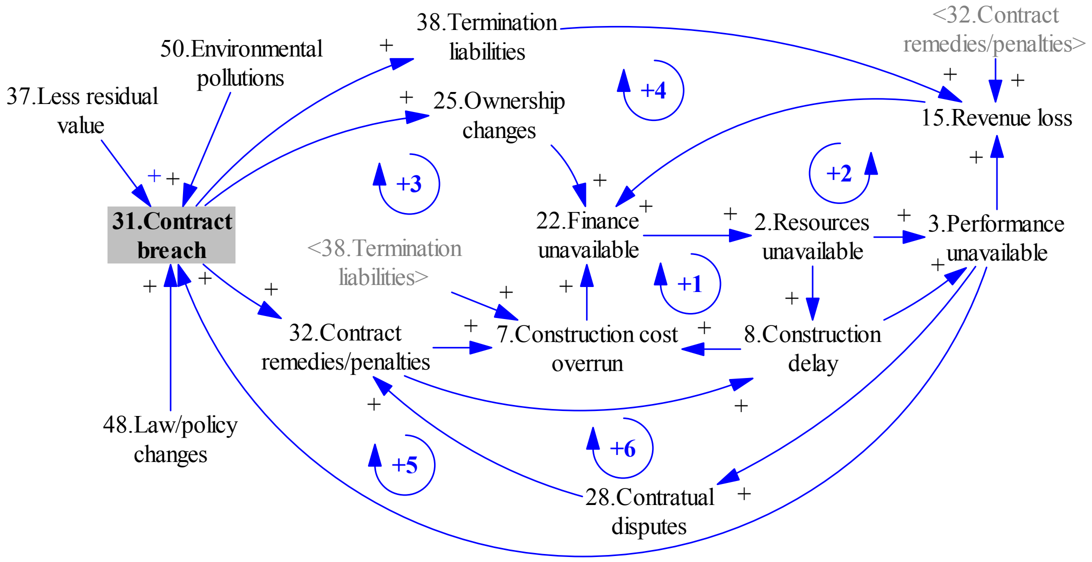


Figure V31 Cause Loop Diagram for 'Contract Break' Risk Event

As shown in Figure V31, the 'contract breach' would be likely to directly cause 'ownership change' since the project contractor cannot fulfil its contract obligation any longer (Hodge, 2004). The 'ownership change' would be likely to cause 'finance unavailable' since there would be a great time delay to contract a new owner with financial support to deliver services. This would further lead to 'resources unavailable' that there is no enough money to employ the skilled manpower and to purchase the required materials and equipment for construction and operation. As previously described, consequently this would create a vicious circle (the positive loop 1) to make more risk in 'construction delay' which would result in more risk in 'construction cost overrun' at construction stage, and another vicious circle (the positive loop 2) to make more risk in 'performance unavailable' which would result in more risk in 'revenue loss' at operation stage. Moreover, as previously stated, the 'performance unavailable' would be likely to cause 'contract breach' because the project contractor cannot deliver services that need to meet contract requirements any more. This would create a vicious circle (the positive loop 3) to make more risk in 'ownership changes.' Furthermore, the 'contract breach' would directly cause 'termination liabilities' (The Work Bank, 1999) that the possible service disruption would increase the government's liabilities at taxpayer's costs, which would be likely to result in 'construction cost overrun' at construction stage and 'revenue loss' at operation stage respectively which would result in 'finance unavailable', which would consequently create a vicious circle (the positive loop 4) to make more risk in 'contract break.' On the other hand, in case that the ownership won't change, then 'contract breach' would be likely to directly cause 'contract remedies/penalties' (Hodge, 2004) that it's necessary to take actions to remedy the problem that cannot meet contract requirements, which would cause 'construction delay' and 'construction cost overrun' at construction stage and 'revenue loss' at operation stage respectively, which would further lead to 'performance unavailable' which would consequently create a vicious circle (the positive loop 5) to make more risk in 'contract breach.' In addition, the 'performance unavailable' would be likely to cause 'contractual disputes' which cause 'contract remedies/penalties' which result in 'construction delay' and 'performance unavailable' since it needs to take additional time to settle disputes. Consequently it would create a vicious circle (the positive loop 6) to make more risk in 'contract breach' again yet. In general, the 'delay in contract change negotiation' risk event would result in compounding consequences on ‘construction cost overrun’ and ‘revenue loss’ respectively through these six feedback dynamics over the construction and operation phases.

The ‘contract break’ would be likely to be triggered by ‘law/policy changes’ that the contract performance cannot adapt to the updated law/policy (EC, 2002); ‘environmental pollutions’ that the performance cannot meet environmental regulations and contract requirements (Ghosh & Jintanapakanont, 2004); ‘less residual value’ that the value of infrastructure is less than contract requirement (EC, 2002; NAO, 2004a).

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for the cases, the Work Bank’s case study report (The Work Bank, 1999) indicated that if the BOT concession contracts for the North-South Expressway (NSE) and the Kuala Lumpur-Karak Highway (Malaysia) are terminated due to default of the concessionaire, no compensation is to be paid to the concessionaire for the loss of its rights or investment. However, where termination is due to the Government’s default, the Government will generally grant compensation for the loss suffered by the concessionaire, which would include the loss of future profits. So the Government takes full risks of default and contract termination.

In addition, it would occur in PFI contract for the New IT Systems for Magistrates' Courts: the Libra Project. The UK Public Accounts Committee criticized that the government authority didn’t terminate contract with the PFI project service contractor, LCL, when it has been failed to delivery project and break contract for London Underground. As the result, the risk transfer didn’t really take place (PAC, 2003a). Moreover, Hodge (2004)’s case study in the Melbourne City Link indicated that the project contractor, Transurban, initiated an AUD$37 million claim against the government authority for a decrease in customers and subsequent financial loss due to contract breach.

V32. Contract remedies/penalties

The ‘contractual remedies/penalties’ refers to the risk of time delay and costs for the remedies for poor performance that fails to meet any requirements of the contracts.

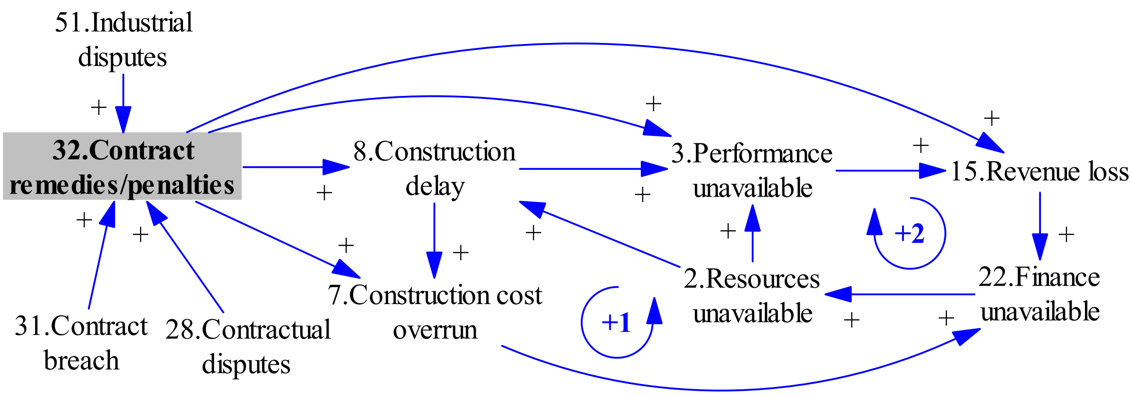


Figure V32 Cause Loop Diagram for ‘Contract Remedies/Penalties’ Risk Event

As shown in Figure V32, the ‘contractual remedies/penalties’ would be likely to directly cause ‘construction delay’ and ‘construction cost overrun’ at construction stage, and ‘performance unavailable’ and ‘revenue loss’ at operation stage as well since the additional time and costs to fix problems that make project performance failed to meet contract requirements (EC, 2002; Ghosh & Jintanapakanont, 2004; Hodge, 2004). As stated above in “(31) Contract breach,” this would create two vicious circles (the positive loop 1 and 2) to make more risk in ‘construction cost overrun’ and ‘revenue loss’ respectively.

The ‘contractual remedies/penalties’ would be likely to be triggered by ‘construction disputes’ (Hodge, 2004), ‘contract breach’ (Hodge, 2004), and ‘industrial disputes’ (EC, 2003) that it’s necessary to take actions to remedy the problems and settle the disputes arisen from the failed project performance which cannot meet contract requirements or public protects, etc.

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for the cases, the European Commission’s report indicated that the London Underground received substantial and sustained under performance, it required a range of remedies set up in the PPP contract to ensure no break in service under the contract (EC, 2002). In addition, the Hodge (2004)’s case study on the Melbourne City Link indicated the subcontractor, TOJV, needed to complete remedial work on tunnel as a result of leaks. The Ghosh & Jintanapakanont (2004)’ case study on the Thailand Underground Rail Project also reflected that the contractual issues and disputes was the fundamental risk in project management .

V33. Default of subcontractors

The ‘default of subcontractors’ refers to the risk of subcontractors/suppliers or service providers go out of business or encounter difficulties in supplying the contracted services to specification through the required life of the capability due to insolvency or incapability, which leads to the construction risks or operation risks.

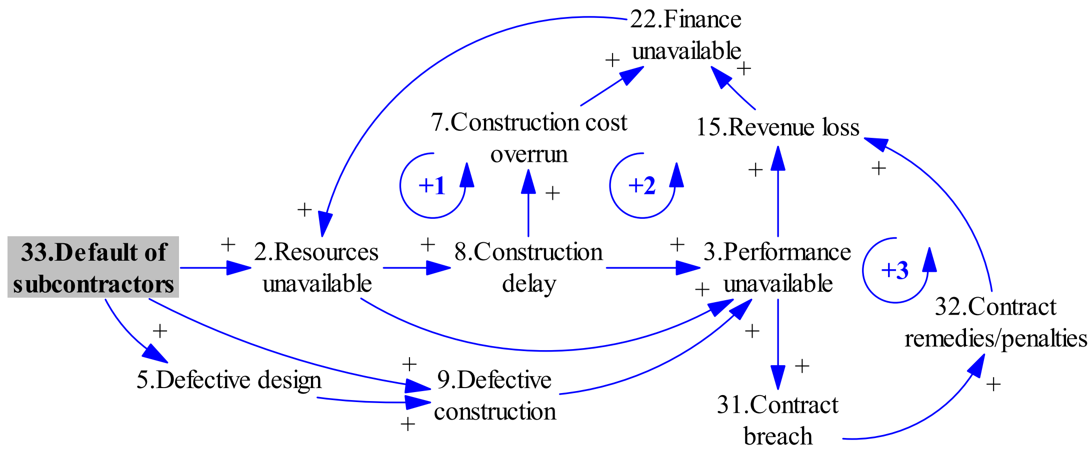


Figure V33 Cause Loop Diagram for 'Default of Subcontractors' Risk Event

As shown in Figure V33, the 'default of subcontractors' would be likely to directly cause 'resources unavailable' because the manpower, material or equipment suppliers cannot provide contracted services due to insolvency or incapability (Hodge, 2004; NAO, 2006). As previously stated, consequently this would create a vicious circle (the positive loop 1) to make more risk in 'construction delay' which would cause more risk in 'construction cost overrun' which would lead to more risk in 'finance unavailable' which would result in more risk in 'resource unavailable' at the construction stage. It would also create another vicious circle (the positive loop 2) to make more risk in 'performance unavailable' which would make more risk in 'revenue loss' which would lead to more risk in 'finance unavailable' which would result in more risk in 'resources unavailable' yet again. On the other hand, the 'default of subcontractors' would be likely to directly cause 'defective design' which would cause 'defective construction' (Hodge, 2004) because the design and construction work implemented by design and construction subcontractors cannot meet contract specification due to insolvency or incapability. This would be likely to lead to 'performance unavailable' from which the infrastructure asset has broken down so that it won't be able to deliver its services, which would lead to take 'contract remedies/penalties' risk to fix effective issues. The 'contract remedies/penalties' would further result in 'revenue loss' since it needs additional costs to fix defective issues. Consequently it would create a vicious circle (the positive loop 3) to make more risk in 'finance unavailable' which make more risk in 'resources unavailable' yet again. In general, the 'default of subcontractors' risk event would result in compounding consequences on 'construction cost overrun' and 'revenue loss' respectively through these three feedback dynamics over the construction and operation phases.

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for the cases, the European Commisssion's report (EC, 2002) on the London Underground indicated that material failure by project operators, LUL, to comply with its obligations under contract, and default event where the project infrastructure builders, Infraco's assets have been nationalized or a change in law were documented. In addition, the Hodge (2004)'s case study on the Melbourne City Link indicated this project suffered serious construction delay due to insufficient tolling technologies of subcontractor, TOVJ. the project subcontractor, TOVJ, In addition, the UK National Audit Office's report (NAO, 2006) reflected that the PFI contract for National Physical Laboratory cannot achieve satisfactory output specification without the sufficiently technical capability of the subcontractors. The Ghosh & Jintanapakanont (2004)' case study in the Thailand Underground Rail Project also indicated the default of subcontractors is one of the most important risks for project delivery delay.

V34. Inspection and testing delay

The 'inspection and testing delay' refers to the risk of delay of the third parties like subcontractors/suppliers or any other service providers for design, construction, and operation, for example, the performance inspection and testing by independent consultant, which may result in delay of delivering services.

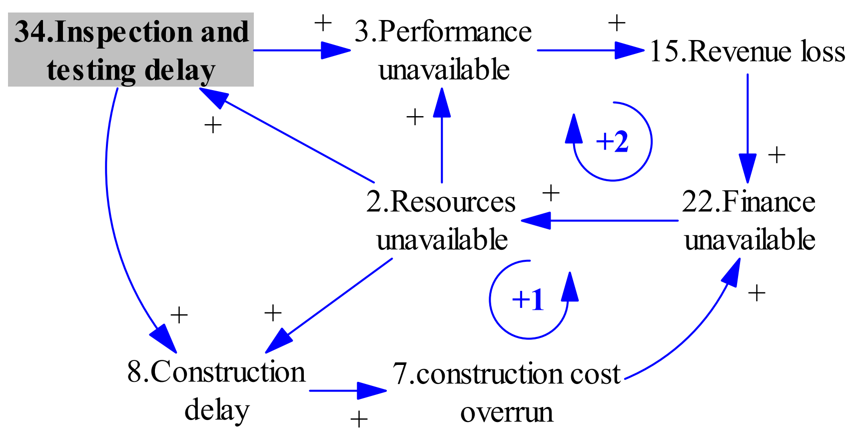


Figure V34 Cause Loop Diagram for 'Inspection and Testing Delay' Risk Event

As shown in Figure V34, the 'inspection and testing delay' would be likely to directly cause 'construction delay' at construction stage and 'performance unavailable' at operation stage respectively (Ghosh & Jintanapakanont, 2004). As previously stated, consequently this would create a vicious circle (the positive loop 1) to cause more risk in 'construction cost overrun' which would lead to more risk in 'finance unavailable' which would result in more risk in 'resource unavailable' which would lead to more risk in 'construction delay' at the construction stage. It would also create another vicious circle (the positive loop 2) to which would make more risk in 'revenue loss' which would lead to more risk in 'finance unavailable' which would result in more risk in 'resources unavailable' which lead to more risk in 'performance unavailable' at the operation stage. In general, the 'default of subcontractors' risk event would result in compounding consequences on 'construction cost overrun' and 'revenue loss' respectively through these two feedback dynamics over the construction and operation phases.

The 'inspection and testing delay' would be likely to be triggered by 'resources unavailable' that the skilled manpower might not be available due to the default of subcontractor who is responsible for inspection and testing (Ghosh & Jintanapakanont, 2004).

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As Ghosh & Jintanapakanont (2004)' case study in the Thailand Underground Rail Project, the delay due to the third party is one of the most important components for project delivery delay.

V35. Latent defects

The 'latent defects' refers to the possibility of loss or damage arising from latent defects within existing infrastructure that infringe the patents held by the third parties.

As shown in Figure V35, the 'latent defects' would be likely to directly cause 'contractual disputes' (EC, 2002) because the contractual claims would be arisen from the technologies that the project contractors employ to build and perform the existing infrastructure have been infringed the patents held by the third-parties. The 'contractual disputes' would cause 'contract remedies/penalties', which would lead to 'construction delay' and 'construction cost overrun' at construction stage, and 'performance unavailable' and 'revenue loss' at operation stage as well since it needs extra time and costs to settle disputes. Consequently, as previously stated, it would create a vicious circle (the positive loop 1) at construction stage to cause more risk in 'finance unavailable' which would lead to more risk in 'resources unavailable' which would result in more risk in 'construction delay' which would make more risk in 'construction cost overrun.' It would also create a vicious circle (the positive loop 2) at operation stage to cause more risk in 'finance unavailable' which would lead to more risk in 'resources unavailable' which would result in more risk in 'performance unavailable' which would make more risk in 'revenue loss.' Moreover, the 'performance unavailable' would be likely to cause 'contract breach' and 'contractual disputes' since the services delivery is failed to meet contract requirements, and the arguments arisen from which parties have to take responsibility for performance failure. As previous descriptions, consequently this would create two vicious circles (the positive loop 3 and 4) to result in more risk in 'contract remedies/penalties' which would make more risk in 'revenue loss.' In general, the 'latent defects' risk event would result in compounding consequences on 'construction cost overrun' and 'revenue loss' respectively through these four feedback dynamics over the construction and operation phases.

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for the case, the European Commission's report (EC, 2002) on the London Underground indicated that the PPP infrastructure contractor, SSL Infraco, would be liable for the consequences of latent defects in the Jubilee Line Extension.

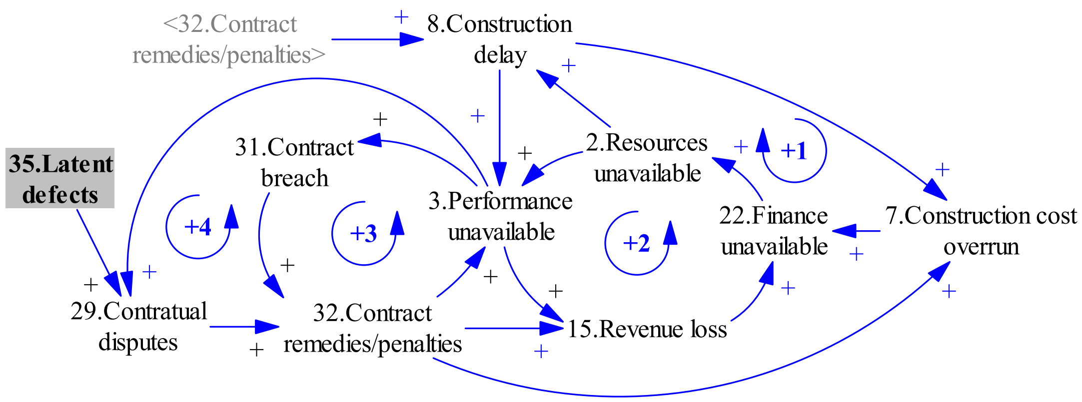


Figure V35 Cause Loop Diagram for 'Latent Defects' Risk Event

V36. Shorter asset life

The 'shorter asset life' refers to the risk that design life of the facility proves to be shorter than the planned, which lead to additional cost of upgrade.

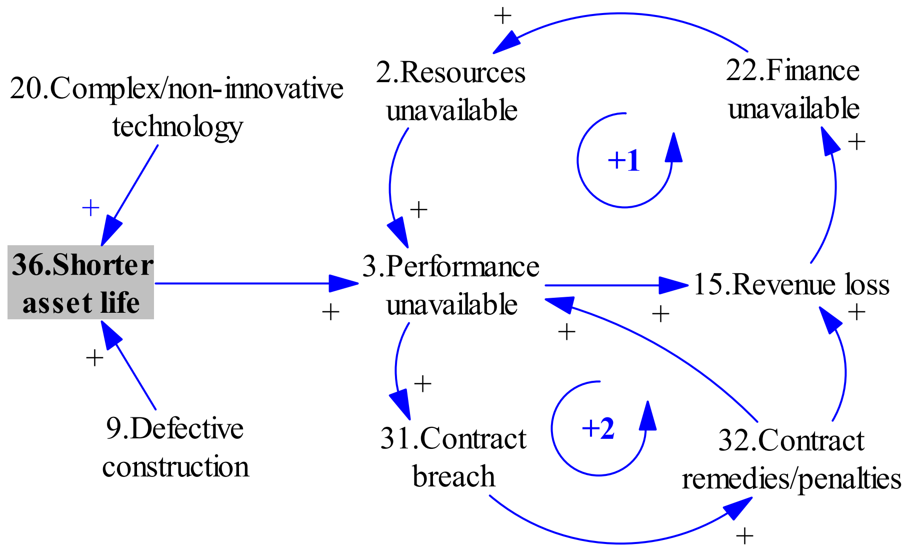


Figure V36 Cause Loop Diagram for 'Shorter Asset Life' Risk Event

As shown in Figure V36, the 'shorter asset life' would be likely to directly cause 'performance unavailable' (EC, 2002; NAO, 2004a) because the life of infrastructure is shorter than contract requirement. As stated above, consequently this would create a vicious circle (the positive loop 1) to cause more risk in 'revenue loss' which would make more risk in 'finance unavailable' which would lead to more risk in 'resources unavailable' which would result in more risk in 'performance unavailable'. Moreover, as stated above, the 'performance unavailable' would also create another vicious circle (the positive loop 2) to make more risk in 'contract breach' which would make more risk in 'contract remedies/penalties' which would result in 'revenue loss' and 'performance unavailable' yet again. In general, the 'shorter asset life' risk event would result in compounding consequences on 'revenue loss' through these two feedback dynamics over the operation phase.

The 'shorter asset life' would be likely to be triggered by 'defective construction' (EC, 2002; NAO, 2004a) that the quality of construction cannot meet contract requirement so that it would be likely to reduce the planned asset life; 'complex/non-innovative technology' since the asset is difficult to maintain and upgrade so it would be likely to result in early obsolescence.

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for the case, the European Commission's report (EC, 2002) and the National Audit Office's report (NAO, 2004a) on the London Underground indicated that the PPP infrastructure contractors, Infrocos, should assume the responsibility to ensure the Underground infrastructure is restored to full health and maintained in an expected value and life condition consistent with good industry practice.

V37. Less residual value

The 'less residual value' refers to the risk that project assets at termination or expiry of the PPP agreement will not be in the prescribed condition which the private party agreed to transfer it to government.

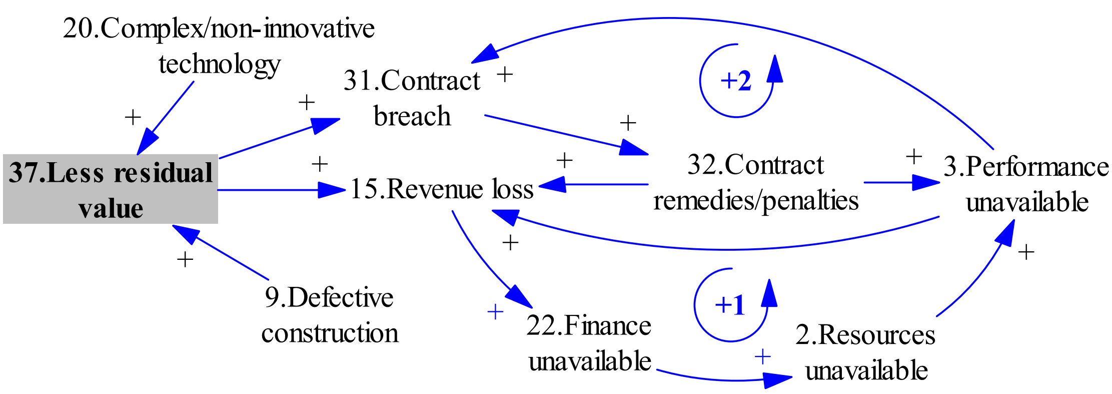


Figure V37 Cause Loop Diagram for 'Less Residual Value' Risk Event

As shown in Figure V37, the 'less residual value' would be likely to directly cause 'revenue loss' because the value of infrastructure is less than contract requirement (EC, 2002; NAO, 2004a). As previously stated, this would create a vicious circle (the positive loop 1) to cause more risk in 'finance unavailable' which would cause more risk in 'resources unavailable' which would cause more risk in 'performance unavailable' which would lead to more risk in 'revenue loss' yet again. Moreover, as previous descriptions, the 'performance unavailable' would create another vicious circle (the positive loop 2) to cause more risk in 'contract breach' which make more risk in 'contract remedies/penalties' which result in more risk in 'performance unavailable' yet again. In general, the 'less residual value' risk event would result in compounding consequences on 'revenue loss' through these two feedback dynamics over the operation phase.

The 'less residual value' would be likely to be triggered by 'defective construction' that the quality of construction cannot meet contract requirement so that it would be likely to reduce the planned asset value; 'complex/non-innovative technology' since the asset is difficult to maintain and upgrade so it would be likely to result in the greater depreciation (EC, 2002; NAO, 2004a).

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As described above, the PPP infrastructure contractors, Infrocos, should assume the responsibility to ensure the London Underground infrastructure is restored to full health and maintained in an expected value and life condition(EC, 2002). In addition, the National Audit Office's report (NAO, 2004a) on the London Underground indicated that the PPP infrastructure contractors, Infracos, must ensure all range of assets under its control are projected to have at least half their lives left to run at contract close in 2033.

V38. Termination liabilities

The 'termination liabilities' refers to the asset ownership of private party or public party is terminated due to contract breach, which leads to the possible service disruption and increase the government's liabilities at taxpayer's costs.

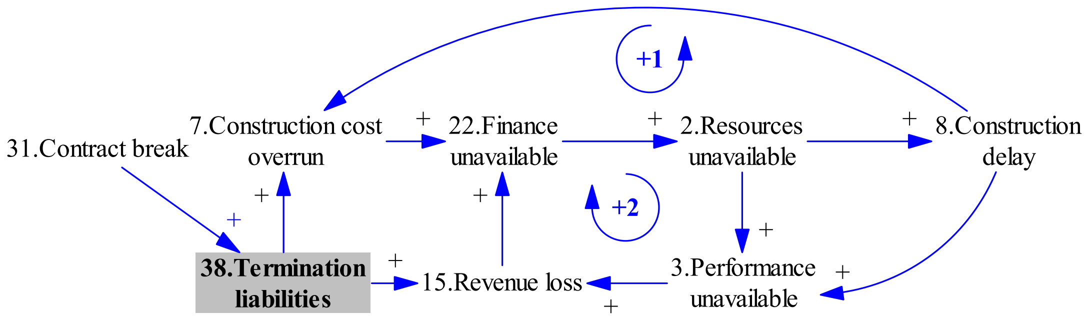


Figure V38 Cause Loop Diagram for 'Termination Liabilities' Risk Event

As shown in Figure V38, the 'termination liabilities' would be likely to directly cause 'revenue loss' because the possible service disruption arisen from 'contract breach' (NAO, 2006) would increase the government's liabilities at taxpayer's costs, which would be likely to result in 'construction cost overrun' at construction stage and 'revenue loss' at operation stage respectively (The Work Bank, 1999). As previously stated, both would result in 'finance unavailable'. This would consequently create a vicious circle (the positive loop 1) to make more risk in 'resources unavailable' which would make more risk in 'construction delay' which would lead to more risk in 'construction cost overrun' at construction stage; this would also create another vicious circle (the positive loop 2) to make more risk in 'resources unavailable' which would lead to more risk in 'performance unavailable' which would result in more risk in 'revenue loss.' In general, the 'termination liabilities' risk event would result in compounding consequences on 'construction cost overrun' and 'revenue loss' respectively through these two feedback dynamics over the construction and operation phases.

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As described above, the Work Bank's case study report (The Work Bank, 1999) indicated that if the BOT concession contracts for the North-South Expressway (NSE) and the Kuala Lumpur-Karak Highway (Malaysia) are terminated due to default of the concessionaire, no compensation is to be paid to the concessionaire for the loss of its rights or investment. However, where termination is due to the Government's default, the Government will generally grant compensation for the loss suffered by the concessionaire, which would include the loss of future profits.

In addition, it would occur in PFI contract for the National Physical Laboratory. As described above, because of highly complex technique challenging requirements, the project contractor seriously continued to jeopardize the successful delivery of the project, which would lead to terminate contract and adversely transfer risk back to the government authority (NAO, 2006).

V39. Higher levels of inflation rate

The 'higher levels of inflation rate' refers to the possibility that actual inflation rate will exceed the projected inflation rate, which will especially result in the price escalation associated with the delivery, operate and maintenance of the provision of services.

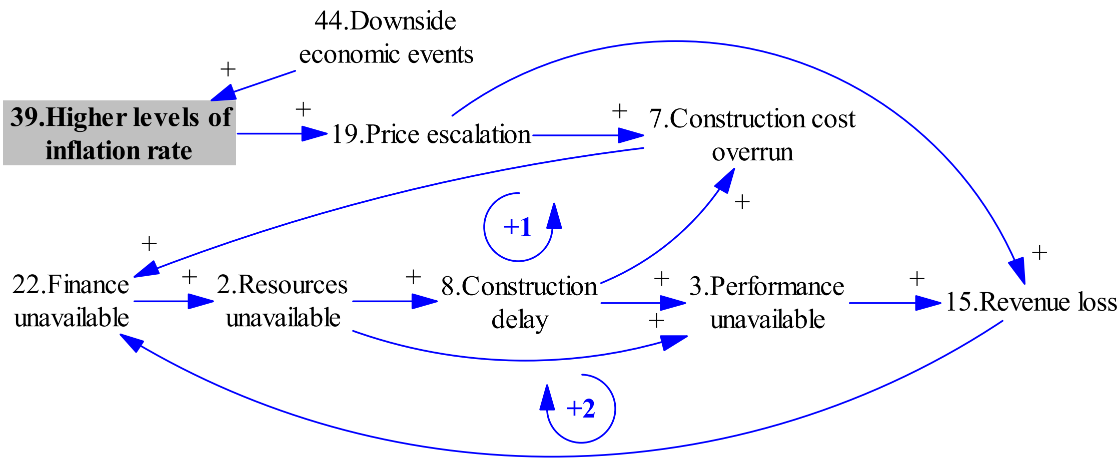


Figure V39 Cause Loop Diagram for 'Higher Levels of Inflation Rate' Risk Event

As shown in Figure V39, the 'higher levels of inflation rate' would be likely to directly cause 'price escalation' that increases the costs for construction and operation (EC, 2002; Lu, 2004). This would cause 'construction cost overrun' (PAC, 2006a) at construction stage, and 'revenue loss' at operation stage as well. As previously stated, both would result in 'finance unavailable'. This would consequently create a vicious circle (the positive loop 1) to make more risk in 'resources unavailable' which would make more risk in 'construction delay' which would lead to more risk in 'construction cost overrun' at construction stage; this would also create another vicious circle (the positive loop 2) to make more risk in 'resources unavailable' which would lead to more risk in 'performance unavailable' which would result in more risk in 'revenue loss.' In general, the 'higher levels of inflation rate' risk event would result in compounding consequences on 'construction cost overrun' and 'revenue loss' respectively through these two feedback dynamics over the construction and operation phases.

The 'higher levels of inflation rate' would be likely to be triggered by 'downside economic events' that the inflation rate increases due to the impact of specific downside economic events (The Work Bank, 1999).

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for the cases, it may happen in Channel Tunnel Rail Link. The UK Public Account Committee (PAC) reported that the high levels of inflation rate on construction projects will drive up the cost overrun of the Section 2 of the Link (PAC, 2006a). In addition, as Ghosh & Jintanapakanont (2004)' case study in the Thailand Underground Rail Project, the financial risk due to the higher expected inflation is one of the most important impact on project delivery.

V40. Higher levels of exchange rate

The 'higher levels of exchange rate' refers to the possibility that actual exchange rate will exceed the projected exchange rate, which will lead to the increase of costs required for the construction or operations phase of the project.

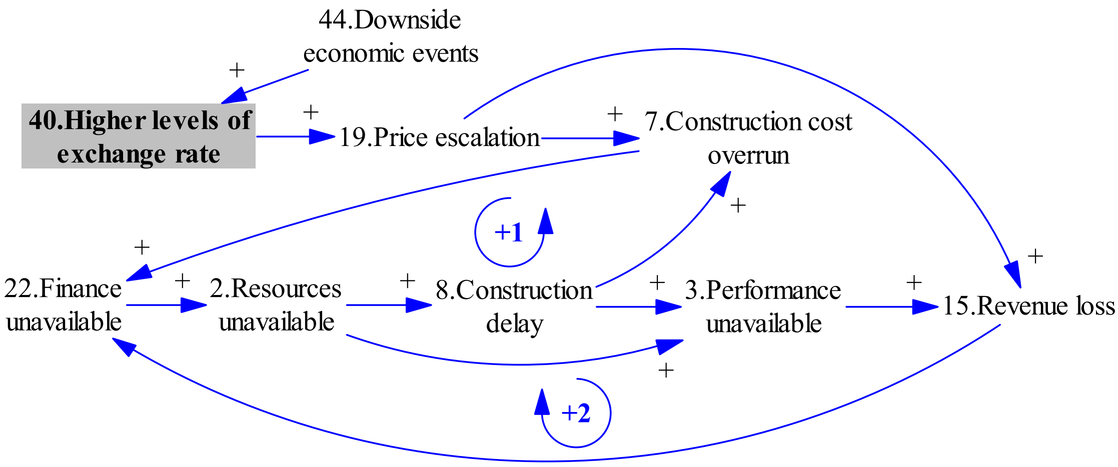


Figure V40 Cause Loop Diagram for 'Higher Levels of Exchange Rate' Risk Event

As shown in Figure V40, the 'higher levels of exchange rate' would be likely to directly cause 'price escalation' that increases the costs for construction and operation (EC, 2002; Lu, 2004). This would cause 'construction cost overrun' at construction stage, and 'revenue loss' at operation stage as well. As previously stated, both would result in 'finance unavailable'. This would consequently create a vicious circle (the positive loop 1) to make more risk in 'resources unavailable' which would make more risk in 'construction delay' which would lead to more risk in 'construction cost overrun' at construction stage; this would also create another vicious circle (the positive loop 2) to make more risk in 'resources unavailable' which would lead to more risk in 'performance unavailable' which would result in more risk in 'revenue loss.' In general, the 'higher levels of exchange rate' risk event would result in compounding consequences on 'construction cost overrun' and 'revenue loss' respectively through these two feedback dynamics over the construction and operation phases.

The 'higher levels of exchange rate' would be likely to be triggered by 'downside economic events' that the exchange rate increases due to the impact of specific downside economic events (The Work Bank, 1999).

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for the cases, the Work Bank's case study report (The Work Bank, 1999) indicated that the Malaysian Government provided guarantee with an agreement "External Risks Supplements Agreement" for the North-South Expressway (NSE) and the Kuala Lumpur-Karak Highway to compensate for any shortfall in toll revenue arising from the fluctuation of exchange rate or interest rate. In addition, Lu (2004)'s case study on the Water Conservancy and Hydropower Project in Southern China reflected that the loss due to devaluation of Renminbi (China currency) was about RMB$724 million. In addition, as Ghosh & Jintanapakanont (2004)' case study in the Thailand Underground Rail Project, the financial risk due to the exchange-rate fluctuation is one of the most important impact on project delivery.

V41. Higher levels of interest rate

The "higher levels of interest rate" refers to the possibility that actual interest rate will exceed the projected interest rate, which would lead to the increase of costs required for the construction or operations phase of the project, and would affect the availability and cost of funds.

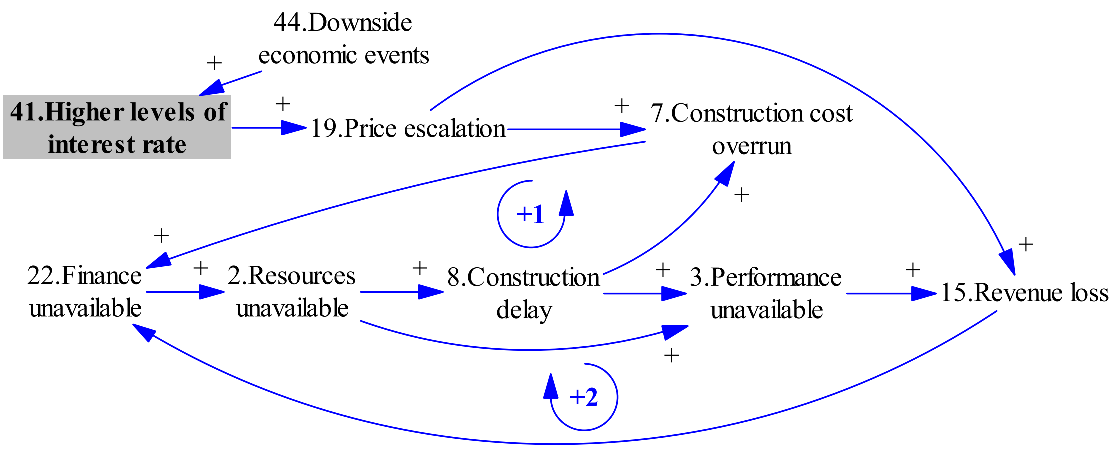


Figure V41 Cause Loop Diagram for 'Higher Levels of Interest Rate' Risk Event

As shown in Figure V41, the 'higher levels of interest rate' would be likely to directly cause 'price escalation' that increases the costs for construction and operation (Lu, 2004). This would cause 'construction cost overrun' at construction stage, and 'revenue loss' at operation stage as well (Smith, 2006; The Work Bank, 1999). As previously stated, both would result in 'finance unavailable'. This would consequently create a vicious circle (the positive loop 1) to make more risk in 'resources unavailable' which would make more risk in 'construction delay' which would lead to more risk in 'construction cost overrun' at construction stage; this would also create another vicious circle (the positive loop 2) to make more risk in 'resources unavailable' which would lead to more risk in 'performance unavailable' which would result in more risk in 'revenue loss.' In general, the 'higher levels of interest rate' risk event would result in compounding consequences on 'construction cost overrun' and 'revenue loss' respectively through these two feedback dynamics over the construction and operation phases.

The 'higher levels of interest rate' would be likely to be triggered by 'downside economic events' that the exchange rate increases due to the impact of specific downside economic events (EC, 2002; Lu, 2004).

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As described above, the Work Bank's case study report (The Work Bank, 1999) indicated that the Malaysian Government provided guarantee with an agreement "External Risks Supplements Agreement" for the North-South Expressway (NSE) and the Kuala Lumpur-Karak Highway to compensate for any shortfall in toll revenue arising from the fluctuation of exchange rate or interest rate. In addition, the Smith (2006)'s case study on the Harnaschpolder Wastewater Treatment Project (the Netherlands) reflected that subsequent rise in interest rates actually created substantial additional financing cost.

V42. Less demand

The 'less demand' refers to the possibility that the demand for the services generated by a project may be less than projected, which results in less revenue. As for a revenue PPP project, the future income from the users is expected to provide a major element of the revenue needed to repay the cost of constructing infrastructure. It means the less demand will lead to the insolvency of the project contractor to repay the debt of infrastructure construction to the financiers, and poor services against the interests of infrastructure users. In the worst circumstance, it causes the project contractor going bankrupt and then the government needs to buy the project ownership back (ownership change) before the end of concession period at the costs of taxpayer.

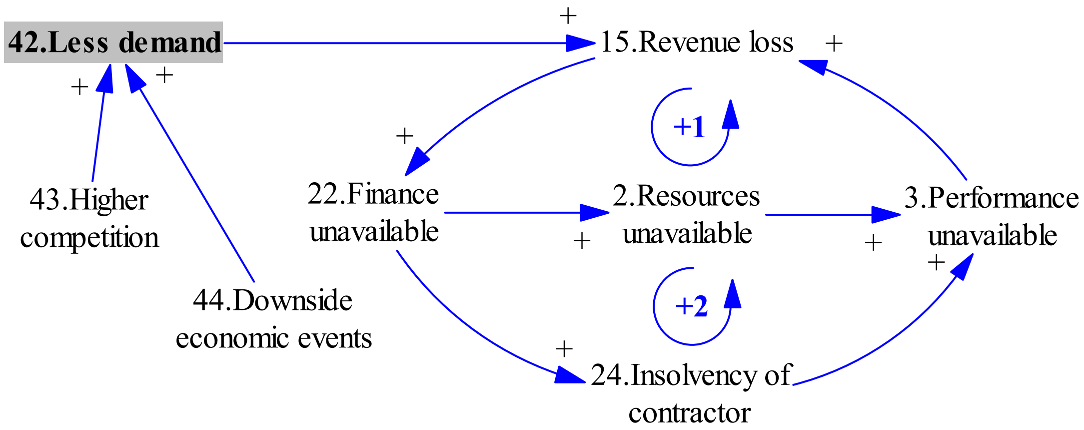


Figure V42 Cause Loop Diagram for 'Less Demand' Risk Event

As shown in Figure V42, the 'less demand' would be likely to directly cause 'revenue loss' (PAC, 2003c; PAC, 2006a) when the demand for the services generated by a project is less than projected, which would further cause 'finance unavailable.' As previously stated, this would create a vicious circle (the positive loop 1) to cause more risk in 'resources unavailable' which would lead to more risk in 'performance unavailable' which would result in more risk in 'revenue loss.' On the other hand, the 'finance unavailable' would also cause 'insolvency of contractor' which lead to 'performance unavailable' since the operating party is completely not able to deliver services any longer due to financial difficulty. As previously stated, this would create a vicious circle (the positive loop 2) to cause more 'revenue loss' which would result in 'finance unavailable' yet again. In general, the 'less demand' risk event would result in compounding consequences on 'revenue loss' through these two feedback dynamics over the operation phase.

The 'less demand' would be likely to be triggered by 'higher competition' (Hodge, 2004; Lu, 2004; PAC, 2002b; PAC, 2006a) and 'downside economic events'(PAC, 2006a) that the demand for the services generated by the project might be less than projected due to these impacts.

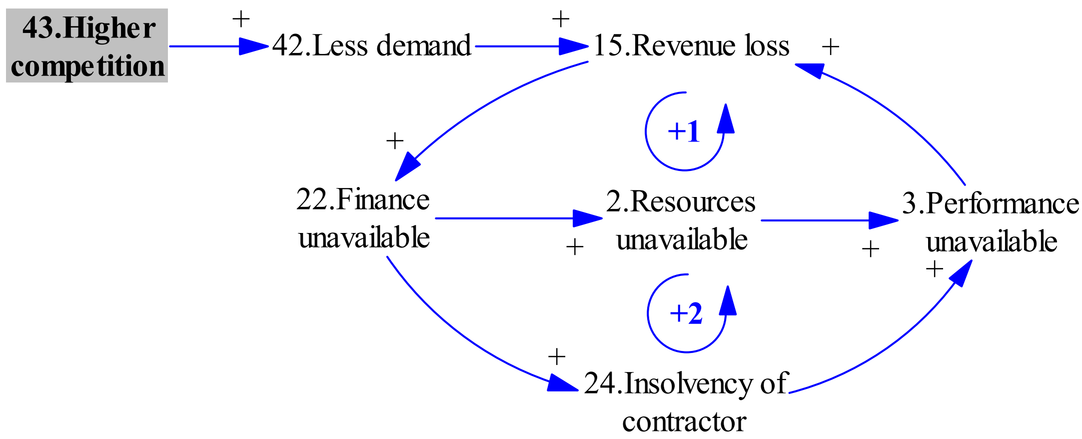
This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. It has ever happened in Channel Tunnel Rail Link. The UK Public Account Committee (PAC) reported that in 1996 the Department for Transport (DfT) awarded a contract to London & Continental Railways Limited (LCR), a private sector consortium, to build the Channel Tunnel Rail Link (the Link.) In bidding for the project in 1996, LCR forecast that passenger numbers using Eurostar would reach 21.4 million in 2004 in bidding the project in 1996, but actual passenger numbers for 2004 were only 7.3 million. The under performing against forecast passenger volume leads to the government authority (DfT) lent more the currently estimated ￡260 million to LCR to cover future cash shortfalls at the continuing exposure of the taxpayer to the risks inherent in this project. In addition, especially it will produce a compound effect to reduce a lower demand than originally envisaged for the CTRL if this risk event combines another independent event, the Channel Tunnel fire (PAC, 2006a).

In addition to the Link project, the PAC's report (PAC, 2003c) revealed that the PPP project contractor, the National Air Traffic Services (NATS), had ever faced financial crisis on downturn in income due to less demand than expected in the air traffic volume.

V43. Higher competition

The 'higher competition' refers to the possibility that the demand for the services generated by a project may be less than projected due to higher competition, which leads to less demand or reducing price and accordingly revenue below projections.

As shown in Figure V43, the 'higher competition' would be likely to directly cause 'less demand' that the demand for the services is impacted by market competition (Hodge, 2004; Lu, 2004; PAC, 2002b; PAC, 2006a). As previously stated in "(42) Less demand", this would create two vicious circles (the positive loop 1 and 2) to cause more risk in 'revenue loss.' In general, the 'higher competition' risk event would result in compounding consequences on 'revenue loss' through these two feedback dynamics over the operation phase.



FigureV43 Cause Loop Diagram for 'Higher Competition' Risk Event

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for case, this risk is likely to occur in a PFI project, the Channel Tunnel Rail Link (CTRL). The UK PAC's report (PAC, 2002b) indicated the demand for the Link has been less than the originally forecasts due to the extraordinary success of European low cost airlines.

In addition, Hodge (2004)'s case study in the Melbourne City Link indicated that demand to use the Link tunnel reduced by 30% due to competition of an alternative route through Eurundjeri Way. Lu (2004)'s case study on the Zhuhai International Airport indicated that the actual utilization rate was less than 10% of the capacity due to the potential competition from other alternatives like Huangtian International Airport, the Hong Kong New Airport at Chi Lap Kok and Macao International Airport.

V44. Downside economic events

The 'downside economic events' refers to the possibility that the demand for the services generated by a project may be less than projected due to the impact of specific downside economic events, which results in revenue below projections.

As shown in Figure V44, the 'Downside Economic Events' would be likely to directly cause 'higher levels of inflation rate'(The Work Bank, 1999), 'higher levels of exchange rate'(The Work Bank, 1999) and 'higher levels of interest rate'(EC, 2002; Lu, 2004), which would cause 'price escalation' so that the costs for construction and operation would be increased. As previously stated in "(19) Price escalation," the 'price escalation' would lead to 'construction cost overrun' at construction stage and 'revenue loss' at operation stage respectively. Bothe would lead to 'finance unavailable' due to running out of capital needed for construction and pay for the debt. Consequentially it would create a vicious circle (the positive loop 1) to cause more risk in 'resources unavailable' which would cause more risk in 'construction delay' which would cause more risk in 'construction cost overrun' at construction stage. At operation stage, it would create another vicious circle (the positive loop 2) to make more risk in 'performance unavailable' which make more risk in 'revenue loss' which make more risk in 'finance unavailable' yet again. On the other hand, as previously stated in "(42) Less demand," the 'downside economic events' would also cause 'less demand' (PAC, 2006a) so that the revenue is reduced, which would cause 'revenue loss.' This would create a vicious circle (the positive loop 3) to result in more risk in 'finance unavailable' which would result in more risk in 'insolvency of contractor' that the contractor cannot deliver project services due to financial difficulties, which would make more risk in 'performance unavailable' which would make more risk in 'revenue loss' yet again. In general, the 'downside economic events' risk event would result in compounding consequences on 'construction cost overrun' and 'revenue loss' respectively through these two feedback dynamics over the construction and operation phases.

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for the cases, the Work Bank's case study report (The Work Bank, 1999) indicated that the effects of the Asian Economic Crisis during 1997-98 had great impact on the PPP toll road projects. As a result, the interest rates increased from 19 percent to over 60 percent per annum and then the project debts suddenly increased.

V45. Political interference

The 'political interference' refers to the possibility of unforeseeable conduct by the political parties that materially and adversely affect the public decision-making process or project implementation.

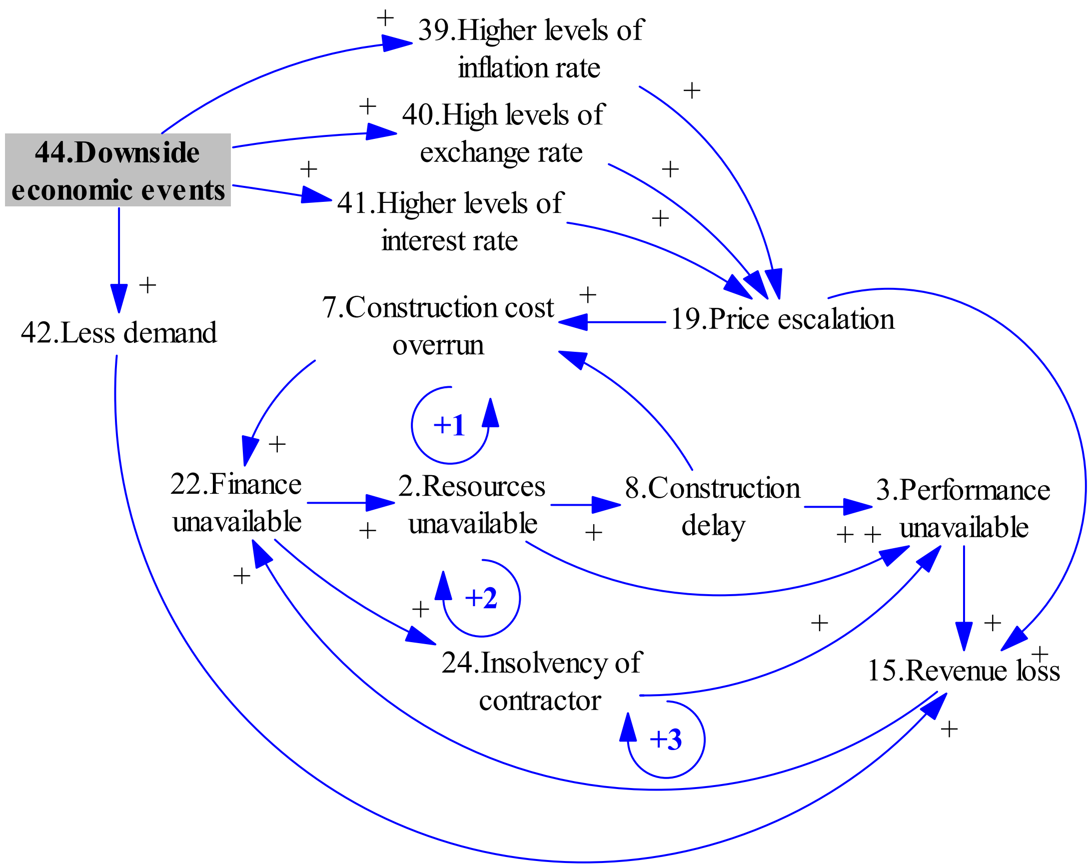


Figure V44 Cause Loop Diagram for 'Downside Economic Events' Risk Event

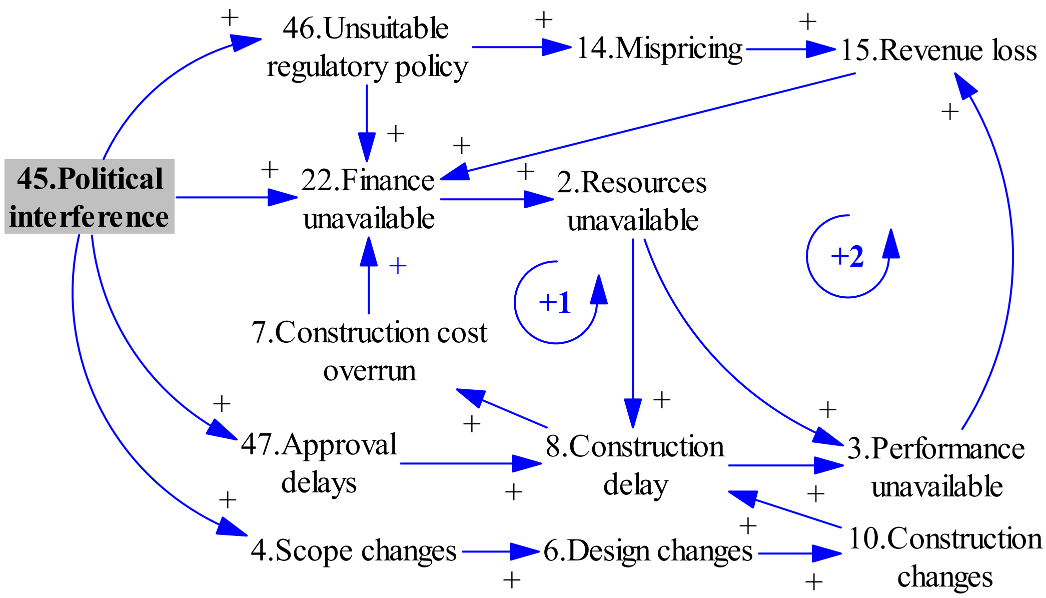


Figure V45 Cause Loop Diagram for 'Political Interference' Risk Event

As shown in Figure V45, the 'political interference' would be likely to directly cause 'unsuitable regulatory policy' (EC, 2004b) since the politics is easy to adversely affect the public decision-making for regulatory policy under an uncertain political and legal environment. This would be likely to cause 'mis-pricing' because the government authority doesn't allow the project pricing cap to vary according to the actual market demand variants in the long-term, which would further lead to 'revenue loss' which would result in 'finance unavailable' (Lu, 2004; PAC, 2003c) since the operate contractor has no enough capital to pay for debt. The 'political interference' and 'unsuitable regulatory policy' would also be likely to directly cause 'finance unavailable' since the financial difficulties arising from that the government authorities allow a low equity-debt ratio of project financing but the political imperatives make an inflexible pricing cap for service delivery conflicting with the principles of market regulation. As previously stated, this would consequentially create a vicious circle (the positive loop 1) at construction stage to cause more risk in 'resources unavailable' which would make more risk in 'construction delay' which would cause 'construction cost overrun' which would cause 'finance unavailable'. The 'finance unavailable' would also create another vicious circle (the positive loop 2) at operation stage to result in more risk in 'resources unavailable' which would result in more risk in 'performance unavailable' which would result in more risk in 'revenue loss' which would lead to 'finance unavailable' yet again. Moreover, the 'political interference' would also be likely to directly cause 'approval delays' (Lu, 2004) since the government authorities may delay the project contractor from obtaining the required consents or permits for project performance, which would cause 'construction delay' which would cause 'construction cost overrun' and 'performance unavailable' so that it would join feedback loop 1 and 2 to reinforce 'construction cost overrun' and 'revenue loss.' Furthermore, the 'political interference' would also be likely to directly cause 'scope changes' (EC, 2004d) since the output specification originally set up in the PPP contract is against the political benefits so that it would possibly be forced to change by the uncertain political and legal environment. The 'scope changes' would be likely to cause 'design changes' which would cause 'construction changes' which would cause 'construction delay' which would join feedback loop 1 and 2 to reinforce 'construction cost overrun' and 'revenue loss' yet again. In general, the 'political interference' risk event would result in compounding consequences on 'construction cost overrun' and 'revenue loss' respectively through these two feedback dynamics over the construction and operation phases.

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As shown in European Committee's case studies (EC, 2004b) on the Constanta Water and Wastewater project (Romania), there is no complete regulatory framework and the concession is regulated by contract, so there is an inherent risk that political imperatives, for instance price pressures, conflict with the principles of good regulation founded on proper process. Moreover, another Romania PPP project for solid waste management, the Prescom in Targoviste (Romania), also indicated that the uncertain political and legal environment leading to litigation and uneven competition from public enterprise (EC, 2004b). The Work Bank's case study report (The Work Bank, 1999) also indicated frequent threats by Thai officials to terminate the PPP project for the Bangkok Elevated Road and Track System, which eventually discouraged the project contractor to secure full project financing.

V46. Unsuitable regulatory policy

The 'unsuitable regulatory policy' refers to the possibility that the public regulatory policies do not reflect project investment expectations or do not reflect the public interests.

As shown in Figure V46, the 'unsuitable regulatory policy' would be likely to directly cause 'mis-pricing' since the government authority doesn't allow the project pricing cap to vary according to the actual market demand variants in the long-term (NAO, 2004b; PAC, 2003c), which would further cause 'revenue loss' which would cause 'finance unavailable.' The 'unsuitable regulatory policy' would also be likely to directly cause 'finance unavailable' since the financial difficulties arising from that the government authorities allow a low equity-debt ratio of project financing but the political imperatives make an inflexible pricing cap for service delivery conflicting with the principles of market regulation (PAC, 2006a). As previously stated, this would consequentially create a vicious circle (the positive loop 1) at construction stage to cause more risk in 'resources unavailable' which would make more risk in 'construction delay' which would cause 'construction cost overrun' which would cause 'finance unavailable'. The 'finance unavailable' would also create another vicious circle (the positive loop 2) at operation stage to result in more risk in 'resources unavailable' which would result in more risk in 'performance unavailable' which would result in more risk in 'revenue loss' which would lead to 'finance unavailable' yet again. In general, the 'unsuitable regulatory policy' risk event would result in compounding consequences on 'construction cost overrun' and 'revenue loss' respectively through these two feedback dynamics over the construction and operation phases.

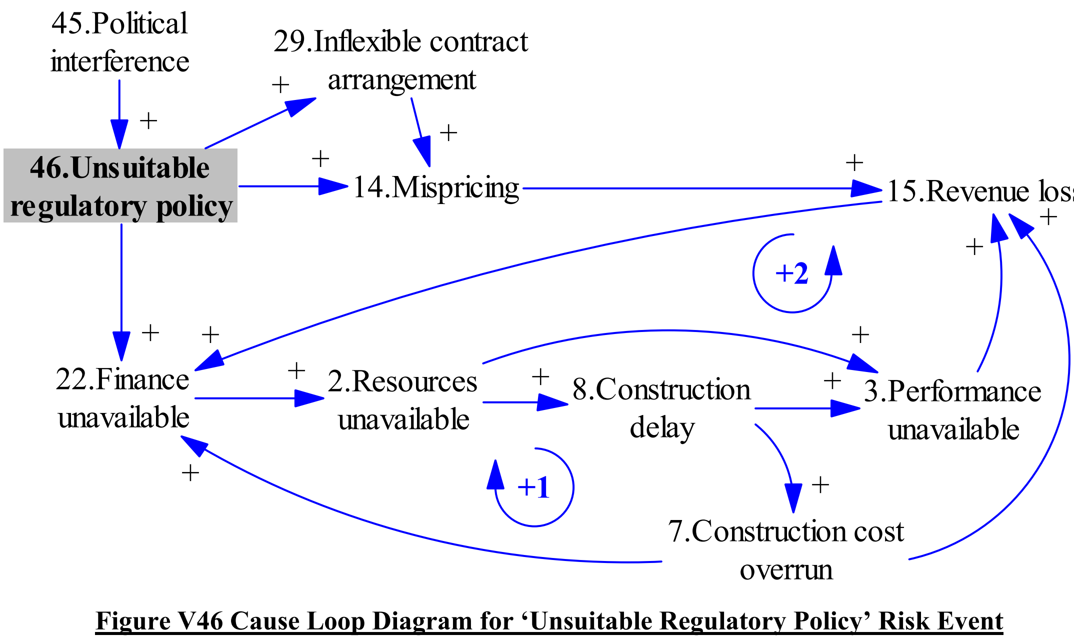


Figure V46 Cause Loop Diagram for 'Unsuitable Regulatory Policy' Risk Event

The 'unsuitable regulatory policy' would be likely to be triggered by 'political interference'(EC, 2004b) since the politics is easy to adversely affect the public decision-making for regulatory policy under an uncertain political and legal environment.

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for the cases, it has happened in PPP project for National Airport Traffic Services (NATS). As described above, the UK Public Account Committee (PAC) reported that the unsuitable regulatory policy of government authority didn't require a strong financial structure for the PPP project bidders, which led to the financial risks that the project contractor, NAT, has no insufficient equity capital to deal with adverse event like less revenue due to less demand on international air traffic volume. Moreover, the government authority didn't allow the price cap to vary according to the amount of traffic and inflation rate, which led NATS to financial difficulties so that the services would be sacrificed against the public interests (PAC, 2003c).

In addition, Hodge (2004)'s case study in the Melbourne City Link indicated that the government authority has accepted the risk of paying compensation to project contractor, Transurban, in certain circumstances where either State or Commonwealth laws or requirements ultimately prevent the completion or operation of the City Link. Lu (2004)'s case study in Liaoning Wastewater Treatment Plant (China) indicated that invested capital could not be recovered on the tariffs to be collected from domestic and industrial users due to the absence of a well-designed regulatory policy.

V47. Approval delays

The 'approve delays' refers to the delays to obtain the consents from each the government authorities. If obtained, the additional cost and time are required.

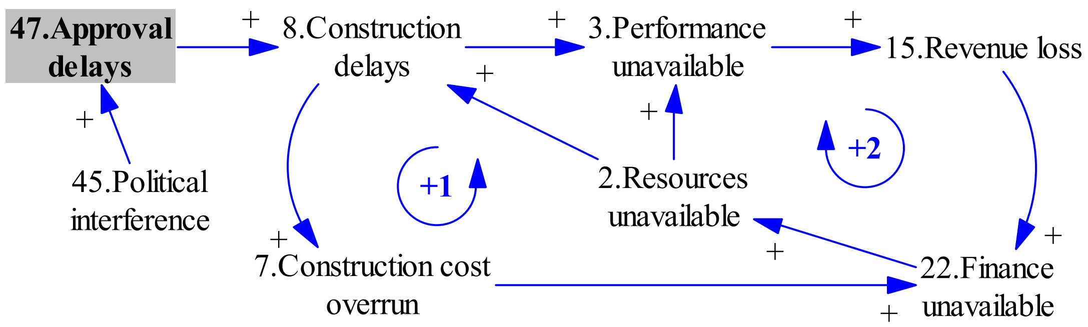


Figure V47 Cause Loop Diagram for 'Approval Delays' Risk Event

As shown in Figure V47, the 'approve delays' arising from 'political interference' (Lu, 2004) would be likely to directly cause 'construction delay' (Lu, 2004) since it needs extra time to obtain the required consents or permits for project performance from the government authorities, which would cause 'construction cost overrun' and 'performance unavailable' so that it would create two feedbacks (the positive loop 1 and 2) to reinforce 'construction cost overrun' at construction stage and 'revenue loss' at operation stage respectively, as previously described in "(45) Political interference."

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. One of the cases is the PPP project for National Airport Traffic Services (NATS) described above. Lu (2004)'s case study on the Water and Wastewater Infrastructure in Southern China indicated that it is not easy for the project contractor to obtain the permits or licenses necessary for the project to proceed as scheduled from eight government agencies who have regulatory authority over the project.

V48. Law/policy changes

The 'low/policy changes' refers to the risk of a change in law/policy will lead to the additional cost and time to comply with the change.

As shown in Figure V48, the 'low/policy changes' would be likely to directly cause 'contract breach'(EC, 2002) that the contract performance cannot adapt to the updated law/policy, which would further cause 'ownership changes' 'termination liabilities' and 'contract remedies/penalties'. As previously stated in "(31) Contract breach", this would result in compounding consequences on 'construction cost overrun' and 'revenue loss' respectively through six feedback dynamics (the positive loops 1-6) over the construction and operation phases. Moreover, the 'low/policy changes' would be likely to directly cause 'tax increases' (Lu, 2004) because the government authorities increase tax rates more than expected, which would cause 'revenues loss.' This would join positive loop 2 and then reinforce more risk in 'revenue loss.' In general, the 'low/policy changes' risk event would result in compounding consequences on 'construction cost overrun' and 'revenue loss' respectively through these two feedback dynamics over the construction and operation phases.

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for the cases, the European Commission's report (EC, 2002) indicated that the infrastructure contractors, infras, for the London Underground would have the risk that it cannot comply its contract obligation due to change in law. Hodge (2004)'s case study in the Melbourne City Link indicated that the government authority has assumed responsibility for any outstanding project debt in the event that the arrangements are terminated as a result of changes in State or Commonwealth legislation, which would prevents the project contractor, Transurban, from delivering or operating the City Link.

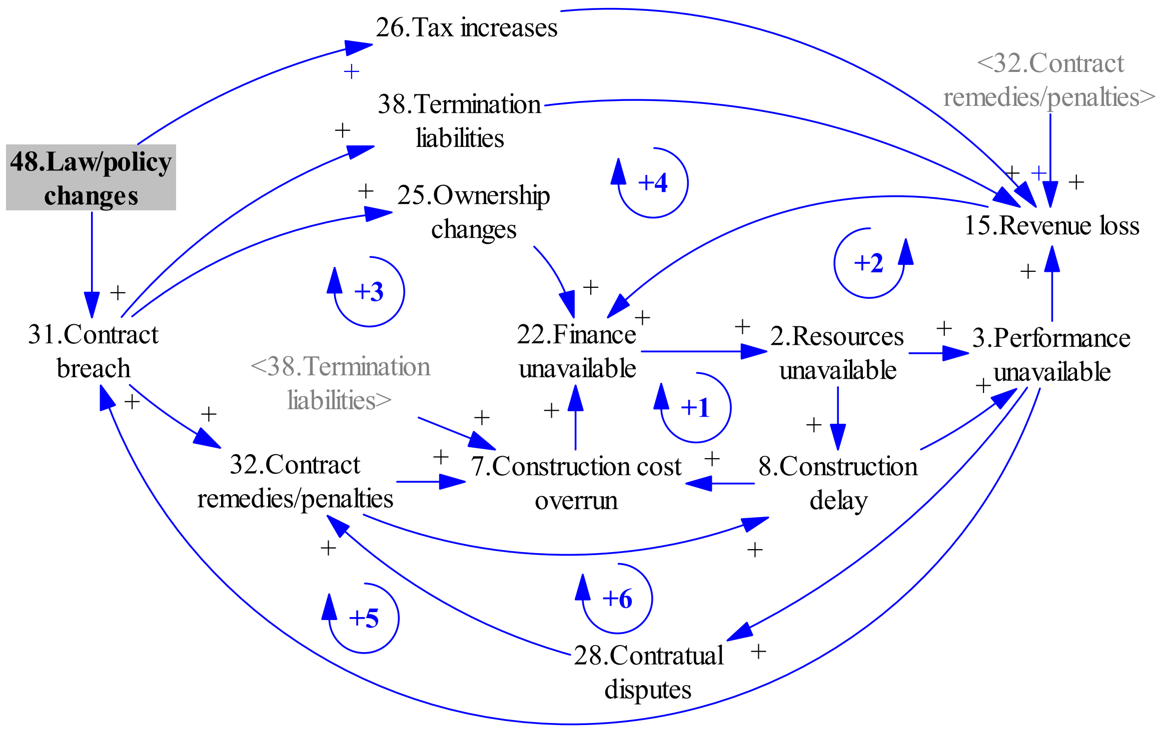


Figure V48 Cause Loop Diagram for 'Law/Policy Changes' Risk Event

V49. Unforeseen site conditions

The 'unforeseen site conditions' refers to the unanticipated adverse site conditions such as unusual surface condition of geology and ground water are discovered, which will lead to additional construction time and cost.

As shown in Figure V49, the 'unforeseen site conditions' would be likely to directly cause 'construction delays' (Ghosh & Jintanapakanont, 2004) because construction delay problems would be arisen from the unanticipated adverse site conditions, which would cause 'construction cost overrun' since the extra costs were incurred in maintaining the purchased materials and equipments and paying for the wages of recruited manpower during the construction time delay. Furthermore, the 'construction cost overrun' risk would possibly lead to 'finance unavailable' which would lead to 'resources unavailable' because the construction party has no enough money to employ the skilled manpower and the required material and equipment for construction work. Consequentially it would create a vicious circle (the positive loop 1) to cause more risk in 'construction delay' which would cause more risk in 'construction cost overrun.' Moreover, the 'construction delay' would also lead to the 'performance unavailable' that the infrastructure will not be available to be operated for services, which would result in the 'revenue loss.' In general, the 'unforeseen site conditions' risk event would result in compounding consequences on 'construction cost overrun' through this feedback dynamics over the construction and operation phases.

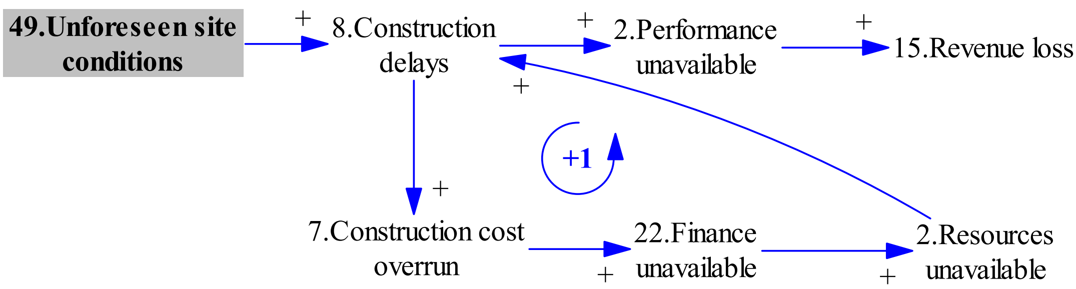


Figure V49 Cause Loop Diagram for 'Unforeseen Site Conditions' Risk Event

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. In addition, the Ghosh & Jintanapakanont (2004)' case study in the Thailand Underground Rail Project indicated that unforeseen site conditions will cause difficulties in tunneling with costly process and time delay.

V50. Environmental pollutions

The ‘environmental pollutions’ refers to the possibility of liability for losses or delay to remedy the problems arising from that the infrastructure produces environmental pollutions such as air, water and noise at the level which cannot meet environmental regulations and contract requirements.

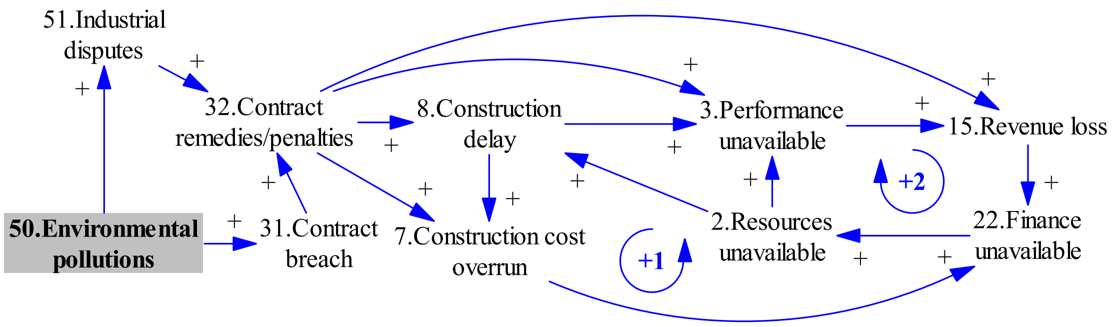


Figure V50 Cause Loop Diagram for ‘Environmental Pollutions’ Risk Event

As shown in Figure V50, the ‘environmental pollutions’ would be likely to directly cause ‘industrial disputes’ and ‘contract breach’ (Ghosh & Jintanapakanont, 2004) since the infrastructure produces environmental pollutions such as air, water and noise at the level which cannot meet environmental regulations and contract requirements. Both would cause ‘contract remedies/penalties’ which would further result in ‘construction delay’ and ‘construction cost overrun’ at construction stage and ‘performance unavailable’ and ‘revenue loss’ at operation stage as well since it needs to take additional time and extra costs to settle disputes and solve pollution issues. As previously stated, this would create two vicious circles (the positive loops 1 and 2) to make more risk in ‘finance unavailable’ which would make more risk in ‘resources unavailable’ which would result in ‘construction delay’ at construction stage (loop 1) and ‘performance unavailable’ at operation stage (loop 2). In general, the ‘environmental pollutions’ risk event would result in compounding consequences on ‘construction cost overrun’ and ‘revenue loss’ through these two feedback dynamics over the construction and operation phases.

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for the case, the experience from the Great Belt and Oresund Links/Demark showed the costs for environmental protection will lead to the substantial financial risk, especially the construction cost overrun (Flyvbjerg et al., 2003). In addition, the Ghosh & Jintanapakanont (2004)’ case study in the Thailand Underground Rail Project indicated that this risk will be against environment protection and regulation policy.

V51. Industrial disputes

The ‘industrial disputes’ refers to the risk of strikes, industrial action, civil commotion, or public protests causing delay and cost to the project.

As shown in Figure V51, the ‘industrial disputes’ would be likely to directly cause ‘construction delay’ at construction stage and ‘performance unavailable’ at operation stage since the project performance would be stopped due to the events such as public protests and strikes. As previously stated, the ‘construction delay’ would create a vicious circle (the positive loop 1) to cause ‘construction cost overrun’ which would cause ‘finance unavailable’ which would lead to ‘resources unavailable’ which would result in ‘construction delay’ yet again. On the other hand, the ‘performance unavailable’ would create another vicious circle (the positive loop 2) to cause ‘revenue loss’ which would cause ‘finance unavailable’ which lead to ‘resources unavailable’ which would result in ‘performance unavailable.’ In addition, the ‘industrial disputes’ would directly cause ‘contract remedies/penalties’(EC, 2003), which would result in more risk in ‘construction delay’ and ‘construction cost overrun’ at construction stage, and more risk in ‘performance unavailable’ and ‘revenue loss’ at operation stage as well since it needs to take additional time and extra costs to settle disputes. Furthermore, the ‘industrial disputes’ would be likely to result in ‘resources unavailable’ since the strikes, industrial action, civil commotion, or public protests would cause that materials, equipment, and manpower cannot be supplied. This would make more risk in ‘construction delay’ and more risk in ‘performance unavailable’ as well. In general, the ‘industrial disputes’ risk event would result in compounding consequences on ‘construction cost overrun’ and ‘revenue loss’ through these two feedback dynamics over the construction and operation phases.

The ‘industrial disputes’ would be likely to be triggered by the ‘unsuitable regulatory policy’(EC, 2003) risk event since the industrial action or public protests are arisen from that the public regulatory policies do not reflect project investment expectations or do not reflect the public interests; or by the ‘environmental pollutions’(Ghosh & Jintanapakanont, 2004) risk event since the industrial action or public protests are arisen from that infrastructure produces pollutions.

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for the cases In addition, the European Commission’s report (EC, 2003) indicated that there were public protests to toll increases for the Vasco da Gama Bridge concession project. In addition, the Ghosh & Jintanapakanont (2004)’ case study on the Thailand Underground Rail Project reflected that people must be given an opportunity to object and to comment on whether the environment safeguard and regulation policy is acceptable.

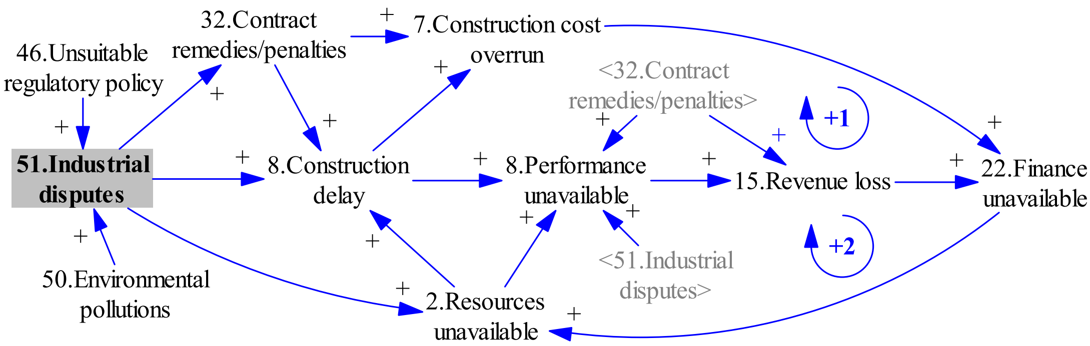


Figure V51 Cause Loop Diagram for 'Industrial Disputes' Risk Event

V52. Force Majeure

The 'Force Majeure' refers to the possibility of occurrence of naturally unexpected events like earthquake, storm, flood, etc. or man-made events like war, and fire that are beyond the control of both public and private parties which may affect the construction or operation of the project.

As shown in Figure V52, the 'Force Majeure' would be likely to directly cause 'resources unavailable' (EC, 2002; Grey, 2004) since the events like earthquake, storm, flood, war, and fire, etc. that would make the supply of materials, equipment or manpower unavailable. As previously described, this would create a vicious circle (the positive loop 1) at the construction stage to cause more risk in 'construction delay' which would cause 'construction overrun' which would lead to 'finance unavailable' which would result in 'resources unavailable.' On the other hand, this would also create a vicious circle (the positive loop 1) at the operation stage to cause more risk in 'performance unavailable' which would cause 'revenue loss' which would lead to 'finance unavailable' which would result in 'resources unavailable' yet again. In addition, the 'Force Majeure' would be likely to directly cause 'accidents and safety issues' since the naturally unexpected events or man-made events that are beyond the control of both public and private parties would be likely to affect the safety of infrastructure, which would lead to 'performance unavailable' and reinforce the loop 2. Moreover, the 'Force Majeure' would be likely to directly cause 'scope changes'(Lu, 2004) as well since the uncontrolled events such as naturally unexpected events and man-made events would make the scope of output specification changed. As previously stated in "(4) Scope changes", the 'scope changes' would further cause 'design changes' which would cause 'construction changes' which would cause 'construction delay' which would join the loops 1 and 2 so that it would create a vicious circle (the positive loop 3) to make more risk in 'construction cost overrun' and more risk in 'revenue loss' respectively. In general, the 'Force Majeure' risk event would result in compounding consequences on 'construction cost overrun' and 'revenue loss' respectively through these three feedback dynamics over the construction and operation phases.

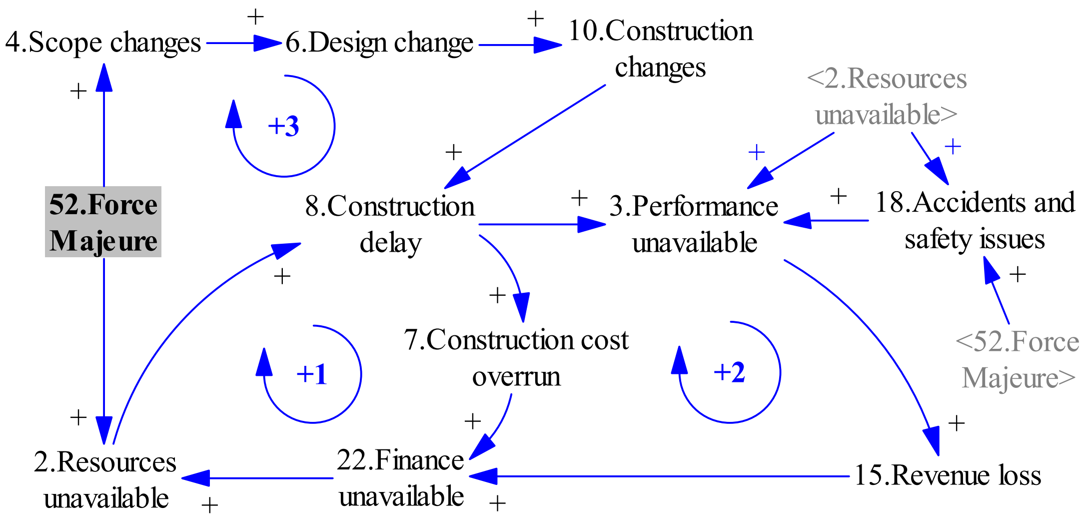


Figure V52 Cause Loop Diagram for 'Force Majeure' Risk Event

This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for the cases, the European Commission's report (EC, 2002) on the London Underground indicated that the Specific Line Upgrade was delayed due to certain Force Majeure. Hodge (2004)'s case study on the Melbourne City Link indicated that the government authority has assumed control of the project in a damaged condition, under certain catastrophic and uninsurable events. Lu (2004)'s case study on the Labin B Power Plant (China) indicated that the government authority took risk to guarantee any circumstance outside the control of both parties due to Force Majeure. The Ghosh & Jintanapakanont (2004)' case study on the Thailand Underground Rail Project reflected that the risk due to natural disaster may low probability to happen but very high impact on project performance.

Appendix VI Analysis of THSR Risks

VI1. 'Land Unavailable' on THSR

As discussed in the Section V1 and the CLD illustrated in Figure V1, failure to acquire the lands on schedule would be possibly be a result of industrial disputes risk events, and would likely cause construction delay risks. Relative to the THSR project, the interview statements were:

> "The overall length of lands for the whole route of THSR runs through the west corridor of Taiwan is about 345 kilometers. Among of them, the private lands occupy about 789 hectares, which were acquired by expropriation, whereas the public lands occupy about 101 hectares, which were acquired by appropriation. These include lands for routes and five station zones that include Taoyuan Station, Hsinchu Station, Taichung Station, Chaiyi Station and Tainan Station. In addition, the lands for constructing and operating six maintenance depots and bases from north Taiwan to south Taiwan are required, which includes Hsichih Depot, Liuchia Depot, Wujhi Depot, Taibao Base, Main Workshop and Tsoying Depot. The private and public lands occupy about 221 hectares. ***Most of the scheduled land acquisition can be completed to support the start of other work packages, but a delay in land acquisition on schedule would seriously delay the completion of other work packages including track work, civic work, station construction, depot construction and signal & communication systems of the M/E core system."***
>
> "All of land acquisition requires a negotiation with the land owners, a setup of property rights of superficies and an approval request from the related government authority for lands. However, you know there are 1,607 houses, 225 factories, 1,095 graves, and 70 stables on the lands. Thus negotiation for acquiring these lands is very complicated. ***The major delay was still caused by several disputes and strikes from the land owners*** from Taipei to Kaohsiung due to various reasons like that the land owners were usually unhappy with the acquisition prices, or they cannot find another places for settle, or the Green groups wanted to stop this project because they thought it would have a great impact on the environment. In addition, ***the minor delay was caused by obtaining an approval from the government authorities to change property right for industrial purpose***. This project has been approved by central government, but property right change is still under control of local governments. Some of local governments did not completely support land acquisition, so most of the approval delays for land acquisition are caused by local government."
> "According to the past experiences, there were about 5% -11% of land owners would argue against land acquisition, and about ***3%-13% of processing time for land acquisition would be delayed for the public transport projects; the larger projects, the more delay.***"
>
> "The land acquisition is a preliminary job before starting other work packages. Our job is to remove obstacles and ensure land acquisition can be completion as requested by the Fourth Division (which is responsible for Engineering Management and Contract Performance Supervision). The Fourth Division estimated that ***one year behind construction would incur additional construction administration cost about NT$5.5 b***, which includes manpower costs, material and equipment maintenance costs and interests for purchasing material and equipment, etc."

From the above interview statements, the general risk causal loop diagram for land unavailable shown in Figure V1 fits the likely scenarios for the THSR project. But, from the statements such as, "The major delay was still caused by several disputes and strikes from the land owners…", and "the minor delay was caused by obtaining an approval from the government authorities to change property right for industrial purpose," the direct causes of land unavailable were industrial disputes and approval delays. Therefore, the direct cause and consequences of land unavailable risk events shown in Figure V1 are modified in Figure VI1 to fit the THSR project.

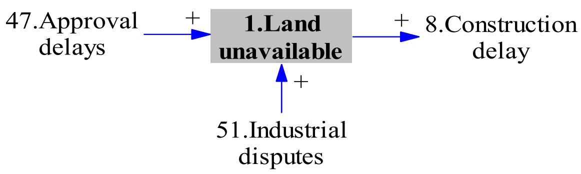


Figure VI1 The Direct Cause and Consequence for 'Land Unavailable'

VI2. 'Resources Unavailable' on THSR

As discussed in the Section V2 and the CLD shown in Figure V2, resources including manpower, material, and energy could not meet the contract requirements for construction and operation which had possibly been triggered by financial unavailable issues of default by subcontractors, industrial disputes and Force Majeure, and would likely cause construction delay. As for the THSR project, the interview statements were:

> "***No doubt the subcontractors are the most important resource for supplies.*** There are 12 subcontracts for civic works: C210 and C215 were carried by joint venture of subcontractors, Obayashi Corp. of Japan and Fu Tsu Construction Co. Ltd of ROC; C220 was carried by joint venture of Daiho Corp. of Japan and Chiu Tai General Contractor Co. Ltd of ROC and Kou Kai Construction Co. Ltd of ROC; C230 by joint venture of Hyundai Engineering & Corp. of Korea, Chung Lin General Contractor Co. Ltd of ROC and Zen Pacific Civil Contractor Co. Ltd of Hong Kong; C240 by joint venture of Hyundai Engineering & Corp. of Korea and Chung Lin General Contractor Co. Ltd of ROC; C250 by joint venture of Hochtief AG of German, Pan Asia Corp. of ROC and Ballast Nedam international of Holland; C260 and C270 by joint venture of Bilfinger and Berger Bauaktiengesellachaft of

German, and Continental Engineering Corp. of ROC; C280 by joint venture of Samsung Corp. of Korea, Korea Heavy Industries & Construction Co. Ltd. of Korea and International Engineering & Construction Corp. of ROC; C291 and C296 by joint venture of Shimizu Corp. of Japan and Evergreen Construction Corp. of ROC; C295 by joint venture of Italian Thai Development Public Company Limited of Thailand, Evergreen Construction Corp. of ROC, and Pacific Electric Wire & Cable Company of ROC. As for station construction, there are 6 subcontracts: S215 was carried by subcontractor Futsu/Obayashi JV; S220 by Daiho; S250 by Taisei/CEC/CTCI/Taian JV; S280 by Teco/Takenaka JV; S290 by Evergreen/Shimizu JV; S395 by SECI. The Core System for Electrical and Mechanical Equipment is supplied by joint venture of TSC which includes Japan Shinkansen System and other 6 Japanese companies for train units, signaling system, electric power and electric train system, telecommunication system, general electrical and mechanical equipment along the rail, training simulator and personnel training, etc. Tract work contract was carried by subcontractors TSC and TSIEC. As for maintenance depot construction, the detailed design contract D370 was carried by subcontractor, Po-Chen International (USA); D220 was carried by Shi-Ya Construction; D290 and D250 by joint venture of Chung-Ding Construction, Do-Yuan Engineering, and Chung-Lu Construction; D295 by joint venture of Do-Yuan Engineering and TVBJ (Australia); D502 by Safop (Italy); D503 by Vector Systems Pte. Ltd (Australia), etc."

"Apparently, ***a subcontractor's skill and coordination capability*** are the most important factors to ensure subcontractors resources ***can be used to properly build, integrate, and perform heterogeneous systems to meet the contract requirements.*** The Taiwan high speed rail is a high-technology project. All of the civic work, track work, mechanical systems and electrical systems were types of innovative technologies. Of special importance was the fact that Taiwan has complicated geographical features and natural conditions such as soil condition, underground water, mountain tunneling, typhoon, flood, and earthquakes, and the like which need high-technology solutions to overcome. The subcontractor selection should ensure it ***has enough skilled technicians and equipment to implement high-technology***. Moreover, there are about 50 major engineering items for all work packages including civic engineering, track work, power system, telecommunication system, and signaling system, etc., which need to be properly ***integrated to ensure the whole system can work well***. If any subcontractor for an item failed, the whole THSR project would risk failure. Most of these outsourcing contracts (subcontracts) were contracted by international tendering and carried out by joint venture of local and international companies. ***The differences on language, culture, technique between subcontractors would challenge whether the subcontractors and concessionaire can coordinate well to ensure the whole system can be built and performed to conform contract requirements***."

"Natural calamity is another threat to disrupt resource supplies. Like Taipei Mass Transit, the service was stopped before due to flooding caused by a typhoon. The THSR has suffered from the 921 (September 21, 1999) earthquake that led to serious equipment and facility damage. We required the concessionaire and their subcontractors who have the Standard of Procedure to deal with the risk from the typhoon and earthquake often happens in Taiwan, which would likely to cause equipment breakdown and power unavailable so that the construction or operation is forced to disrupt."

"The residents along the THSR line who suffered from ***the noise of THSR*** often protested against the THSR project construction and operation. Some of the project performance would therefore be stopped. ***The acceptable level is less than 75 decibels to continue for 8 minutes.*** The point test indicated that it often reaches ***76 to 94 decibels*** which would often cause the arguments and protects from the residents to stop project services."

"Another problem is ***the financial capability of contractor*** which is a potential risk to delay resource supplies and would lead to serious construction and service delay. The concessionaire would be easy to suffer financial difficulties before complete construction, especially when there was a great delay. That is because the project is only expanding with no revenue at construction phase. At operation phase, especially at the beginning of services, like Taipei Mass Transit, the demand is usually less than expected. This would lead to financial difficulties, too. I would say that the financial difficulties for concessionaire would cause significant impact on resource supplies that are required for THSR construction and operation."

"According to the past experience of the similar transport projects like Taipei Mass Transit, the minimum average delay for construction due to the lack of resource supplies is about ***45 days***. According to the contract mechanism, the Fourth Division of BHSR, which is responsible for Engineering Management and Contract Performance Supervision will step in when the lack of resources would delay each work package behind the schedule until ***120 days***."

From the above interview statements, the researcher determined that the direct cause and consequence for land unavailable events shown in Figure V2 fit the likely scenarios for the THSR project.

VI3. 'Performance Unavailable' on THSR

As discussed in the Section V3 and based on the CLD shown in Figure V3, the project performance were delayed or disrupted in delivery of services which lead to revenue losses, which were possibly triggered by construction delays, resource unavailable, failed commissioning tests, inspection and testing delay, low operating productivity, system breakdown, high maintenance frequency, accidents and safety issues, insolvency of contractors, shorter asset life, and industrial disputes. Relative to the THSR project, the interview statements were below:

"There would be lots of challenges to start running this state-of-the-art project. The preliminary condition is that ***all of work package should be completed and passed the inspection & commissioning tests on schedule*** for operation. ***Annual delay to start operation would be likely to cost about NT$19.3 billion including NT$13.8 billion for interest and NT$5.5 billion for operating cost***. Moreover, the basic requirement is that we need high quality engineering work to build and operate this high-technology system which should ***dynamically integrate*** trains, signaling and communication systems, and power systems to meet the commissioning test requirement that the THSR is able to efficiently and safely operate under high-speed running in 350 km/hr. The train and track are Japanese specifications,

but the signaling and communication systems are Germany specifications. They need to be ***integrated very well*** to ensure ***the whole THSR system*** can be operated without any defect during ***its expected service life***."
"For example, if the Turn Out system that is used to guide the trains on the right track is ***out of order***, then the regular trains would be canceled or delayed for services, which would cause that ***the whole system broke down*** or even lead to the ***rail crash***. The unreliable integration between train, track signaling and communication system will then ***need frequent modification and maintenance***. All of these ***would reduce operation efficiency***."

"Another major challenge is the ***skilled manpower and communication issue***. For example, a central control room has been built to monitor and operate THSR for the entire 345km line. It is similar to the brain controlling the body to work properly. It needs to control access to and from depots. It controls the in-cab APT and interlocking that allow route-setting and locking functions to be performed at the stations and depots along the route. Any problem on the controlling system would cause improper operation and even accident and safety issues. However, we require ***the skilled and practical manpower with good communication and coordination*** to use this state-of-the-art artificial intelligence. Originating from different countries, the current staff in the central control room may be skilled to use the central control system but speak different languages. There would be potential risk to reduce the operation quality and efficiency due to ***communication and coordination problems*** between the train drivers, maintenance staff and the staff in the central control room."

"When the THSR stops or there is a delay in service, the direct consequence is revenue loss. Being unable to meet service requirements will be ***penalized***. We estimate that the maximum number of trains that would delay service on time for ***more than 30 minutes in a month is about 45 trains***, and there would be ***no train delay*** if the operation company can monitor and control whole system well. According to the contract terms and conditions, ***the half of ticket fare*** should be refunded to every rider if the train behind the schedule ***more than 30 minutes***; ***the whole ticket fare*** should be refunded if delay ***more than one hour***. Furthermore, the cumulative delay service on time would likely to cause ***20% of trains*** that are unable to provide service as scheduled. We estimate that the ***break-even daily capacity is about 60 trains***. If the number of daily in-service train is less than the break-even daily capacity, then it would lead to revenue losses."

From statement that "all of work package should be completed and passed the inspection and commissioning tests on schedule for operation," the inspection and testing delay and failed commissioning tests risk events are included in construction delay. Therefore, they are removed from CLD shown in Figure V3. From the above statements, the researcher indicated that resources unavailable (the required for skilled and practical manpower), system breakdown, accidents and safety issues, high maintenance frequency, and poor cooperation/coordination (communication and coordination problem) would cause low operating productivity (reduce operation efficiency) and then lead to performance unavailable events which cannot meet contract service requirements (contract breach). Thus, the Figure V3 is modified as Figure VI3 to fit the THSR project.

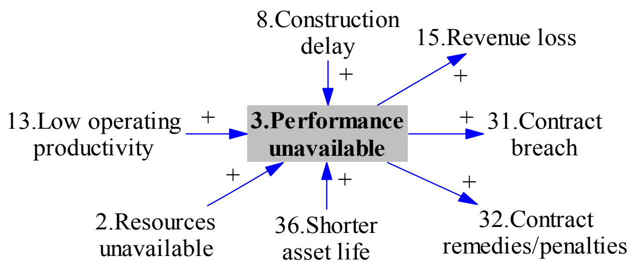


Figure VI3 The Modified Direct Cause and Consequence for 'Performance Unavailable'

VI4. 'Scope Changes' on THSR

As discussed in the Section V4 and the CLD shown in Figure V4, the project scope changed after contracting which lead to time delay and extra costs, possibly triggered by law/policy changes political interference and Force Majeure. Relative to the THSR project, the interview statements were below:

"The scope change would be a major source to cause construction cost overrun. The ***politics*** were one of the typical reasons to make the output specifications radically changed. Initially, there were 3 stops sited in the cities of Taoyuan, Taichung and Kaohsiung along the whole 345 km route from the north to south of Taiwan planned for THSR project. The purpose is to make the THSR a real high-speed train with minimum stops. However, the citizens of cities that had no stops worried that it would be bad news to their metropolitan development in the future. These cities officials strongly expected that if they were on the route of THSR that it would help to boost economic development. Later on, these cities started to lobby the central government to influence policy and plan with the assistant of legislators. ***Eventually the stops were changed from three to six.***"

"During construction the 9/21 earthquake happen in 1999 which caused the most serious damage in the late 20th century' this changed lots of rules for the THSR. ***The policy-maker therefore changed rule that requires earthquake-proof technology.***"

"Furthermore, the THSR route passes the South Taiwan Science Park, one of the major manufacturer pools of electronics and semiconductor in the world. When the trains pass, it will cause unendurable vibration that would significantly influence the products that are manufactured on the delicate instruments. ***The semiconductor industry officials strongly argued*** that the public and private sector should sort it out together. Similarly, ***the residents*** who live near the whole THSR route often **protested the enormous noise** produced by the THSR. Thus, ***the rules were changed to request the system design for the higher level of earthquake-proof, vibration-proof and noise-proof technology for THSR project.***"

From these statements, it is apparent that scope changes are usually caused by law/policy changes that arise from political interference (political reasons), Force Majeure (the earthquake), industrial disputes (the industrial argument and protest), and thus lead to design changes. Thus, the direct causes and consequences for scope change shown in Figure V4 were modified as Figure VI4 to fit the THSR project.

Figure VI4 The Modified Direct Cause and Consequence for 'Scope Changes'

VI5. 'Defective Design' on THSR

As discussed in the Section V5 and the CLD shown in Figure V5, the defective design would lead to a defective system that would potentially cause defective construction and performance unavailable events, possibly catalyzed by defaults of subcontractors and resources unavailable events. Relative to the THSR project, the interview statements were below:

"It would be very awful that the THSR is the state-of-art in high-speed rail system, but employs an old ticketing system. The ticketing system is one of cases on ***defective design that would make a defective facility***. For example, the online booking system is very unfriendly. Numerous customers have complained that it takes at least 40 minutes to finish processing a transaction because the system must simultaneously handle the seat arrangements and confirm that the banks can successfully collect the money. Overbooking also continues to occur. Moreover, the malfunction rate for ticket-checking at the gate is still higher than 5%. Frankly speaking, it seems that the THSR was doing flight business. Why do the customers need to go to the platform 20 minutes before train starts? It seems like boarding time to take a flight. That is a train, rather than a plane! This case told us that ***the subcontractors*** are very important and that they need to be familiar with the THSR operations, and ***have skilled design staff*** to design and build the ticketing system for the THSR, rather than copying the current flight ticketing system. Obviously their performance cannot meet contract requirements, so our supervising team has asked them ***to change design and modify ticketing system*** to meet THSR output service requirements."

"Another serious issue is that the defective design would cause problem on ***defective construction about system interface and integration***. The core power system, train vehicle, electrical and mechanical system, and signaling system are a mix of European and Japanese systems. The Japanese train vehicle only fits a one-way and one direction signaling system, but the European signaling system is one-way & two directions system. Apparently, they are not compatible. The benefit for one-way and one direction is that two trains will not crash into each other. The drawback is that once the accident happens, the whole line should be closed. On the contrary, the benefit for the one-way and two directions system is that the route will not need to be closed. However, its drawback is the whole signaling system becomes very complex so that its difficult to integrate with other systems. Any problem about ***unskilled technicians***, ***human ignorance***, ***poor communication***, and even ***system disorder*** would lead to ***serious rail crash***. Our supervising team has also asked them ***to modify information control systems*** for signaling and communication systems to meet the THSR output service requirements."

Based on these statements, the defective design would normally be caused by default of subcontractors, and resource unavailable (unskilled design staff), and could easily lead to defective construction (defective facilities) and complex system interface/integration. Thus, the direct causes and consequences for defective design shown in Figure V5 were modified as Figure VI5 to fit the THSR project.

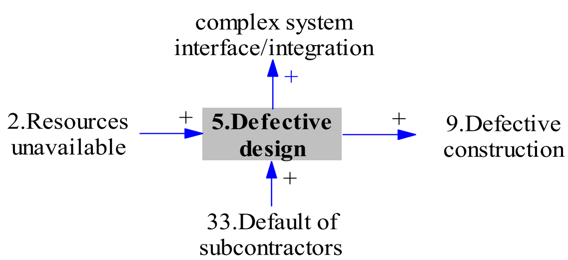


Figure VI5 The Modified Direct Cause and Consequence for 'Defective Design'

VI6. 'Design Changes' on THSR

As described in the Section VI5 and Section VI28, obviously the 'design changes' is one of remedy actions in construction stage that is usually caused by 'scope changes' and 'contractual disputes' and easy to lead to 'construction delay. Thus the direct causes and consequence of 'design changes' illustrated in Figure V6 can basically fit the THSR project well.

VI7. 'Construction Cost Overrun' on THSR

As described in Section VI8, VI9, VI22, VI27, VI40 and VI41, obviously all of additional costs arising from risk events such as 'construction delay' 'variability of interest rate' 'price escalation' and 'insurance increases' would likely cause 'construction cost overrun' at construction stage which would lead to 'finance unavailable.' Thus the direct causes and consequences of 'construction cost overrun' for Figure V7 are modified as Figure VI7 to fit the THSR project.

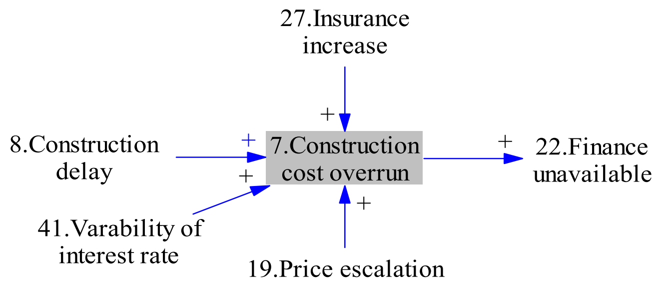


Figure VI7 The Modified Direct Cause and Consequence for 'Construction Cost Overrun'

VI8. 'Construction Delay' on THSR

As described in Section VI1, VI2, VI10, VI25, VI30, and VI49, we conclude that the 'construction delay' would be directly caused by 'land unavailable' and 'resources unavailable' 'construction changes' 'delay in contract change negotiation' 'ownership change delay' and 'unforeseen site conditions.' It would lead to 'construction delay' and 'performance unavailable'. Thus, the direct causes and consequences of 'construction delay' illustrated in Figure V9 are modified as Figure VI8 to fit the THSR project.

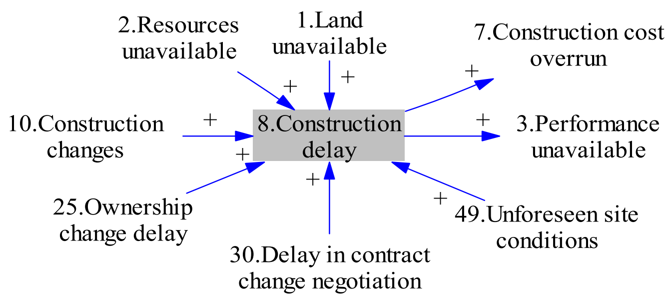


Figure VI8 The Modified Direct Cause and Consequence for 'Construction Delay'

VI9. 'Defective Construction' on THSR

As described in the Section VI2, VI3, VI5, and VI33, we conclude that the 'defective construction' is usually caused by 'defective design' and 'resources unavailable' 'default of subcontractors' and 'poor cooperation/coordination', and usually leads to 'failed commission tests' 'system breakdown' 'high maintenance frequency' 'accidents and safety issues' and 'shorter asset life'. Thus, the direct causes and consequences of 'defective construction' illustrated in Figure V9 are modified as Figure VI9 to fit the THSR project.

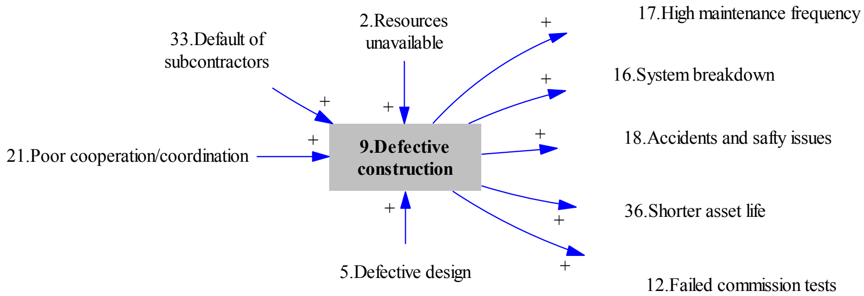


Figure VI9 The Modified Direct Cause and Consequence for 'Defective Construction'

VI10. 5.2.10 'Construction Changes' on THSR

As described in Section VI5, Section VI6 and Section VI28, apparently the 'construction changes' would be caused by 'design changes' and easy to lead to 'construction delay' and 'low operating productivity'. Thus the direct causes and consequences of 'construction changes' illustrated in Figure V10 are modified as Figure VI10 to fit the THSR project.

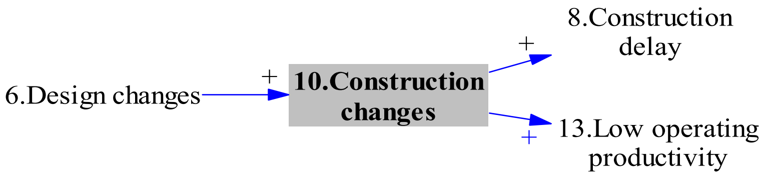


Figure VI10 The Modified Direct Cause and Consequence for 'Construction Changes'

VI11. 'Complex System Interface/Integration' on THSR

As described in Section VI2, VI3, VI5, VI20 and VI21, the THSR project employs Japanese technology for rail power systems, but European technology for signalling systems. This mix ('complex technologies') makes complex interface issue that it difficult to integrate the whole system well. Moreover, from the above statements, the 'defective design' of any subsystems such as ticketing system and signalling control system would make it be incompatible with other subsystems so that the whole system cannot integrated to meet contract requirements. We can therefore conclude that the 'complex system interface/integration' is usually caused by 'complex technologies' and 'defective design', and would lead to 'poor cooperation/coordination' 'system breakdown' 'high maintenance frequency' 'accidents and safety issues' and 'shorter asset life' Thus, the direct causes and consequences of 'complex system interface/integration' illustrated in Figure V11 are modified as Figure VI11 to fit the THSR project.

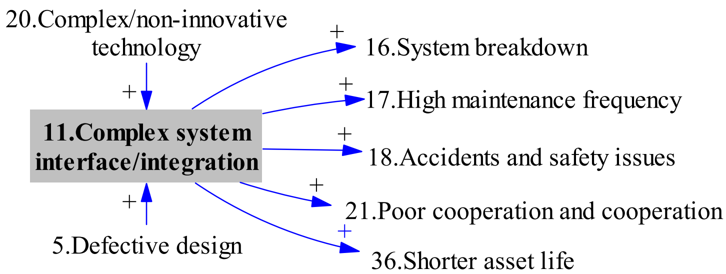


Figure VI11 The Modified Direct Cause and Consequence for 'Complex System Interface/Integration'

VI12. 'Failed Commissioning Tests' on THSR

As discussed in Section V12 and the CLD shown in Figure V12, that the operational commissioning tests cannot meet output specification on the schedule would lead to remedy actions ('contract remedies/penalties') to correct the defective systems so that the whole infrastructure system cannot start to deliver service ('performance unavailable') As for THSR project, the interview statement was below:

> "During commissioning tests, the whole THSR system failed to meet the operation requirements because of series of problem on ***defective facilities***: signalling system and ticketing system. For example, the track sensor that is used to sense if the trains pass and measure the speed couldn't feed back information to the Control Center. The Turn Out system and its detector EDP that is used to arrange the trains on the right track were often out of order. Moreover, the ticketing system had malfunction rate more than the contract requirements. All of these problems would delay operation and even probably cause safety and accident issues during operation. We strongly asked the contractor and its subcontractors to fix problems. The government authority rejected to start operating the THSR without remedying these defects according to the contract requirements."

As described in Section VI3 and VI9, and the above interview statement, the 'defective construction' would absolutely fail commissioning tests to meet contract requirements ('contract breach'), and would lead to further action on fix defective construction. Thus, the direct cause and consequence of 'failed commissioning test' illustrated in Figure V12 are modified as Figure VI12 to fit the THSR project.

Figure VI12 The Modified Direct Cause and Consequence for 'Failed Commissioning tests'

VI13. 'Low Operating Productivity' on THSR

As described in the Section VI2, VI3, VI10 and VI11, we conclude that the 'resources unavailable' 'default of subcontractors' 'construction changes' 'system breakdown' 'high maintenance frequency' 'accidents and safety issues' and 'poor cooperation/coordination' would lead to 'low operating productivity' that performance capability is lower than the contract requirements. Thus, the direct cause and consequence of 'low operating productivity' illustrated in Figure V13 are modified as Figure VI13 to fit the THSR project.

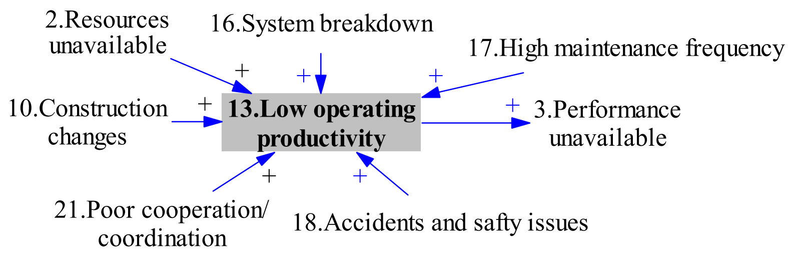


Figure VI13 The Modified Direct Cause and Consequence for 'Low Operating Productivity'

VI14. 'Mis-pricing' on THSR

As described in the Section VI29, we can conclude that the 'mis-pricing' is caused by 'inflexible contract arrangement', and would lead to 'revenue losses.'

> "To protect the end users, the government in authority holds the right to change train fare. The current policy allows the base fare to be increased by inflation rate approved by government. Then it can be further increased less than 20% of the base fare according to the factors such as distance, peak time, and business class. However, how much train fare can be increased depends on how flexible of the government's policy. Therefore, from the perspective of a private sector, it would need to take the risk that if the demand is largely less than the expected."

Thus, the direct cause and consequence of 'mis-pricing' illustrated in Figure V14 are modified as Figure VI14 to fit the THSR project..

Figure VI14 The Modified Direct Cause and Consequence for 'Mis-pricing'

VI15. 'Revenue Loss' on THSR

As described in the Section VI3, VI32, VI14, VI41, VI19, VI26, VI27, VI37, VI42, and VI38, obviously all of additional costs or losses arising from risk events at operation stage such as 'performance unavailable' 'contract remedies/penalties' 'mis-pricing' 'variability of interest rate' 'price escalation' 'tax increases' 'insurance increases' 'less residual value' 'variability of less demand' and 'termination liability' would likely cause 'revenue losses' which would lead to 'finance unavailable.' Thus the Figure V15 for direct causes and consequences of 'revenue losses' were modified as Figure VI15 to fit the THSR project. All of the models for 'revenue loss' effects were addressed in the above sections.

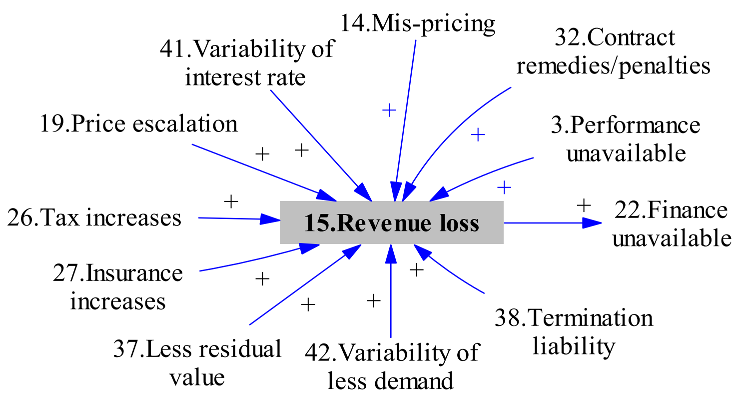


Figure VI15 The Modified Direct Cause and Consequence for 'Revenue Losses'

VI16. 'System Breakdown' on THSR

As described in the Section VI9, VI11 and VI13, we conclude that the 'defective construction' and 'complex system interface/integration' would cause 'system breakdown' that would further lead to 'low operating productivity' that performance capability is lower than the contract requirements. Thus, the direct causes and consequence of 'system breakdown' illustrated in Figure V16 are modified as Figure VI16 to fit the THSR project.

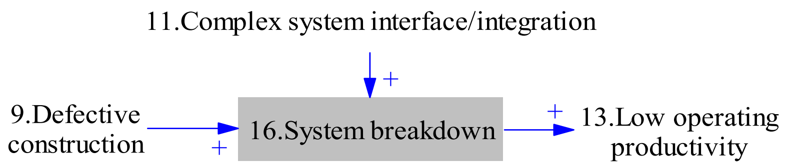


Figure VI16 The Modified Direct Cause and Consequence for 'System Breakdown'

VI17. 'High Maintenance Frequency' on THSR

As described in the Section VI9, VI11 and VI13, we conclude that the 'defective construction' and 'complex system interface/integration' would cause 'high maintenance frequency' that would further lead to 'low operating productivity' that performance capability is lower than the contract requirements. Thus, the direct causes and consequence of 'system breakdown' illustrated in Figure V17 are modified as Figure VI17 to fit the THSR project.

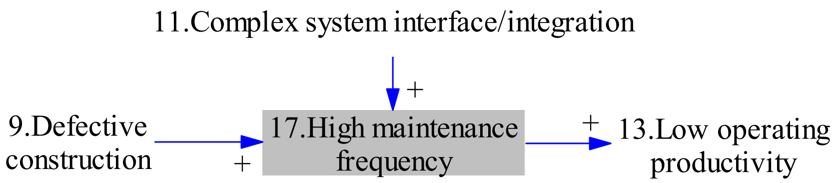


Figure VI17 The Modified Direct Cause and Consequence for 'High Maintenance Frequency'

VI18. 'Accidents and Safety Issues' on THSR

As described in the Section VI2, VI9, VI11 and VI52,, we conclude that the 'resources unavailable' 'defective construction' and 'complex system interface/integration' and 'Force Majeure' would cause 'accidents and safety Issues' that would further lead to 'low operating productivity' that performance capability is lower than the contract requirements and the accident damage . As for THSR project, the interview statement emphasize this issue below:

> "As we stated before, the THSR system consists of different sub-systems made by different countries, which is operated by the staff who come from different countries with different native languages. Especially for the operators work in the Central Control Room, they should be ***skilled with good command of communication and coordination.*** Any of problems on communication and coordination between operators would lead to accidents and safety issues such as derail and rail crash. Moreover, ***defective facilities*** and ***system interface and integration*** would also be easy to cause rail accidents. In addition to the above human factors, the ***powerful national disaster*** such as typhoon and earthquake that would happen in Taiwan every year would have a most serious impact on accident and safety issues. We assume under ***the worst circumstance there would be an accident due to human factor and national disaster every year in Taiwan.*** According to the current rail accident regulation, the death damage is NT$2.5 million per head, the accidental injury is NT$1.4 million per head, and the minor wound is NT$0.4 million per head. Therefore, ***the average maximum accidental damage is about NT$1.3 million per head a year***.

According to the above statements, the direct causes and consequences of 'accidents and safety Issues' illustrated in Figure V18 are modified as Figure VI18 to fit the THSR project.

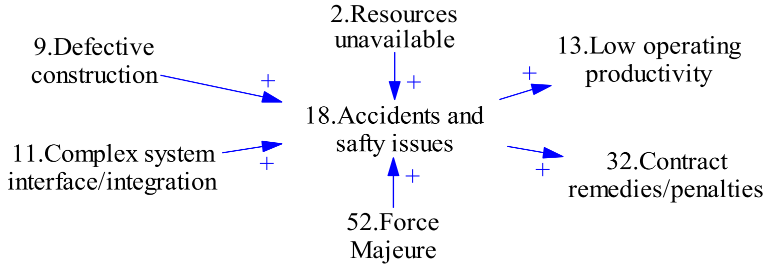


Figure VI18 The Modified Direct Cause and Consequence for 'Accidents and Safety Issues'

VI19. 'Price Escalation' on THSR

As discussed in Section V19 and Figure V19, the 'variability of inflation rate' and 'variability of exchange rate' would be likely to cause 'price escalation' which would lead to higher construction costs and operation costs which would lead to 'cost overrun' and 'revenue loss.' As for THSR project, the interview statement was below:

> "Undoubtedly ***the inflation rate would influence money for time*** which would cause higher construction costs than we budgeted. On the other hand, it would influence operation costs as well. The inflation is greatly influenced by global price and our own economy. Of course, it would influence THSR performance. Unfortunately, we cannot control it. It's responsibility of central government."

According to the above statement, obviously the direct cause and consequences of 'price escalation' illustrated in Figure V19 can basically fit the THSR project well.

VI20. 'Complex Technologies' on THSR

As described in Section VI11, the THSR project employs complex sub-systems that are incompatible each other would make complex interface issue that needs to take additional time and cost to integrate the whole THSR system. As for THSR project, the interview statement was below:

> "This is a sensitive question. Initially the THSR project focused the core system on German and French high-speed technology (German ICE power cars and French TGV Duplex intermediate trailers), but eventually the THSRC changed mind to chose Japanese technology (Kawasaki's 700 series Shinkansen trains). Now the THSR system employs Germany signalling and communication system, but employs Japanese power system. Because they cannot be compatible each other, the Japanese supplier should modify or re-design the system programs to integrate these systems. It's a great risk to take time and cost to maintain these sub-systems to ensure the whole THSR can be operated, since it may reduce reliability and ***reduce the whole life of THSR system.*** "This unreasonable decision made it's suspicious of political influence. There is no evidence for this suspiciousness. However, the ***political power*** represented from different project suppliers always tries to ***interfere and influence the decision on system design and choice.***"

According to the above statements, the direct cause and direct consequence of 'complex technologies' are 'political interference' and 'complex system interface/integration' respectively. Thus the CLD for 'complex technologies' illustrated in Figure V20 can basically fit the THSR project well.

VI21. 'Poor Cooperation/Coordination' on THSR

As described in Section VI2, VI3, VI5, and VI11, the THSR project employs Japanese technology for rail power systems, but European technology for signalling and communication systems. This combination makes complex interface issue that it difficult to integrate the whole system well. As for THSR project, the interviewee made the following supplementary statement:

> "The 'skill' and ***'coordination'*** capability would be the most important factors for the concessionaire, and both construction and operation subcontractors to ensure ***these heterogeneous systems*** can be build, integrate, and operate well to meet the contract requirements. ***The more complex interface and integration the system has, the more coordination is needed.*** At construction stage, it would cause ***construction defects***; at operation stage, the ***serious coordination issue*** it would often lead ***system broke down or service delay***."

From the above statements, obviously the 'poor cooperation/coordination' is usually caused by 'complex system interface/integration' and easy to lead to 'defective construction' and 'low operating productivity'. Thus, the direct cause and consequences of 'complex system interface/integration' illustrated in Figure V21 are modified as Figure VI21 to fit the THSR project.

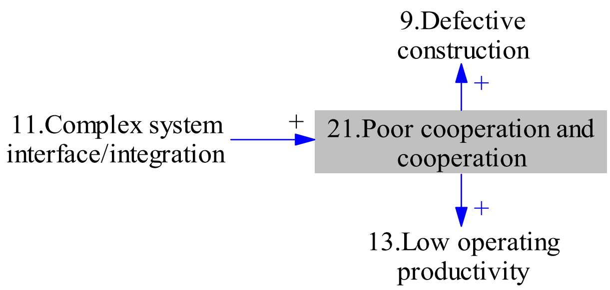


Figure VI21 The Modified Direct Cause and Consequence for 'Poor Cooperation/Coordination'

VI22. 'Finance Unavailable' on THSR

As discussed in the Section V22 and the CLD shown in Figure V22 , the 'finance unavailable' would cause that project are not available on the money amounts and on the conditions anticipated to perform project, which would be possibly caused by 'unsuitable regulatory policy' 'political interference' 'construction cost overrun' 'revenue loss' and 'ownership changes'. It would be likely to lead to 'resource unavailable' and 'insolvency of contractor.' As for THSR project, the interview statement was below:

> "The THSR is a significant contribution for the current governed party. ***From the perspective of politics benefit***, even though the THSR project is a private-financing project, the government has helped the contractor to sign a low-interest project-financing agreement with the banks under the guarantee of government. ***The government's policy*** even allows THSR project to have a financing agreement with ***a low equity-debt ratio at 1/9 (greater than 3/7 would prefer)***. In another word, most of the money used for THSR construction came from the banks rather than the contractor's own capital. Since the large delay in core system work package, the concessionaire has spent large money greater than it borrowed from the bank due to construction administration cost and interest payment. A day delay for operation means a day loss for revenue. ***The construction cost overrun*** due to construction delay and ***revenue loss*** due to operation delay has made the financing institutes lost their confidence to continue lending money to the contractor THSRC. It means it is difficult for the concessionaire to borrow more capital from the banks if they cannot start operation to earn money to repay money that they have spent for construction. Even THSR has been started to operate, the contractor still will face the risks in financial difficulties when the demand is much less than the forecasted. Once the concessionaire has financial difficulties, they won't be able to ***pay their subcontractors for subcontracts implementation***, which would delay project performance. Under the worst circumstance, the concessionaire would be consequently ***incapable of repayment for project debt so that it may go bankrupt and not be able to implement contract any more***. As a result, the contract will be terminated, and ***ownership will be switched to the government in authority*** but it would have the obligation to ***bear liability*** as well."

> "From our point of view (***the lender's perspective***), we focus on the loan repayment capacity to preview and review the contractor's 'financial capacity to borrow.' ***There are two criteria to judge project contractor's financial capacity: 'percentage of construction cost overrun' for construction stage and 'Debt Service Coverage (DSC)' for operation stage***. The basic requirement of financial capacity for construction is no cost overrun. If there is cost overrun, we will feel uncomfortable. The more percentage of construction cost overrun, the more confidence loss on the project contractor's financial capability during construction stage. Our acceptable DSC level is 1.5 for the general PPP case. If the project performance is guaranteed under government, then we can reduce this level from 1.5 to 1.2. If the average DSC at operation stage is lower than 1.2, we would have no confidence in project contractor's financial capacity."

From the above statements, obviously the 'finance unavailable' is usually caused by 'unsuitable regulatory policy' 'construction cost overrun' and 'revenue loss' and easy to lead to 'resources unavailable' and 'insolvency of contractor'. Thus, the direct cause and consequences of 'finance unavailable' illustrated in Figure V22 are modified as Figure VI22 to fit the THSR project.

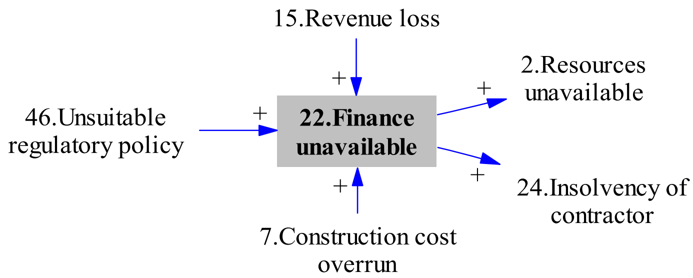


Figure VI22 The Modified Direct Cause and Consequence for 'Finance Unavailable'

VI23. 'Refinancing Liabilities' on THSR

As discussed in Section V23 and Figure V23, the 'finance unavailable' would be likely to cause 'refinancing liabilities' that the materially reduces the private sector's finance costs but increase the public sector's liabilities. As for THSR project, Mr A1, the 1st Division of BHSR, Ministry of Transportation and Communications (MOTC) made the following statement:

> "When the concessionaire has financial difficulties during project life so that it cannot keep implementing the contract, it may ask to argue and change project financing structure to replace the original contract arrangement. In general, the refinancing may only benefit the concessionaire but may be helpless to the THSR project. Moreover, it would make the government to bear the concessionaire's debt repayment risk. We need to assess if the refinancing can meet taxpayer's interests based on the real refinancing structure. However, the refinancing needs to be approved by the government authority. Moreover, the public sector may need to share the refinancing gains with the concessionaire."

From the above statement, basically the direct cause and consequence illustrated in Figure V23 can fit the THSR project well. However, it's a post contracting issue that there is no information on refinancing structure on the pre-contracting stage.

VI24. 'Insolvency of Contractor' on THSR

As the interview statement described in the Section VI22, "under the worst circumstance in financial difficulties ('finance unavailable'), the concessionaire would be consequently incapable of repayment for project debt ('insolvency of contractor') so that it may go bankrupt and not be able to implement contract any more ('contract breach'). As a result, the contract will be terminated, and ownership will be switched to the government in authority ('ownership change') but it would have the obligation to bear liability ('termination liability') as well." the 'finance unavailable' would likely to lead to 'insolvency of contractor'. Therefore, we can conclude that the 'finance unavailable' would cause 'insolvency of contractor' which would lead to 'contract breach' which would lead to 'ownership change delay' and 'termination liabilities.' Thus, the direct cause and consequence of 'insolvency of contractor' illustrated in Figure V24 are modified as Figure VI24 to fit the THSR project.

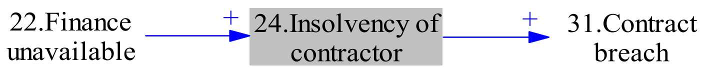


Figure VI24 The Modified Direct Cause and Consequence for 'Insolvency of Contractor'

VI25. 'Ownership Change Delay' on THSR

As the interview statement described in the Section VI47, we can conclude that the 'ownership change delay' is arising from 'approval delay', which would lead to 'construction delay.' The statement also indicated that there is no maximum limitation on approval review, but the ownership change delay would even take one year. Thus, the direct cause and consequence of 'ownership change delay' illustrated in Figure V25 are modified as Figure VI25 to fit the THSR project.

Figure VI25 The Modified Direct Cause and Consequence for 'Ownership Change Delay'

VI26. 'Tax Increases' on THSR

As described in the Section V26 and the CLD shown in Figure V26, the increased tax by government would affect the project finance. As for THSR project, the interview statement was below::

> "The average income tax for the general business is about 25%. But THSR project adapts to the government's regulations on 'Promotion of Private Participation', which can apply to preferential tax ranged from 15%-25%. After taking some exempted taxes into account, the possible tax for THSR would be about average 18%."

From the above statements, obviously the 'tax increase' is controlled under the government's policy on tax. Therefore, it is an external factor to THSR project. Thus, the direct cause and consequence illustrated in Figure V26 are modified as Figure VI26 to fit the THSR project.

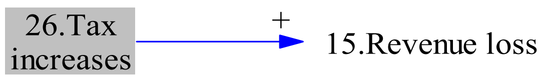


Figure VI26 The Modified Direct Cause and Consequence for 'Tax Increases'

VI27. 'Insurance Increases' on THSR

As described in Section V27 and Figure V27, the 'insurance increases' would contribute to 'construction cost overrun' or 'revenue loss'. A As for THSR project, the interview statement was below:

> "The required insurance for THSR is contracted with the reputable insurers approved by government and on conditions required by government. The insurance cost is based on the fixed terms & conditions with cost increase that is only subject to inflation. The contingency plan is about NT$54.2 billion for the risk premium over concession period."

From the above statements, the direct consequence illustrated in Figure V27 can fit the THSR project well.

VI28. 'Contractual Disputes' on THSR

As discussed in Section V28 and the CLD shown in Figure V28, the 'contractual disputes' would be likely to lead to additional time and costs to solve them. As for THSR project, the interview statement was below:

> "Contract breach is the major ***arguments*** between contract parties, which are for who need to take responsibility for ***contract defects***. For example, the signalling systems had ever been a nightmare for the commission of THSR. Due to far behind schedule on the signalling system, the whole THSR ***seriously delayed to start services***. The Japanese joint venture TSC the designer and manufacturer of THSR signalling system. The concessionaire THSRC would like to claim the loss of signalling system construction delay from TSC, but TSC complain it's due to unreasonable design requirements on the interface integration between European and Japanese systems requested by THSRC. Obviously it has been a great ***contract dispute*** between THSRC and its subcontractor TSC."

From the above statements and that in Section VI35, obviously the 'contractual disputes' is usually caused by 'contract breach' and 'latent defects', and easy to lead to any actions for dispute solution. Thus, the direct causes of 'contractual disputes' illustrated in Figure V28 are modified as Figure VI28 to fit the THSR project.

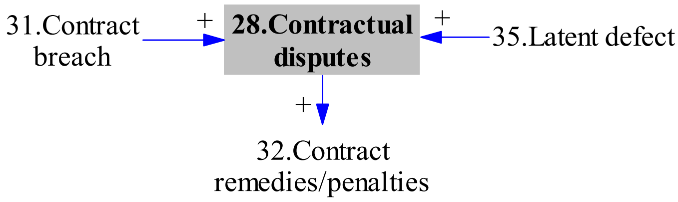


Figure VI28 The Modified Direct Cause and Consequence for 'Defective Design'

VI29. 'Inflexible Contract Arrangement' on THSR

As discussed in Section V29 and the CLD as shown in Figure V29, the 'inflexible contract changes' would be likely to lead to additional time and costs to change contract contents. As for THSR project, the interview statement was below:

> "THSR contract is one of the most important infrastructure projects in the recent 10 years, which will have huge positive economic effects to reduce the metropolitan development difference between the south Taiwan and south Taiwan. Even though the concessionaire has the ownership of THSR during concession period, for public interests, ***the government' policy*** is that ***the public sector in authority still have to hold the right to approve major contract changes*** such as **scope change and ticket price change**, which also includes the right to approve major contract changes ***between the concessionaire and its subcontracts***. Of course, the contractors may not happy with this contract change mechanism, which would delay contract changes, and the contractor may not be able to make ticket pricing as they would expect. However, from the point of view of the government, the public interests are our first priority."

According to the above statements, the direct cause of 'inflexible contract changes' is 'unsuitable regulatory policy' and direct consequences are 'delay in contract change negotiation' and 'mis-pricing' respectively. Thus the CLD for 'inflexible contract changes' illustrated in Figure 4.2.29 can basically fit the THSR project well.

VI30. 'Delay in Contract Change Negotiation' on THSR

As described in Section VI29 and VI47, we can conclude that the 'delay in contract negotiation' is caused by 'inflexible contract arrangement (for example, major contract changes between concessionaire and subcontractors need to obtain approval from the government)' and 'approval delay (for example, the scope changes and ticket price changes should obtain approval from the government)', and would lead to 'construction delay'.

Thus, the direct causes and consequence of 'delay in contract negotiation' illustrated in Figure V30 are modified as Figure VI30 to fit the THSR project.

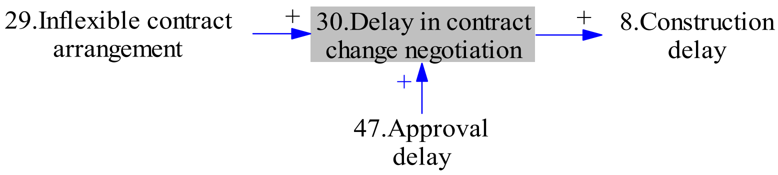


Figure VI30 The Modified Direct Cause and Consequence for 'Delay in Contract Change Negotiation'

VI31. 'Contract Breach' on THSR

As described in Section VI3 and VI12, VI24, VI38, VI48, there are four major scenarios that would cause 'contract breach', which are 'performance unavailable' that the contractor is unable to deliver service according to the contract requirements, 'failed commission tests' that the built systems cannot pass the commission tests according to the contract specification requirements, 'insolvency of contractor' that the contractor cannot implement contract requirements any longer due to financial difficulty, and 'law/policy changes' that the contract requirements become more stricter than the original expectation so that the contractor cannot make it, for example, the stricter economical protection rules. In addition, the interviewees made a supplementary statement below:

> "When there is 'contract breach' in TSHR project, there are two things would happen: first, it would cause '***contractual disputes***' that the government authority, the concessionaire, and the subcontractors would argue who will need to take responsibility for the defects; second, it would cause ***'contract termination'*** that the issue is very serious to sort out. From the stand of government, we prefer sorting out disputes to terminating contract. We hope contact can be smoothly implemented to deliver services."

From the above statements, we can conclude that the 'contract breach' would be caused by 'performance unavailable' 'failed commission tests' 'insolvency of contractor' and 'law/policy changes', and would be likely to lead to 'contractual disputes' and 'termination liabilities.' Thus, the direct causes and consequences of 'contract breach' illustrated in Figure V31 are modified as Figure VI31 to fit the THSR project.

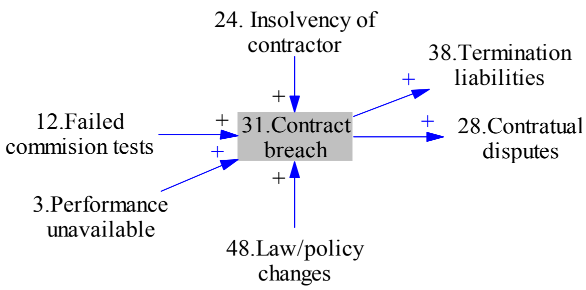


Figure VI31 The Modified Direct Cause and Consequence for 'Contract Breach'

VI32. 'Contract Remedies/Penalties' on THSR

As described from Section VI3 to VI18, the 'performance unavailable (failure in services' and 'accidents and safety issues (accident damage)' will lead to 'contract remedies/penalties' that will lead to 'revenue losses.' Thus, the direct cause and consequence of 'contract remedies/penalties' illustrated in Figure 4.2.32 are modified as Figure 5.2.32 to fit the THSR project.

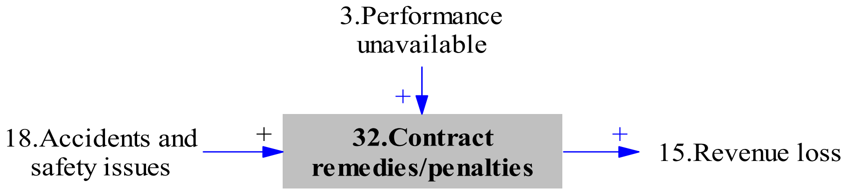


Figure VI32 The Modified Direct Cause and Consequence for 'Contract Remedies/Penalties'

VI33. 'Default of Subcontractors' on THSR

As discussed in Section V33 and the CLD as shown in Figure V33, the 'default of subcontractors' would likely lead to 'defective design' and 'defective construction' that need additional time and costs to remedy. As for THSR project, the interview statement was below:

> "The subcontractors are the core of PPP project supply chain, which take responsible to design, build, and operate THSR project. There have ever been some defective design and facilities happened in THSR project, which would make the whole system down and serious safety issues. For example, the 'Turn Out' system and its signal detector EDP are often out of order that the train cannot be guided into the right track, which would often lead to derail and possibly the rail crash accident. The 'Bogie' is often out of order, too. It is used to drive the carriage to move along the track. Once it damages seriously, not only it would lead the carriage to be derailed but also cause the train engine damaged. All of these defective facilities are subcontractors' responsibilities."

From the above statements and that in Section VI2 and Section VI3, apparently the 'default of subcontractors' would usually lead to 'defective design', 'defective construction', and 'resources unavailable.' Thus the direct consequences of 'design changes' illustrated in Figure V33 can basically fit the THSR project well.

VI34. 'Inspection and Testing Delay' on THSR

As described in Section VI3, the variable 'inspection and testing delay' has been included in 'construction delay.' So, this risk variable is removed from the research.

VI35. 'Latent Defects' on THSR

As discussed in Section V35 and Figure V35, the 'latent defects' that the employed technologies infringe the patents held by the third parties would likely cause the 'contractual disputes' which would likely lead to additional time and costs to solve them. As for THSR project, the interview statement was below:

> "Because of including many heterogeneous systems, the solution for latent defects is almost one of the terms and conditions of large-scale construction engineering contract. The purpose is ***to prevent contract disputes from the contractor, customer, and the third parties*** in case that there is any patent infringement about technologies employed in these heterogeneous systems. Fortunately, the THSR technology is the most updated and innovative, I believe it would not have problem about 'latent defects' but we still need to reduce this risk by including the related terms and conditions about it in the PPP contract."

From the above interview statements, the direct causes and consequence of 'latent defects' illustrated in Figure V35 can basically fit the THSR project well.

VI36. 'Shorter Asset Life' on THSR

As discussed in the Section VI9 and VI11, the 'shorter asset life' that the facility life would be shorter than planned would likely be caused by 'defective construction' and 'complex system interface/integration'; it would lead to 'less residual value' and 'performance unavailable'. The interviewees made a supplementary statement below:

> "The THSR employs Japanese power system, but European signalling and communication system. We worry that upgrading THSR would be difficult, since there is an interface and integration problem between different systems. If any of subsystems is not compatible with others, the whole THSR system cannot be operated well. For example, the current Trainset is Japanese Shinkansen 700 series with max operation speed 350km/hr. ***If we would like to upgrade 500km/hr after 25 years, we suspect the current signalling and communication system and other sub-systems can support the new train system***. Even though the current whole system can be upgraded, we may need to expense much more than we expected."

Thus, the direct cause and consequence of 'shorter asset life' illustrated in Figure V36 is modified as Figure VI36 to fit the THSR project.

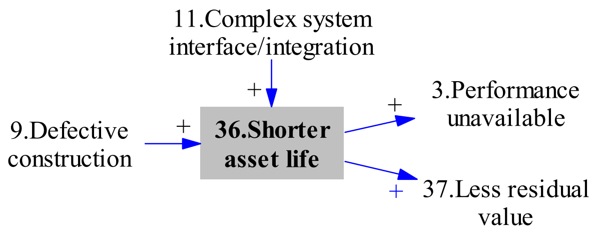


Figure VI36 The Modified Direct Cause and Consequence for 'Shorter Asset Life' Risk Event

VI37. 'Less Residual Values' on THSR

As discussed in Section VI26 and VI36, the 'less residual value' would be caused by 'shorter asset life'; it would lead to 'revenue losses.' Thus, the direct cause and consequence of 'shorter asset life' illustrated in Figure V37 is modified as Figure VI37 to fit the THSR project.

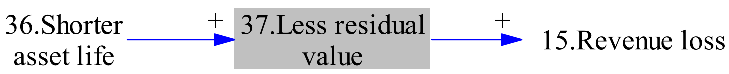


Figure VI37 The Modified Direct Cause and Consequence for for 'Less Residule Value'

VI38. 'Termination Liabilities' on THSR

As described in Section VI31, under the worst circumstance the 'contract breach' would cause 'termination liabilities' that would cause 'construction delay' arising from ownership change delay at construction stage and 'revenue losses' at operation stage. Thus, the direct cause and consequences of 'termination liabilities' illustrated in Figure V38 is modified as Figure VI38 to fit the THSR project.

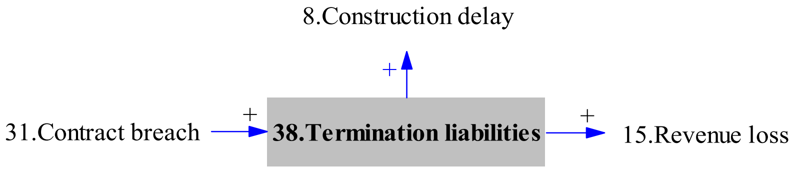


Figure VI38 The Modified Direct Cause and Consequence for 'Termination Liabilities'

VI39. 'Variability of Inflation Rate' on THSR

As discussed in the Section V39 and the CLD shown in Figure V39, the 'variability of inflation rate' would be likely to cause 'price escalation'. As for THSR project, the interview statement was below:

> "***The economical policies*** are always ***fluctuated by compounding lots of complex factors such as global economy, internal economy, politics, and environment protection.*** The microeconomic factors, such as inflation rate, interest rate, foreign exchange rate are demand, are dependent each other. It's difficult for us to make a specific pattern to predict their influence on THSR performance. However, to stable economic growth for our country, all of these microeconomic factors are controlled by the central government of Taiwan. In addition, these microeconomic factors are external risk to THSR project, so we always employ ***the policies and data announced by the Directorate-General of Budget, Accounting and Statistics (DBAS), Executive Yuan.***"

"Construction Price Index (CPI) is usually used for construction projects to measure ***the escalation of materials and labour costs.*** According to the DBAS (2000; 2007)'s data, the average annual inflation rate was about 4.98% for construction material from year 1986 to 1997 in Taiwan; 1.35% for construction wage***. The average annual increase rate for CPI*** is about ***3.69%, ranged from about 2% to 6%*** from year 1986 to 1997 in Taiwan. ***In the future, the CPI is predicted that it would likely to continuously increase due to higher global oil prices and higher construction material demand due to economic boost in China, but the government's policy is to keep it stable and being less than 7%.***"

From the above statements, we can conclude that 'variability of inflation rate' is an external risk to THSR project but would lead to 'price escalation' in common sense for THSR project. Thus, the direct consequence of 'variability of inflation rate' illustrated in Figure V39 is modified as Figure VI39 to fit the THSR project.

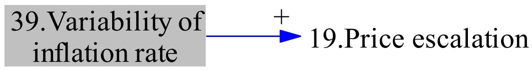


Figure VI39 The Modified Direct Cause and Consequence for 'Variability of Inflation Rate'

VI40. 'Variability of Exchange Rate' on THSR

As discussed in the Section V40 and the CLD shown in Figure V40, the 'variability of exchange rate' would be likely to cause 'price escalation'. As for THSR project, the interview statement was below:

"The depreciated exchange rate against US dollar would increase the costs of importing materials for project construction and operation. Basically its change is up to the currency market. However, it's easy to be influenced by the fluctuation of local stock market and the manipulation of international investors. For a healthy investment environment, ***the Central Bank would keep interfering currency market to stabilize the exchange rate.*** According to the CEPD's data, the past twenty years indicated that exchange rates for ***New Taiwan dollar were changed between about 25 and 35 against US dollar***. The long-term policy, the exchange rate would be ***held about 33 by the Central Bank.***"

From the above statements, we can conclude that 'variability of exchange rate' is an external risk to THSR project but would lead to 'price escalation' for THSR project. Thus, the direct cause and consequence of 'variability of exchange rate' illustrated in Figure V40 are modified as Figure VI40 to fit the THSR project.

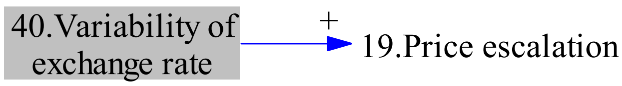


Figure VI40 The Modified Direct Cause and Consequence for 'Variability of Exchange Rate'

VI41. 'Variability of Interest Rate' on THSR

As discussed in Section V41 and CLD shown in Figure V41, increasing interest rate rather expected would be possibly triggered by 'downside economic events' and would be likely to cause 'price escalation.' As for THSR project, the interview statement was below:

"The increased interest rate would increase the repayment arising from borrowing money for construction. Generally speaking in Taiwan the interest rate will drop off to about 2% from 6% after 1999. The interest rate is also easy to be influenced by global economy and politics. For example, some countries such as China, Russia, India, and oil export countries have large foreign exchange reserves. Their behaviour of how to use these reserves for foreign investment would have great impact on interest rate. However, like inflation rate and exchange rate, the Central Bank would keep interfering to stabilize the interest rate for a healthy investment environment. ***For long-term policy, the interest rate would be held around 2% to 4%, and the highest impact is around 9%***."

From the above interview statements, the 'variability of interest rate' is manipulated by the Central Bank in Taiwan. Therefore, we can conclude that 'variability of exchange rate' is an external risk to THSR project but would lead to increase expense for THSR project. Thus, the direct cause and consequence of 'variability of interest rate' illustrated in Figure V41 is modified as Figure V41 to fit the THSR project.

Figure VI41 The Modified Direct Cause and Consequence for 'Variability of Interest Rate'

VI42. 'Variability of Less Demand' on THSR

As discussed in the SectionV42 and the CLD shown in Figure V42, the 'variability of less demand' than expected would be possibly triggered by 'higher competition' and would be likely to cause 'revenue loss.' As for THSR project, the interview statement was below:

> "There are many research reports indicated that the demand for ridership will be grew up from yearly average 2% to 6%. There are lots of factors would influence ridership demand. Among of them, travel time and travel cost are two most important factors. High way road systems, flights, railway, and high-speed railway are four major transport systems from North to South Taiwan. Flight has shorter travel time, higher operation cost, but lower infrastructure cost than high speed railway. High way road system has longer travel time, higher operation cost, but much lower infrastructure cost. Take accidents and time delay and pollution cost into account, the high speed railway is the lowest among these systems. If we take ***the whole life costing into account*** and convert it into NT$/Person*Km, which includes 'infrastructure cost' 'operation cost' 'travel time cost' 'noise costs' 'air pollutions and CO_2 cost' 'discards cost' 'land impact cost' 'delay and congestion cost' and 'accident cost', then ***the high speed railway system costs 4.4918 NT$/PKm. This is the lowest cost among all transport systems.*** As for mid and long distance travellers, ***the high speed railway system is the most attractive.*** Moreover, ***all of these systems use petroleum as fuel. People have no choice when the international petroleum is increasing.*** Therefore, there are ***almost no other transport systems that are able to compete the high speed railway system for the mid and long distance travellers in the future.*** On the contrary, the high speed railway system would have great impact on flight system in Taiwan."
>
> "We have our own (BHSR's) ridership demand forecast for THSR. But I know there are lots of different demand research reports from different points of view with different evaluation methodologies. I suggest they would be taken into account to minimise the evaluation bias."

From the above interview statements, it indicates that the 'variability of less demand' would not be influenced by 'higher competition' and 'downside economic events' in Taiwan for THSR case, since THSR has the lowest whole life cost and the users doesn't change their transport using behaviour due to specific economic event like higher petroleum price. Therefore, the direct cause and consequence of 'variability of less demand' are illustrated in Figure V42 is modified as Figure VI42 to fit THSR case.

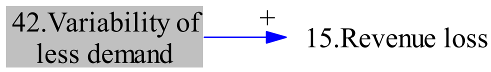


Figure VI42 The Modified Direct Cause and Consequence for 'Variability of Less Demand' Risk Event

VI43. 'Higher Competition' on THSR

As described in Section VI43, there is no 'higher competition' risk for THSR project. Therefore, we remove causal loop diagram shown in Figure VI43 for 'higher competition' risk.

VI44. 'Downside Economic Events' on THSR

As described from Section VI39 to VI42, the 'downside economic events' would likely influence the government's economic policies on inflation, exchange rate, interest rate, etc. However, the 'downside economic event' is uncontrollable so that it's an external factor to THSR project. Thus, the direct cause and consequence for 'downside economic events' illustrated in Figure V44 are modified as Figure VI44 to fit the THSR project.

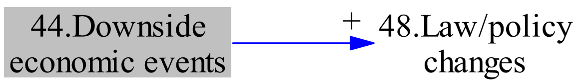


Figure VI44 The Modified Direct Cause and Consequence for 'Downside Economic Events'

VI45. 'Political Interference' on THSR

As described in Section VI4 and VI20, for example, the 'political interference' from different parties would influence government's policy to change THSR service scope ('law/policy changes'), and would be likely to influence decision on choose complex and inefficient systems ('complex technologies') for THSR project. The interviewees a supplementary statement about 'political interference' below:

> "Unfortunately, the influence of politics is extensive on a large-scale construction project like THSR. For example, the current government considered THSR is one of its great contributions. To gain benefits from annual election, ***the authority in supervising THSR project allows*** the contractor THSRC to start test runs before THSRC can complete the rectification of all the more than 20 defects and problems listed in the latest inspection report concerning the independent verification and validation facility (IV&V) issued by the Lloyd's. This led to great ***public arguments***."
> "Most of reasonable regulations on large-scale infrastructure projects are ***influenced by politics***, which may be from the standpoint of the business benefits rather than that of taxpayers."

From the above statements, we can conclude that the 'political interference' would lead to 'law/policy changes' 'complex technologies' and 'unsuitable regulatory policy' for THSR project. Thus, the direct consequences of 'political interference' illustrated in Figure V45 are modified as Figure VI45 to fit the THSR project.

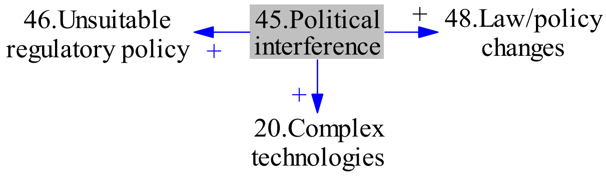


Figure VI45 The Modified Direct Cause and Consequence for 'Political Interference' Risk Event

VI46. 'Unsuitable Regulatory Policy' on THSR

As described in Section VI22, VI29, VI47, and VI51, we can conclude that the 'unsuitable regulatory policy' is caused by 'political interference' and would lead to 'financial unavailable (for example, allow a low equity-debt ratio of project financing from the standpoint of short-term business benefits)' 'inflexible contract arrangement (for example, major contract changes between concessionaire and subcontractors need to obtain approval from the government)' 'industrial disputes (the negotiation argument on land acquisition price)' and 'approval delay (for example, the scope changes and ticket price changes should obtain approval from the government)'.

Thus, the direct causes and consequences of 'unsuitable regulatory policy' illustrated in Figure V46 are modified as Figure VI46 to fit the THSR project.

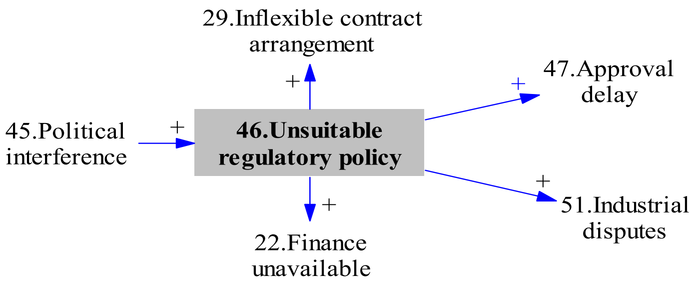


Figure VI46 The Modified Direct Cause and Consequence for 'Unsuitable Regulatory Policy' Risk Event

VI47. 'Approval Delays' on THSR

As discussed in the Section V27 and as CLD shown in Figure V47, the 'approval delay' that the possible time delay arising from obtaining consents from the government authority, which is possibly directly triggered by 'political interference' and directly lead to 'construction delay.' The interviewee summarised three types of approval delays by government's regulations as the following statements:

> "In addition to changing property right for land acquisition, changing major contract contents and changing project ownership are two major things that need to obtain approval from the government authority. From the point of view of project management, ***the current regulation for the procedure to get an approval from the government is too complex to efficiently perform THSR project. There is no maximum limitation on approval review***, so the approval delay can be very unstable. From our past experience on Transit projects, the greatest argument is the ownership change delay, which would even take government authority ***one year***; contract change would also lead to great argument that would may need to take from ***0.5 months to 6 months***."

From the above statements, we can conclude that 'approval delay' would be caused by 'unsuitable regulatory policy' and lead to 'land unavailable' 'ownership change delay' and 'delay in contract change negotiation' for THSR project. Thus, the direct cause and consequences of 'approval delay' illustrated in Figure V47 are modified as Figure VI47 to fit the THSR project.

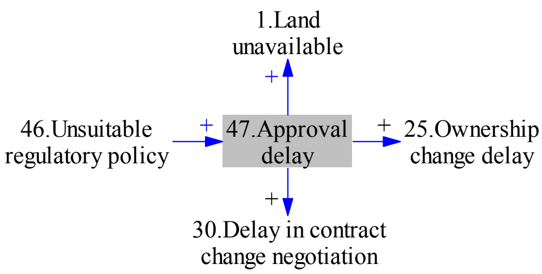


Figure VI47 The Modified Direct Cause and Consequence for 'Approval Delay'

VI48. 'Law/Policy Changes' on THSR

As described in the Section VI2, VI4, VI31, VI44, VI45, VI51, and VI52, we conclude that the 'downside economic events' 'political interference' 'industrial disputes' and 'Force Majeure' would cause 'law/policy changes' that would further lead to 'scope changes' and 'contract break.' For example, the 'downside economic events' would lead to policy changes on interest rate, inflation rate, exchange rate, etc; the 'political interference' would influence government's policy on THSR service scope, and then lead to 'scope change'; the 'industrial disputes' on environmental pollutions and 'Force Majeure' on national disaster would cause stricter policies on noise-proof and earthquake-proof standard than the contractors can follow so that it would lead to 'contract breach.'

Thus, the direct cause and consequences of 'law/policy changes' illustrated in Figure V48 are modified as Figure VI48 to fit the THSR project.

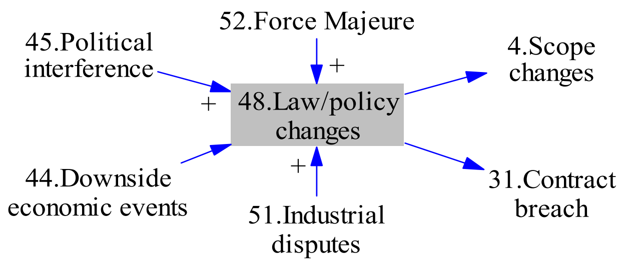


Figure VI48 The Modified Direct Cause and Consequence for 'Law/Policy Changes' Risk Event

VI49. 'Unforeseen Site Conditions' on THSR

As discussed in the Section V49 and Figure V49, the 'unforeseen site conditions' that the unanticipated adverse site conditions would directly lead to 'construction delay.' As for THSR project, the interview statement was below::

> "There are ten new stations, along with a large number of new bridges, tunnels and viaducts on the line's total 345km length. The route includes steep gradients to cross the terrain. It's a great challenge for construction under the complicated geographical features and natural calamity such as soil condition, underground water, mountain tunnelling, typhoon, flood, and earthquake, etc. Any unforeseen site conditions more than we expected would cause construction delay, especially for tunnelling that would be very difficult and costly process. We have conducted prior survey on site conditions, but it's difficult to predict the delay under this risk. However, based on our past experience, the unforeseen site conditions would always delay about 5%-15% of the tunnelling schedule."

From the above interview statements, the direct cause and consequence of 'unforeseen site conditions' illustrated in Figure V49 can basically fit the THSR project well.

VI50. 'Greater Environmental Expectation' on THSR

As discussed in the Section V50 and Figure V50, the 'greater environmental expectation' that the people have more expectation than the regular environmental protection regulation. As for THSR project, the interview statement was below:

> "The contractor has been suffered ***serious protests*** from the electronic industry and residents along the route of THSR. They complained that the contractor didn't deal with the noise, underground water, and vibration issues well. They would take further actions to prevent THSR from operating if the public sector is unable to step in to sort out these problems. However, this would force the government ***change some environmental protection regulations*** to meet the public expectation."

From the above statements, we can conclude that 'greater environmental expectation' would lead to 'industrial disputes' for THSR project. Thus, the direct cause and consequence of 'greater environmental expectation' illustrated in Figure V50 are modified as Figure VI50 to fit the THSR project.

Figure VI50 The Modified Direct Cause and Consequence for 'Greater Environmental Expectation'

VI51. 'Industrial Disputes' on THSR

As described in the Section VI1, VI2, VI4, VI46, VI48, and VI50, we conclude that the 'unsuitable regulatory policy' and 'higher environmental protection expectation' would cause 'industrial disputes' that would further lead to 'land unavailable (for example, the negotiation argument on land acquisition price)' 'resources unavailable (for example, the environmental protests due to noise pollution would cause that the residents would try to stop contractors from THSR operations)' and 'law/policy changes (for example, the environmental protection regulations on noise-proof would change and become stricter)'. Thus, the direct cause and consequence for 'industrial disputes' illustrated in Figure V51 are modified as Figure VI51 to fit the THSR project.

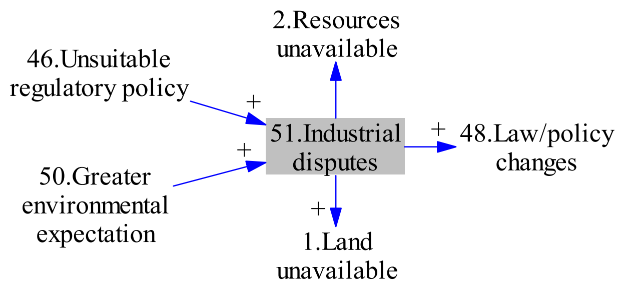


Figure VI51 The Modified Direct Cause and Consequence for 'Industrial Disputes'

VI52. 'Force Majeure' on THSR

As described in the Section VI2, VI5, VI18, and VI48, we conclude that the 'Force Majeure' would lead to 'accidents and safety issues (for example, the powerful typhoon and earthquake would cause death or injure damage)' 'resources unavailable (for example, powerful typhoon and earthquake would lead to equipment breakdown and power unavailable so that the construction or operation is forced to disrupt.)' and 'law/policy changes (For example, the damage due to earthquake would likely to change rule and policy that requires earthquake-proof technology)'. Thus, the direct consequences of 'Force Majeure' illustrated in Figure V52 are modified as Figure VI52 to fit the THSR project.

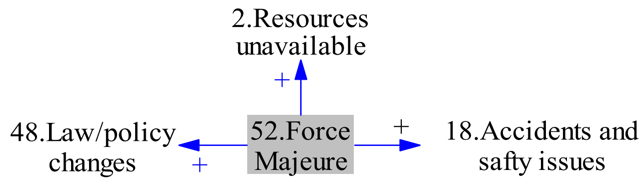


Figure VI52 The Modified Direct Cause and Consequence for 'Force Majeure'

Appendix VII Analysis of The Risk Network Models

VII1. RCN for 'Land Unavailable' on THSR

Based on the scenario statements described in Section VI1 and the Figure VI1, the direct causes for land unavailable events were approval delays and industrial disputes, and the direct consequence was construction delays. Therefore, the linear multiple-regression model was applied to address the relationship between land unavailable, approval delays and industrial disputes for the SD model as shown in Figure VII1:

$$RD_k(lu) = \beta_{0k} + \beta_{1k} * RD_k(id) + \beta_{2k} * RD_k(ad) + \varepsilon_k,\ k = c$$

Where

RD_k: *random variable for the expected risk effect;*
k: time period, c (construction stage); o (operation stage);
lu: risk event for 'land unavailable';
id: risk event for 'industrial disputes';
ad: risk event for 'approval delay';
β_{0k}: *the constant term for the multiple regression model;*
β_{1k}, β_{2k}: *the relational coefficients for the independent risk variables;*
ε_k: *the random error for the multiple regression model;*

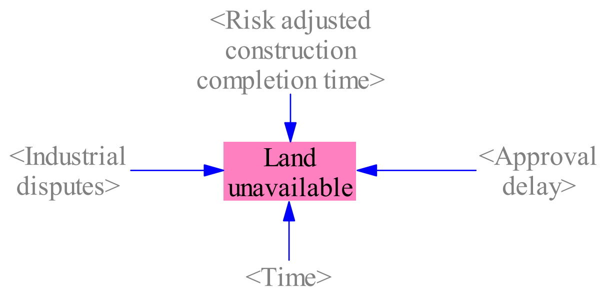


Figure VII1 The SD Model for 'Land Unavailable' Risk Effect

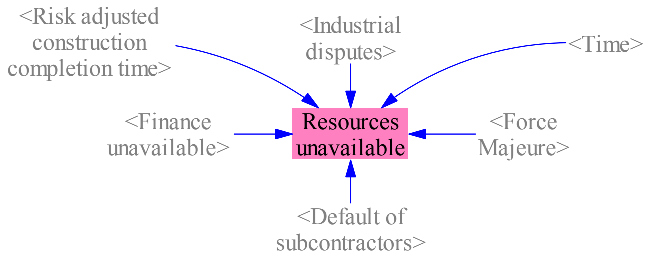
VII2. RCN for 'Resource Unavailable' on THSR

Based on the scenario statements described in Section VI2 and the Figure VI2, the direct causes for resources unavailable events were default of subcontractors, Force Majeure, industrial disputes, and financial unavailable, and the direct consequence was construction delay. Therefore, the linear multiple-regression model was applied to address the relationship between resources unavailable events, default of subcontractor, Force Majeure, industrial disputes, and finance unavailable events for the SD model as illustrated in Figure VII2.

$$RD_k\ (ru) = \beta_{0k} + \beta_{1k}*RD_k(ds) + \beta_{2k}*RD_k(fm) + \beta_{3k}*RD_k(id) + \beta_{4k}*RD_k(fu) + \varepsilon_k,\ k = c, o$$

Where

RD_k: *random variable for the expected risk effect;*
k: time period, c (construction stage); o (operation stage);
ru: risk event for 'resource unavailable';
ds: risk event for 'default of subcontractors';
fm: risk event for 'Force Majeure';
id: risk event for 'industrial disputes';
fu: risk event for 'financial unavailable';
β_{0k}: *the constant term for the multiple regression model;*
$\beta_{1k}, \beta_{2k}, \beta_{3k}, \beta_{4k}$: *the relational coefficients for the independent risk variables;*
ε_k: *the random error for the multiple regression model;*



<u>Figure VII2 The SD Model for 'Resources Unavailable' Risk Effect</u>

VII3. RCN for 'Performance Unavailable' on THSR

Based on the scenario statements described in Section VI3 and the Figure VI3, the direct cause for performance unavailable event were low operating productivity, and the direct consequences were revenue losses, contract remedies/penalties, and contract breaks. Therefore, the linear multiple-regression model was applied to address the relationship between performance unavailable and low operating productivity for the SD model illustrated in Figure VII3:

$$RD_k\ (pu) = \beta_{0k} + \beta_{1k} * RD_k(lop) + \varepsilon_k,\ k = o$$

Where

RD_k: random variable for the expected risk effect;
k: time period, c (construction stage); o (operation stage);
pu: risk event for 'performance unavailable';
lop: risk event for 'low operating productivity';
β_{0k}: the constant term for the multiple regression model;
β_{1k}: the relational coefficients for the independent risk variables;
ε_k: the random error for the multiple regression model;

As for the direct consequence of contract remedies/penalties, according to the interview statements described in Section V13, the researcher assumed that *the number of trains* that would likely delay on-time service was in linear proportion to the expected risk effect caused by risk event performance unavailable between the maximum consequence (the maximum number of delayed trains) and minimum consequence (the minimum number of delayed trains). Therefore, by using interpolation, the likely number of delayed trains was:

$$DeT = Int[(RD(pu) - RD_{min})/(RD_{max} - RD_{min}) * (DeT_{max} - DeT_{min}) + DeT_{min}]$$

Where

DeT: the number of trains that would likely delay on-time service;
Int[x]: integer function;
RD: random variable for the expected risk effect;
pu: risk event 'performance unavailable';
RD_{max}: 25;
RD_{min}: 1;
DeT_{max}: 45 trains;
DeT_{min}: 0 train;

Thus, the penalty (refund) for on-time delay that is the average of delay for more than 30 minutes and one hour was:

$$Afr = (1+0.5)/2 * AAF$$
$$ODR = DeT * Afr * Apt * AM$$

where

Afr: the average fare refund;
ODR: on-time delay refund;
DeT: the number of trains that would likely delay on-time service;
AAF: the annual average fare, as shown in Section 6.1.3;
Apt: the average person per train = 350 person/train;
AM: average mileage = 160 km;

According to the interview statement in Section VI3, another consequence for capacity loss arising from less capacity than break-even daily capacity was:

$$CLE = Int(DeT*0.2)$$
$$CL = CLE*12/(BEDC*2*365)*TOC$$

Where

CLE: capacity loss effect;
Int[x]: Integer function;
DeT: the number of trains that would likely delay on-time service;
CL: capacity loss;
BEDC: break-even daily capacity for a single way =60;
TOC: annual total operating cost

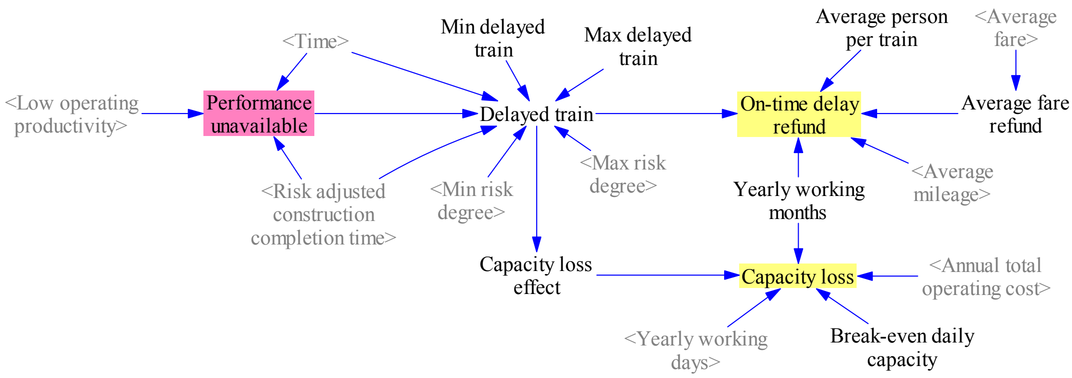


Figure VII3 The SD Model for 'Performance Unavailable' Risk Effect

VII4. RCN for 'Scope Changes' on THSR

Based on the scenario statements described in Section VI4 and the Figure VI4, the direct cause for 'scope changes' is 'law/policy changes', and the direct consequence is 'design changes.' Therefore, the linear multiple-regression model used to address the direct cause relationship between 'scope changes' and 'law/policy changes' in the SD risk model illustrated in Figure VII4 was:

$$RD_k\ (sc) = \beta_{0k} + \beta_{1k}*RD_k(lpc)+\varepsilon_k,\ k = c,\ o$$

Where

RD_k: random variable for the expected risk effect;
k: time period, c (construction stage); o (operation stage);
sc: risk event 'scope changes';
lpc: risk event 'law/policy changes';
β_{0k}: the constant term for the multiple regression model;
β_{1k}: the relational coefficients for the independent risk variables;
ε_k: the random error for the multiple regression model;

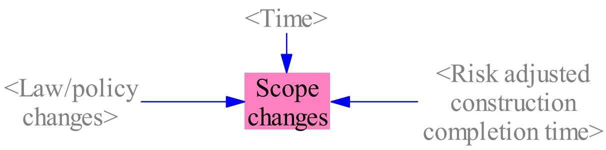


Figure VII4 The SD Model for 'Scope Changes' Risk Effect

VII5. RCN for 'Defective Design' on THSR

Based on the scenario statements described in Section VI5 and the Figure VI5, the direct causes for 'defective design' are 'default of subcontractors' and 'resource unavailable', and the direct consequences are 'defective construction' and 'complex system interface/integration.' Therefore, the linear multiple-regression model used to address the direct cause relationship between 'land unavailable', 'approval delays' and 'industrial disputes' in the SD model illustrated in Figure VII5 was:

$$RD_k\ (dd) = \beta_{0k} + \beta_{1k} * RD_k(ds) + \beta_{2k} * RD_k(ru) + \varepsilon_k,\ k = c, o$$

where

RD_k: *random variable for the expected risk effect;*
k: time period, c (construction stage); o (operation stage);
dd: risk event 'defective design';
ds: risk event 'default of subcontractors';
ru: risk event 'resources unavailable';
β_{0k}: *the constant term for the multiple regression model;*
$\beta_{1k,}\ \beta_{2k}$: *the relational coefficients for the independent risk variables;*
ε_k: *the random error for the multiple regression model;*

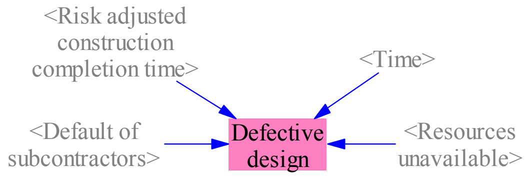


Figure VII5 The SD Model for 'Defective Design' Risk Effect

VII6. RCN for 'Design Changes' on THSR

Based on the scenario statements described in Section VI6 and the Figure V6, the direct causes for 'design changes' are 'scope changes' and 'contractual disputes', and the direct consequence is 'construction changes.' Therefore, the linear multiple-regression model used to address the direct cause relationship between 'design changes', 'scope changes' and 'contractual disputes' in the SD model illustrated in Figure VII6 was:

$$RD_k\ (dch) = \beta_{0k} + \beta_{1k} * RD_k(sc) + \beta_{2k} * RD_k(cd) + \varepsilon_k,\ k = c, o$$

where

RD_k: *random variable for the expected risk effect;*
k: time period, c (construction stage); o (operation stage);
dch: risk event 'design changes';
sc: risk event 'scope changes';
cd: risk event 'contractual disputes';
β_{0k}: *the constant term for the multiple regression model;*
$\beta_{1k,}\ \beta_{2k}$: *the relational coefficients for the independent risk variables;*
ε_k: *the random error for the multiple regression model;*

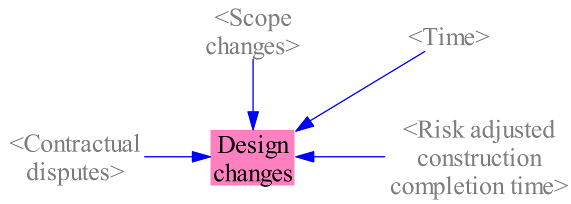


Figure VII6 The SD Model for 'Design Changes' Risk Effect

VII7. RCN for 'Construction Cost Overrun' on THSR

Based on the scenario statements described in Section VI7 and the Figure VI7, the direct causes for construction cost overrun were construction delay, variability of interest rate, price escalation and insurance increases, and the direct consequence was finance unavailable. Therefore, the risk variable construction cost overrun for the SD model in Figure VII7 was:

$$E = C_{radj}+C_{ins}+C_{int}$$

$$CE = \int_{RCST}^{RCCT} E$$

$$CPC = \int_{RCST}^{RCCT} AC$$

$$CCO = CE\text{-}CPC$$

where

E: annual expense;
C_{radj}*: risk adjusted annual construction cost;*
C_{ins}*: annual insurance cost;*
C_{int}*: annual interest;*
CE: cumulative expensive;
CPC: cumulative project capital;
AC: annual raising capital
RCCT: risk adjusted construction completion time;
RCST: risk adjusted construction start time;
CCO: construction cost overrun

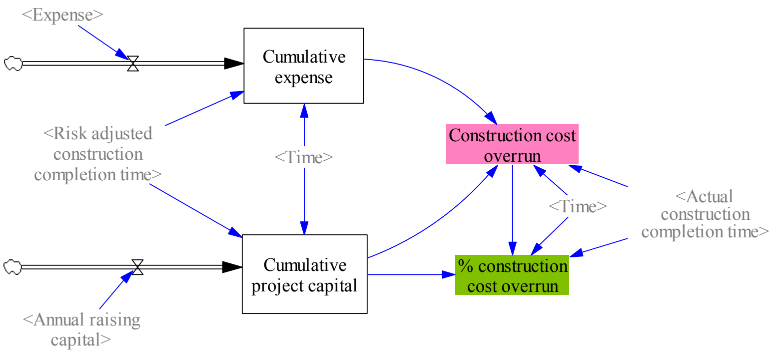


Figure VII7 The SD Model for 'Construction Cost Overrun' Risk Effect

VII8. RCN for 'Construction Delay' on THSR

Based on statements made in Section VI8 and the FigureVI8, the direct causes for construction delay were land unavailable and resources unavailable, construction changes, delay in contracts, change negotiation, ownership changes, delays, and unforeseen site conditions. The direct consequences were construction delay and performance unavailable. As shown in Figure VII8, the variable time delay effect on construction delay was assumed to be in linear proportion to the expected effect between the maximum time consequence (maximum time delay in each work package) and minimum consequence (maximum time delay in each work package). Therefore, the variable time delay effect in every work package was modeled below:

$$TD_{ij} = (RD_i\text{-}RD_{min})/(RD_{max}\text{-}RD_{min})*(TCMAX_{ij}\text{-}TCMIN_{ij})+TCMIN_{ij}$$

where

TD_{ij}*: time delay effect for the risk event on a work package (in percentage);*
RD_i*: random variable for the expected risk effect;*
$TCMAX_{ij}$*: maximum time delay effect for a risk event on a work package (in percentage);*
$TCMIN_{ij}$*: minimum time delay effect for a risk event on a work package (in percentage);*
RD_{max}*: 25;*
RD_{min}*: 1;*
i: risk event index;
j: work package index

The variable increased completion time for work package was:

$$\Delta TD_{ik} = \sum TD_{ik}\cdot(SCT_k\text{- } SST_k)+ \sum TD_{im}\cdot(SCT_m\text{- } SST_m)$$

$$\Delta TD_{im} = \sum TD_{im}\cdot(SCT_m\text{- } SST_m)$$

where

ΔTD_{ik}*: increased completion time for a work package caused by a risk event;*
TD_{ik}*: time delay effect for a risk event in a work package (in percentage);*
SCT_k*: scheduled completion time for a work package;*

SST_k: scheduled start time for a work package;
i: risk event index;
m: work package index for 'land acquisition';
k: work package index $j\neq m$ (because when execution of workpackage k depends on execution of 'land acquisition' workpackage m)

Thus, the risk-adjusted construction completion time for a work package was:

$$RCCT_j = SCT_j + \Delta TD_{ij}$$

Where

$RCCT_j$: the risk-adjusted construction completion time for a work package;
SCT_j: scheduled completion time for a work package;
i: risk event index;
j: work package index

As the result, the risk variable 'construction delay' was:

$$CD = Max(RCCT_j) - Max(SCT_j)$$

where

CD: construction time delay;
$Max(x_j)$: the maximum value of the elements of an array xj;
$RCCT_j$: the risk-adjusted construction completion time for a work package;
SCT_j: scheduled completion time for a work package;
i: risk event index;
j: work package index

As shown in Figure VII8, the variable 'construction delay cost' was:

$$CDC = CD * ACDC$$

where

CD: construction time delay;
ACDC: average administration cost due to construction time delay

The 'construction delay cost' is then added into the variable 'risk-adjusted annual total construction cost' illustrated in Figure VII8 which is linked with the Project Cash Flow model.

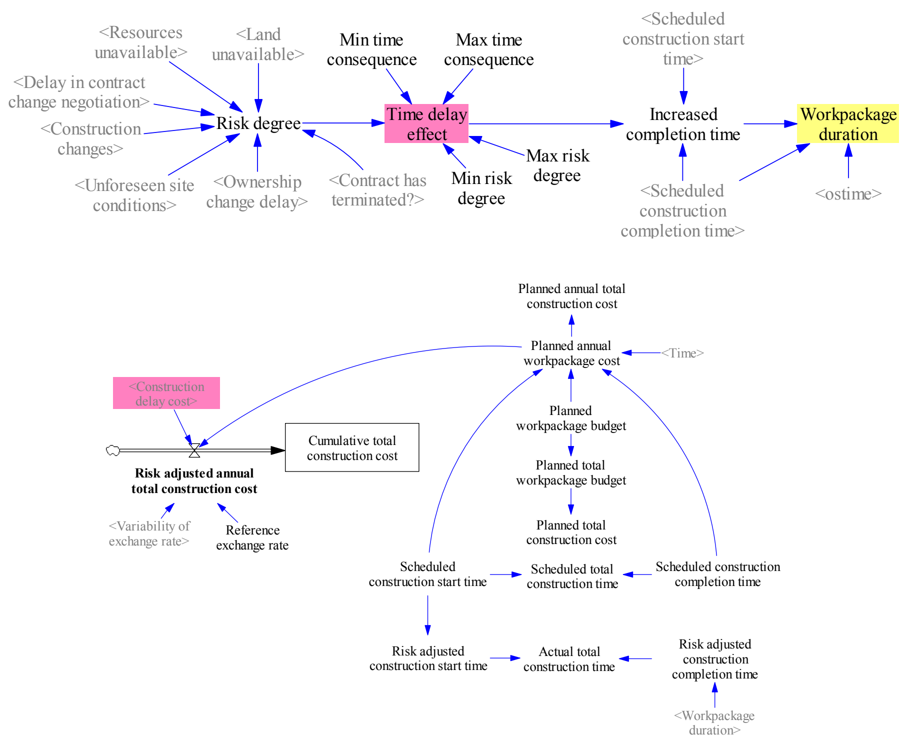


Figure VII8 The SD Model for 'Construction Delay'and Construction Delay Cost

VII9. RCN for 'Defective Construction' on THSR

Based on the scenario statements described in Section VI9 and the Figure VI9, the direct causes for 'defective construction' are 'defective design' 'default of subcontractors' 'resources unavailable' and 'poor cooperation/coordination', and the direct consequences are 'failed commission tests' 'system breakdown' 'high maintenance frequency' 'accidents and safety issues' and 'shorter asset life' Therefore, the linear multiple-regression model used to address the direct cause relationship function in the SD model illustrated in Figure VII9 was:

$$RD_k\,(dc) = \beta_{0k} + \beta_{1k} * RD_k(dd) + \beta_{2k} * RD_k(ds) + \beta_{3k} * RD_k(ru) + \beta_{4k} * RD_k(pcc) + \varepsilon_k, k = c,\ o$$

Where

RD_k: random variable for the expected risk effect;
k: time period, c (construction stage); o (operation stage);
dc: risk event 'defective construction';
dd: risk event 'defective design';
ds: risk event 'default of subcontractors';
ru: risk event 'resources unavailable';
pcc: risk event 'poor cooperation/coordination'
β_{0k}: the constant term for the multiple regression model;
$\beta_{1k,} \beta_{2k,} \beta_{3k,} \beta_{4k}$: the relational coefficients for the independent risk variables;
ε_k: the random error for the multiple regression model;

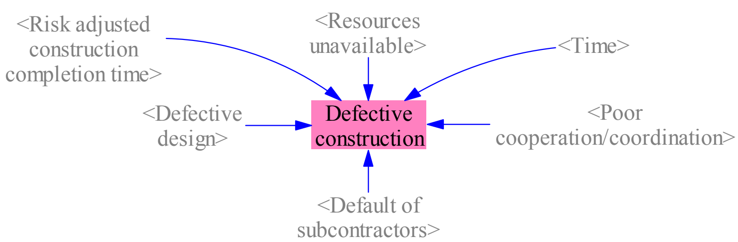


Figure VII9 The SD Model for 'Defective Construction' Risk Effect

VII10. RCN for 'Construction Changes' on THSR

Based on the scenario statements described in Section VI10 and the Figure VI10, the direct cause for 'construction changes' is 'design changes', and the direct consequences are 'construction delay' and 'low operating productivity.' Therefore, the linear multiple-regression model used to address the direct cause relationship function in the SD model illustrated in Figure VII10 was:

$$RD_k\,(cc) = \beta_{0k} + \beta_{1k} * RD_k(dch) + \varepsilon_k,\ k = c,\ o$$

Where

RD_k: random variable for the expected risk effect;
k: time period, c (construction stage); o (operation stage);
cc: risk event 'construction changes';
dch: risk event 'design changes';
β_{0k}: the constant term for the multiple regression model;
β_{1k}: the relational coefficients for the independent risk variables;
ε_k: the random error for the multiple regression model;

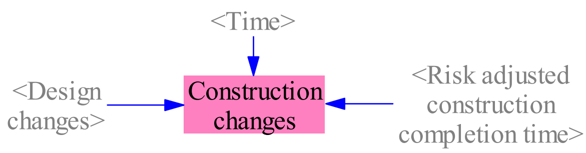


Figure VII10 The SD Model for 'Construction Changes' Risk Effect

VII11. RCN for 'Complex System Interface/Integration' on THSR

Based on the scenario statements described in Section VI11 and the Figure VI11, the direct causes for 'complex system interface/integration' are 'complex technologies' and 'defective design', and the direct consequences are 'poor cooperation/coordination' 'system breakdown' 'high maintenance frequency' and 'accidents and safety issues.' Therefore, the linear multiple-regression model used to address the direct cause rrelationship in the SD model illustrated in Figure VII11 was:

$$RD_k\ (csi) = \beta_{0k} + \beta_{1k}*RD_k(ct) + \beta_{2k}*RD_k(dd) + \varepsilon_k,\ k = c,\ o$$

Where

RD_k: *random variable for the expected risk effect;*
k: time period, c (construction stage); o (operation stage);
csi: risk event 'complex system interface/integration';
ct: risk event 'complex technology';
dd: risk event 'defective design';
β_{0k}: *the constant term for the multiple regression model;*
β_{1k}, β_{2k}: *the relational coefficients for the independent risk variables;*
ε_k: *the random error for the multiple regression model;*

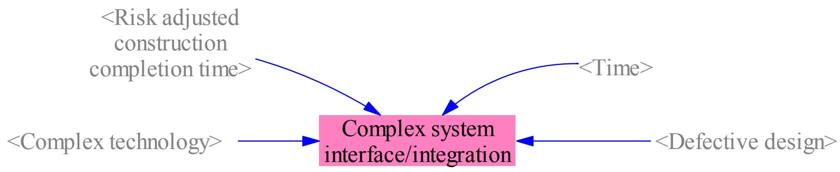


Figure VII11 The SD Model for 'Complex System Interface/Integration' Risk Effect

VII12. RCN for 'Failed Commissioning Tests' on THSR

Based on the scenario statements described in Section VI12 and the Figure VI12, the direct cause for 'failed commissioning test' is 'defective construction', and the direct consequence is 'contract breach'. Therefore, the linear multiple-regression model used to address the direct cause relationships in the SD model illustrated in Figure VII12 was:

$$RD_k\ (fct) = \beta_{0k} + \beta_{1k}*RD_k(dc) + \varepsilon_k,\ k = c$$

Where

RD_k: *random variable for the expected risk effect;*
k: time period, c (construction stage); o (operation stage);
fct: risk event 'failed commissioning test';
dc: risk event 'defective construction';
β_{0k}: *the constant term for the multiple regression model;*
β_{1k}: *the relational coefficients for the independent risk variables;*
ε_k: *the random error for the multiple regression model;*

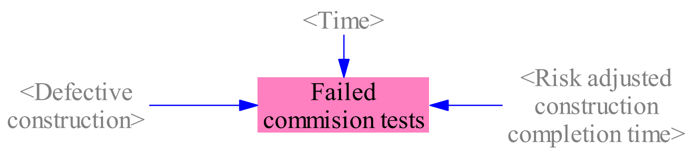


Figure VII12 The SD Model for 'Failed Commissioning Tests' Risk Effect

VII13. RCN for 'Low Operating Productivity' on THSR

Based on the scenario statements described in Section VI13 and the Figure VI13, the direct causes for 'low operating productivity' are 'resources unavailable' 'default of subcontractors' 'construction changes' 'system breakdown' 'high maintenance frequency' 'accidents and safety issues' and 'poor cooperation/coordination', and the direct consequence is 'performance unavailable.' Therefore, the linear multiple-regression model used to address the direct cause relationships in the SD model illustrated in Figure VII13 was:

$$RD_k\ (lop) = \beta_{0k}\beta_{1k}*RD_k(ru)+\beta_{2k}*RD_k(cc)+\beta_{3k}*RD_k(hmf)+\beta_{4k}*RD_k(sb)+\beta_{5k}*RD_k(asi)+\ \beta_{6k}*RD_k(pcc)+\varepsilon_k,\ k = o$$

Where

- RD_k: *random variable for the expected risk effect;*
- *k: time period, c (construction stage); o (operation stage);*
- *lop: risk event 'low operating productivity';*
- *ru: risk event 'resources unavailable';*
- *cc: risk event 'construction changes';*
- *hmf: risk event 'high maintenance frequency';*
- *sb: risk event 'system breakdown';*
- *asi: risk event 'accidents and safety issues';*
- *pcc: risk event 'poor cooperation/coordination';*
- β_{0k}: *the constant term for the multiple regression model;*
- $\beta_{1k,}\beta_{2k,}\beta_{3k,}\ \beta_{4k,}\beta_{5k,}\beta_{6k,}$: *the relational coefficients for the independent risk variables;*
- ε_k: *the random error for the multiple regression model;*

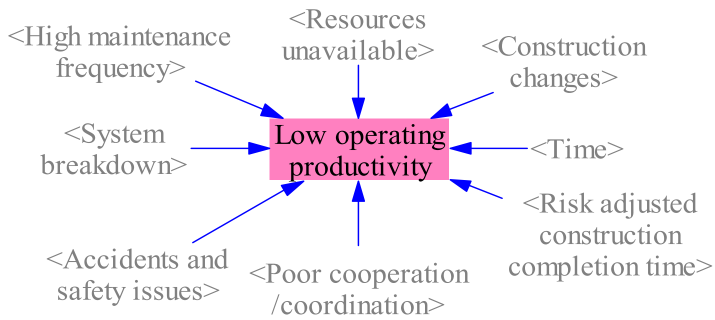


Figure VII13 The SD Model for 'Low Operating Productivity' Risk Effect

VII14. RCN for 'Mis-pricing' on THSR

The direct causes of mis-pricing and the inflexible contract arrangement influence policy on the fare adjustment rate for train ticket which would influence operating revenue are illustrated in the operating revenue sub-model. As shown in Figure VII14, the expected fare adjustment rate is in linear reverse relationship with the expected risk effect caused by the risk event inflexible contract arrangement between the maximum consequence and minimum consequence. Therefore, by using interpolation, the expected fare adjustment rate was:

$$EFA = (RD(ica) - RD_{max})*(FA_{max}\text{-}FA_{min})/(\ RD_{min} - RD_{max})*+FAmin$$

where

- *EFA: the 'expected fare adjustment rate'*
- FA_{max}: *maximum fare adjustment allowance = 0.2;*
- FA_{min} : *minimum fare adjustment allowance = 0;*
- *RD: random variable for the expected effect;*
- *Ica: risk event 'inflexible contract arrangement';*
- RD_{max}: *25;*
- *RDmin: 1*

VII15. RCN for 'Revenue Losses' on THSR

Based on the scenario statements described in Section VI15 and the Figure VI15, the direct causes for 'revenue losses' are 'performance unavailable' 'contract remedies/penalties' 'mis-pricing' 'variability of interest rate' 'price escalation' 'tax increases' 'insurance increases' 'less residual value' 'variability of less demand' and 'termination liability.'

All of the additional costs or less revenue arising from the above risk events have been modeled and directly or indirectly linked to NPV Project Cash Flow model, which are described in the related Sections.

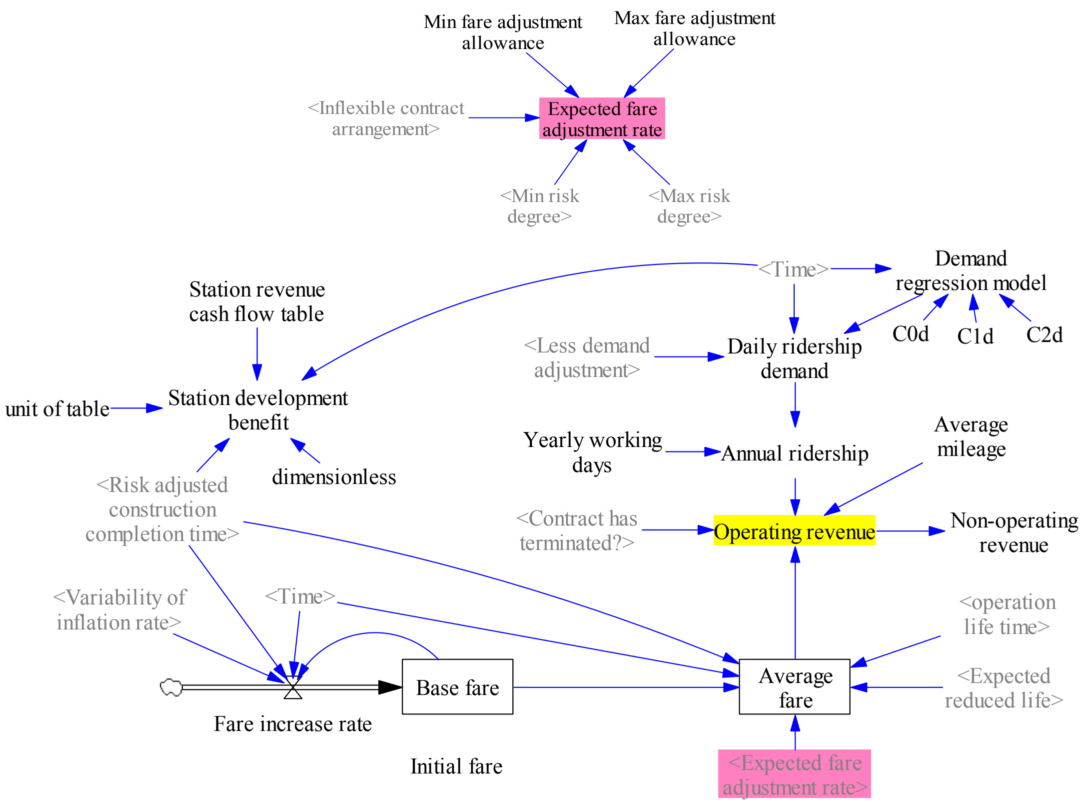


Figure VII14 The SD Model for 'Mis-pricing' Risk Effect

VII16. RCN for 'System Breakdown' on THSR

Based on the scenario statements described in Section VI16 and the Figure VI16, the direct causes for 'system breakdown' are 'defective construction' and 'complex system interface/integration', and the direct consequence is 'low operating productivity.' Therefore, the linear multiple-regression model used to address the direct cause relationship in the SD model illustrated in Figure VII16 was:

$$RD_k\,(sb) = \beta_{0k} + \beta_{1k}*RD_k(dc) + \beta_{2k}*RD_k(csi) + \varepsilon_k,\ k = o$$

where

RD_k: *random variable for the expected risk effect;*
k: time period, c (construction stage); o (operation stage);
sb: risk event 'system breakdown';
dc: risk event 'defective construction';
csi: risk event 'complex system interface/integration';
β_{0k}: *the constant term for the multiple regression model;*
β_{1k}, β_{2k}: *the relational coefficients for the independent risk variables;*
ε_k: *the random error for the multiple regression model;*

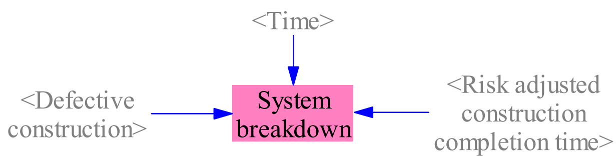


Figure VII16 The SD Model for 'System Breakdown' Risk Effect

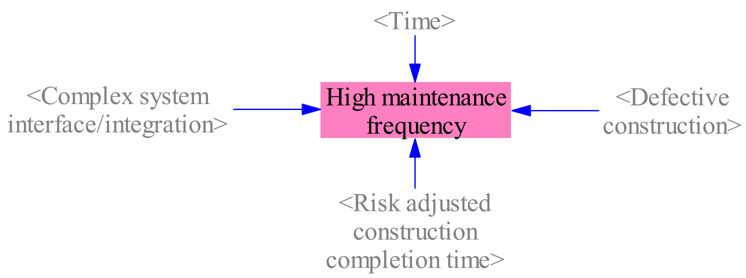
VII17. RCN for 'High Maintenance Frequency' on THSR

Based on the scenario statements described in Section VI17 and the Figure VI17, the direct causes for 'high maintenance frequency' are 'defective construction' and 'complex system interface/integration', and the direct consequence is 'low operating productivity.' Therefore, the linear multiple-regression model used to address the direct cause relationship in the SD model illustrated in Figure VII17 was:

$$RD_k\ (hmf) = \beta_{0k} + \beta_{1k} * RD_k(dc) + \beta_{2k} * RD_k(csi) + \varepsilon_k,\ k = o$$

where

RD_k: random variable for the expected risk effect;
k: time period, c (construction stage); o (operation stage);
hmf: risk event 'high maintenance frequency';
dc: risk event 'defective construction';
csi: risk event 'complex system interface/integration';
β_{0k}: the constant term for the multiple regression model;
$\beta_{1k,} \beta_{2k}$: the relational coefficients for the independent risk variables;
ε_k: the random error for the multiple regression model;



<u>Figure VII17 The SD Model for 'High Maintenance Frequency' Risk Effect</u>

VII18. RCN for 'Accidents and Safety Issues' on THSR

Based statements in Section VI18 and the Figure VI18, the direct causes of accidents and safety issues were resources unavailable, defective construction and complex system interface/integration, and Force Majeure, The direct consequences were low operating productivity, and contract remedies/penalties (the expected accident and safety loss). Therefore, the linear multiple-regression model was applied to address the direct cause relationships for the SD model as illustrated in Figure VII18:

$$RD_k\ (asi) = \beta_{0k} + \beta_{1k} * RD_k(ru) + \beta_{2k} * RD_k(dc) + \beta_{3k} * RD_k(csi) + \beta_{4k} * RD_c(fm) + \varepsilon_k,\ k = o$$

where

RD_k: random variable for the expected risk effect;
k: time period, c (construction stage); o (operation stage);
asi: risk event 'accidents and safety issues';
ru: risk event 'resources unavailable';
dc: risk event 'defective construction';
csi: risk event 'complex system interface/integration';
fm: risk event 'Force Majeure'
β_{0k}: the constant term for the multiple regression model;
$\beta_{1k,} \beta_{2k,} \beta_{3k,} \beta_{4k}$: the relational coefficients for theindependent risk variables;
ε_k: the random error for the multiple regression model;

As for the direct consequence of contract remedies/penalties, according to the interview statements, the maximum accident and safety loss for death penalty and system damage due to human factor and national disaster is NT$0.174 billion. The researcher assumes the expected accident and safety loss is in linear proportion to the expected risk effect caused by 'accidents and safety issues' risk event between the maximum consequence (maximum accident and safety loss) and minimum consequence (minimum accident and safety loss). Therefore, by using interpolation, the expected accident and safety loss at operation stage was:

$$EASL = [RD(asi) - RD_{min}]/(RD_{max} - RD_{min}) * (ASD_{max} - ASD_{min}) + ASD_{min}$$
$$ASD_{max} = Apt * Acdh$$

Where

EASL: expected accident and safety loss;
RD: random variable for the expected risk effect;

asi: risk event 'accidents and safety issues';
RD_{max}: 25;
RD_{min}: 1;
ASD_{max}: maximum accident damage, NT$1.3 millions;
ASD_{min}: minimum accident damage, NT$ 0.00 billions;
Apt: average person per train;
Acdh: average accident damage per head

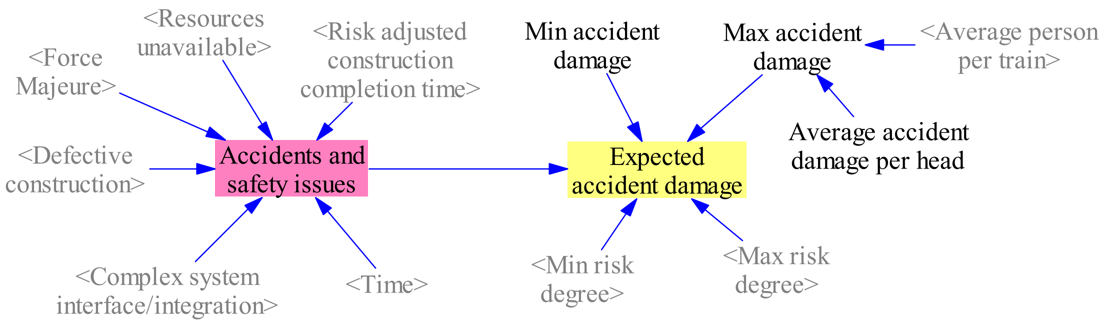


Figure VII18 The SD Model for 'Accident and Safety Issues' Risk Effect

VII19. RCN for 'Price Escalation' on THSR

From the scenario statements described in Section VI19, Section VI39, Figure VI19, and Figure VII39, the variability of inflation rate would influence money for time, which is linked with the discount rate sub-model shown in Figure 6.1.6 to replace the inflation rate. Then, the new value for inflation adjusted discount rate would be linked with project cash flow model shown in Figure 6.1 to change NPV value. The new value for inflation adjusted discount rate illustrated in Figure VII19 (a) was:

$$r'_{wacc} = r_{wacc} + r_{inf} + r_{wacc}\, r_{inf}$$

Where

r'_{wacc}: inflation adjusted discount rate;
r_{wacc}: Weight Average Cost of Capital;
r_{inf}: variability of inflation rate

In addition, the 'variability of inflation rate' would be linked with Operation Revenue sub-model to replace the 'inflation rate' to change 'fare increase rate' below:

$$AFIR' = F_b\, r_{inf}$$

where

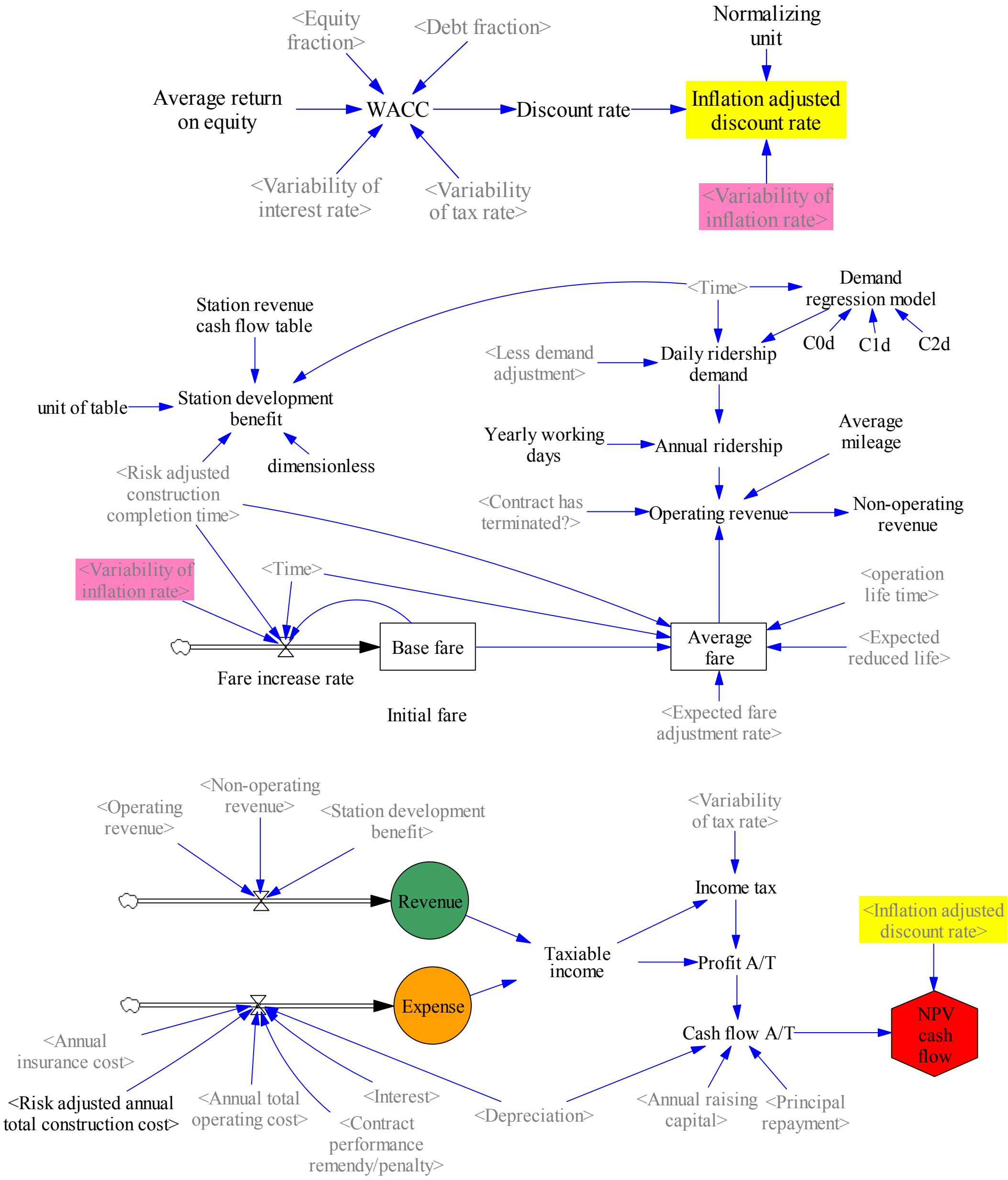
AFIR' = risk adjusted annual fare increase rate;
F_b: base fare;
r_{inf}: variability of inflation rate

Furthermore, based on the scenario statements described in Section VI19, Section VII40, Figure VI19, and Figure VII40, the variability of exchange rate would influence construction cost and operation cost which is linked with the construction cost sub-model shown in Figure 6.1.1 and operation cost sub-model shown in Figure 6.1.1. The new values for construction cost and operation cost illustrated in Figure VII19 (b) were:

$$CC_{adj} = (PATCC+CDC) * r'_{ex} / r_{rex}$$

Where

CC_{adj}: risk adjusted construction cost;
PATCC: planned annual total construction cost;
CDC: construction delay cost
r'_{ex}: risk adjusted exchange rate = $MAX(r_{rex}, r_{ex})$
r_{rex}: reference exchange rate = 33;
MAX(A,B): maximum function of two alternatives A, B;
r_{ex} = 'variability of exchange rat' addressed in Appendix VII40



<u>Figure VII19 (a) Risk Variables 'Variability of Inflation Rate' and 'Inflation Adjusted Discount Rate' Are Linked with Discount Rate Sub-model, Operation Revenue Sub-model and Project Cash Flow Model Respectively</u>

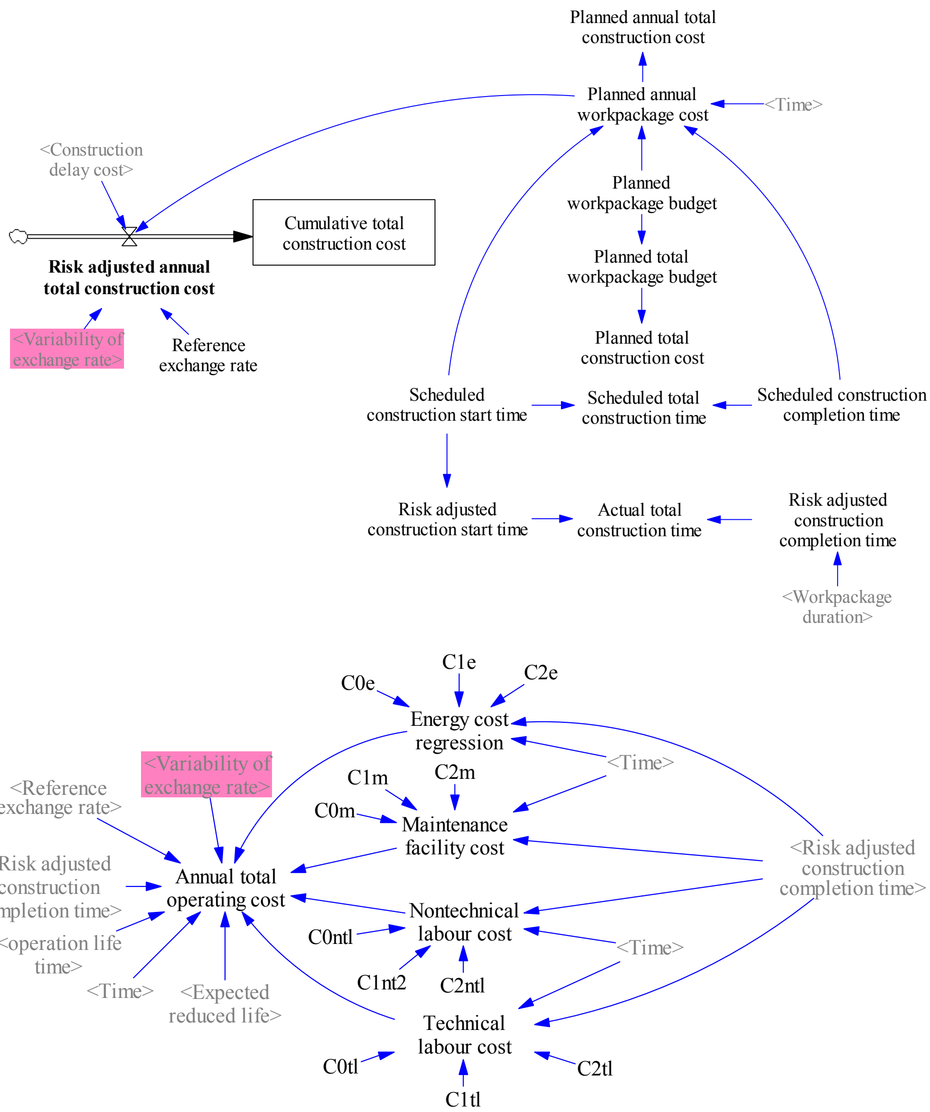


Figure VII19 (b) Risk Variable 'Risk Adjusted Exchange Rate' and 'Reference Exchange Rate' Are Linked with Construction Cost Submodel and Operation Cost Submodel Respectively

VII20. RCN for 'Complex Technologies' on THSR

Based on the scenario statements described in the Section VI20 and Figure VI20, the direct cause for 'complex technologies' is 'political interference' and the direct consequence is 'complex system interface/integration'. Therefore, the linear multiple-regression model used to address the direct cause relationship in the SD model illustrated in Figure VII20 was:

$$RD_k\ (ct) = \beta_{0k} + \beta_{1k} * RD_k(pi) + \varepsilon_k,\ k = c,\ o$$

Where

RD_k: random variable for the expected risk effect;
k: time period, c (construction stage); o (operation stage);
ct: risk event 'complex technologies';
pi: risk event 'political interference';
β_{0k}: the constant term for the multiple regression model;
β_{1k}: the relational coefficients for the independent risk variables;
ε_k: the random error for the multiple regression model;

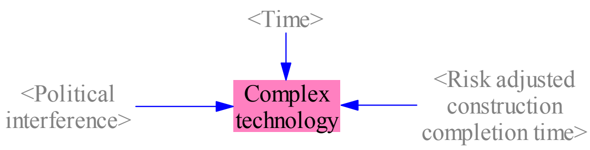


Figure VII20 The SD Model for 'Complex Technologies' Risk Effect

VII21. RCN for 'Poor Cooperation/Coordination' on THSR

Based on the scenario statements described in the Section VI21 and Figure VI21, the direct cause for 'poor cooperation/coordination' is 'complex system interface/integration' and the direct consequences are 'defective construction' and 'low operating productivity'. Therefore, the linear multiple-regression model used to address the direct cause relationship in the SD model illustrated in Figure VII21 was:

$$RD_k\ (pcc) = \beta_{0k} + \beta_{1k} * RD_k(csi) + \varepsilon_k,\ k = c,\ o$$

Where

RD_k: random variable for the expected risk effect;
k: time period, c (construction stage); o (operation stage);
pcc: risk event 'poor cooperation/coordination';
csi: risk event 'complex system interface/integration';
β_{0k}: the constant term for the multiple regression model;
β_{1k}: the relational coefficients for the independent risk variables;
ε_k: the random error for the multiple regression model;

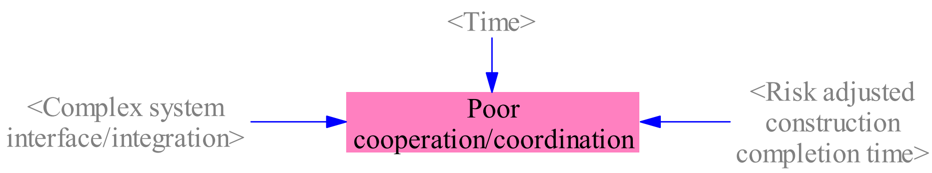


Figure VII21 The SD Model for 'Poor Cooperation/Coordination' Risk Effect

VII22. RCN for 'Finance Unavailable' on THSR

Per statements in Section VI22 and the Figure VI22, the direct causes for finance unavailable were unsuitable regulatory policy, construction cost overruns, and revenue losses. The direct consequences were resources unavailable and insolvency of contractor.

As in Section VI22, the finance unavailable was expressed by two independent variables: percentage of construction cost overrun during construction stage, and debt service coverage (Dsc) during operation stage, which was:

$$RD_k(fu) = \overline{\pi} + \varepsilon_k,\ k=c;$$
$$= \overline{D}_{sc} + \varepsilon_k,\ k=o;$$

Where

RD_k: random variable for the expected risk effect;
fu: risk event 'finance unavailable';
k: time period, c (construction stage); o (operation stage);
$\overline{\pi}$: average percentage of construction cost overrun;
$\overline{D}_{sc}$:average Debt Service Coverage

The percentage of construction cost overrun and the exponential smooth for average percentage of construction cost overrun were:

$$\pi = (EXP-APC)/APC*100\%$$

$$\overline{\pi} = \int_{tsc}^{t} \frac{\pi - \overline{\pi}}{t - t_{cs}}$$

where

EXP: annual total expense;
APC: annual project raising capital;

t: time at construction stage
t_{cs}: construction start time

According to the interview statement, the $RD_k(fu)$ during construction stage was assumed to be a linear reverse relationship with $\overline{\pi}$ when -100% < $\overline{\pi}$ < 0% :

$$RD_k(fu) = 1+\varepsilon_k,\ \overline{\pi} \leq -100\%;$$
$$= (\overline{\pi}+1)(RD_{max} - RD_{min}) + 1+\varepsilon_k,\ -100\% < \overline{\pi} < 0\%;$$
$$= 25+\varepsilon_k,\ \overline{\pi} \geq 0\%$$

Where

RD_{max}: 25;
RD_{min}: 1;
k: time period c (construction stage)

The 'Debt Service Coverage*(Chang & Chen, 2001)*' and the exponential smooth for 'average Debt Service Coverage' were:

$$D_{sc} = Eb/(I+(Pr/(1-Tm))$$
$$\overline{D}_{sc} = \int_{tos}^{t} \frac{D_{sc} - \overline{D}_{sc}}{t - t_{os}}$$

where

E_b: Earnings before Interest, Tax and Depreciation
I: Interest
Pr: Principal Repayment
Tm: Tax Rate

According to the interview statement, the $RD_k(fu)$ during operation stage was assumed to be a linear relationship with $\overline{D}_{sc}$ when 0 < $\overline{D}_{sc}$ < D^*_{sc} (desired DSC level) :

$$RD_k(fu) = 1+\varepsilon_k,\ \overline{D}_{sc} \geq D^*_{sc};$$
$$= RD_{max} - \overline{D}_{sc}(RD_{max} - RD_{min}) / D^*_{sc} + \varepsilon_k,\ \overline{D}_{sc} < D^*_{sc}$$

Where

D^*_{sc}: 1.2;
RD_{max}: 25;
RD_{min}: 1;
k: time period o (operation stage)

VII23. RCN for 'Refinancing liabilities' on THSR

As stated in the Section VII23, the 'refinancing liabilities' is a post-contracting issue that we cannot model and assess if it would become 'liability' risk of the public sector when there is no information on real refinancing structure at the pre-contracting stage.

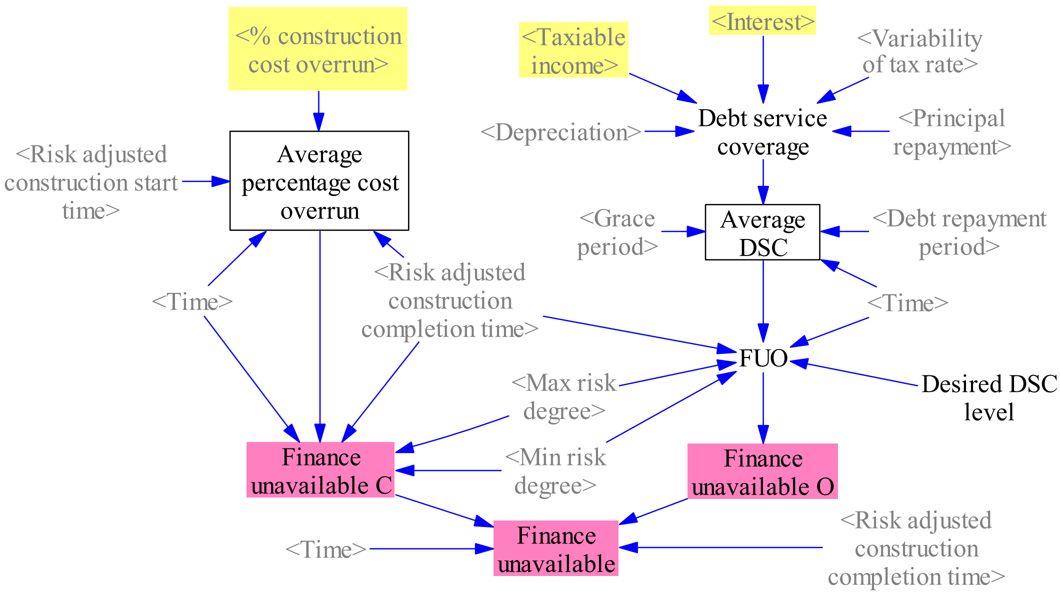


Figure VII22 The SD Model for 'Finance Unavailable' Risk Effect

VII24. RCN for 'Insolvency of Contractor' on THSR

Based on the scenario statements described in Section VI24 and the Figure VI24, the direct cause for 'insolvency of contractor' is 'finance unavailable' and the direct consequence is 'contract breach'. Therefore, the linear multiple-regression model used to address the direct cause relationship in the SD model illustrated in Figure VII24 was:

$$RD_k\ (ioc) = \beta_{0k} + \beta_{1k} * RD_k(fu) + \varepsilon_k,\ k = c,\ o$$

Where

RD_k: random variable for the expected risk effect;
k: time period, c (construction stage); o (operation stage);
ioc: risk event 'insolvency of contractor';
fu: risk event 'finance unavailable';
β_{0k}: the constant term for the multiple regression model;
β_{1k}: the relational coefficients for the independent risk variables;
ε_k: the random error for the multiple regression model;

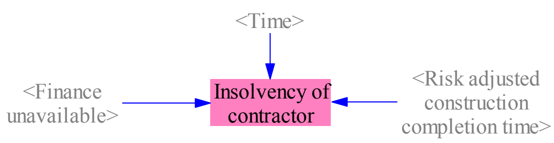


Figure VII24 The SD Model for 'Insolvency of Contractor' Risk Effect

VII25. RCN for 'Ownership Changes Delay' on THSR

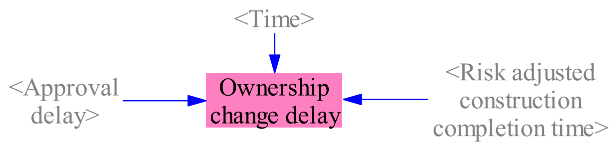
Based on the scenario statements described in Section VI25 and the Figure VI25, the direct cause for 'ownership change delay' is 'approval delay' and the direct consequence is 'construction delay'. Therefore, the linear multiple-regression model used to address the direct cause relationship in the SD model illustrated in Figure 6.2.25 was:

$$RD_k\ (ocd) = \beta_{0k} + \beta_{1k} * RD_k(ad) + \varepsilon_k,\ k = c,\ o$$

Where

RD_k: random variable for the expected risk effect;
k: time period, c (construction stage); o (operation stage);
ocd: risk event 'ownership change delay';
ad: risk event 'approval delay';
β_{0k}: the constant term for the multiple regression model;
β_{1k}: the relational coefficients for the independent risk variables;

ε_k: the random error for the multiple regression model;



<u>Figure VII25 The SD Model for 'Ownership Change Delay' Risk Effect</u>

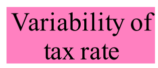
VII26. RCN for 'Variability of Tax Rate'on THSR

Based on the scenario statements described in Section VI26 and the Figure VI26, the 'variability of tax rate' shown in Figure VII26 (a) is an independent risk variable that has no the direct causes. According to the interview statement, the random variable for 'variability of tax rate' was assumed to come from a triangular distribution that had a minimum value of 15%, a maximum value of 25% and the mean value of 18%. It was:

$$t'_m = RANDOM\ TRIANGULAR(a, m, b)$$

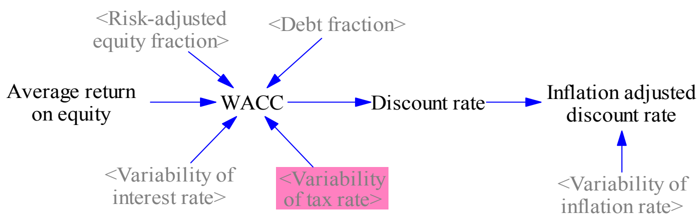
where

t'_m: the random variable for 'variability of tax rate'*;*
a: minimum value= 0.15;
b: maximum value=0.25;
*m: mode=3*mean-a-b=3*0.18-0.15-0.25= 0.14*



<u>Figure VII26 (a) The SD Model for 'Variability of Tax Rate' Risk Effect</u>

From Figure VI26, the consequence of 'tax increases is 'revenue loss.' Thus, the variable 'variability of tax rate' (t'_m) is linked with Discount Rate Sub-model (Figure 6.1.6) and Project Cash Flow model to replace variable 'tax rate' (t_m), as illustrated in Figure VII26(b).



VII27. RCN for 'Insurance Increases' on THSR

According to the interview statements described in Section VI27, the variable 'annual insurance cost' shown in Figure VII27 was below:

$$AIC = CPB/CP$$

where

AIC: annual insurance cost;
CPB: contingency plan budget;
CP: concession period

Then, as illustrated in Figure 6.2.27, the 'annual insurance cost' contributes to project expenses and its cost is adjusted by the 'inflation adjusted discount rate'. It is linked with the NPV Project Cash Flow model (Figure 6.1.7).

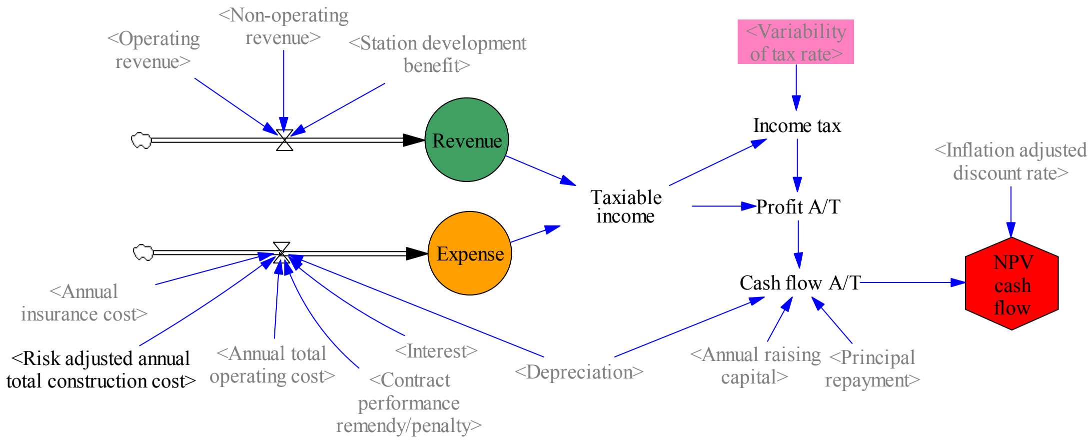


Figure VII26 (b) The 'Variability of Tax Rate' Is Linked with Discount Rate Sub-model and Project Cash Flow Model

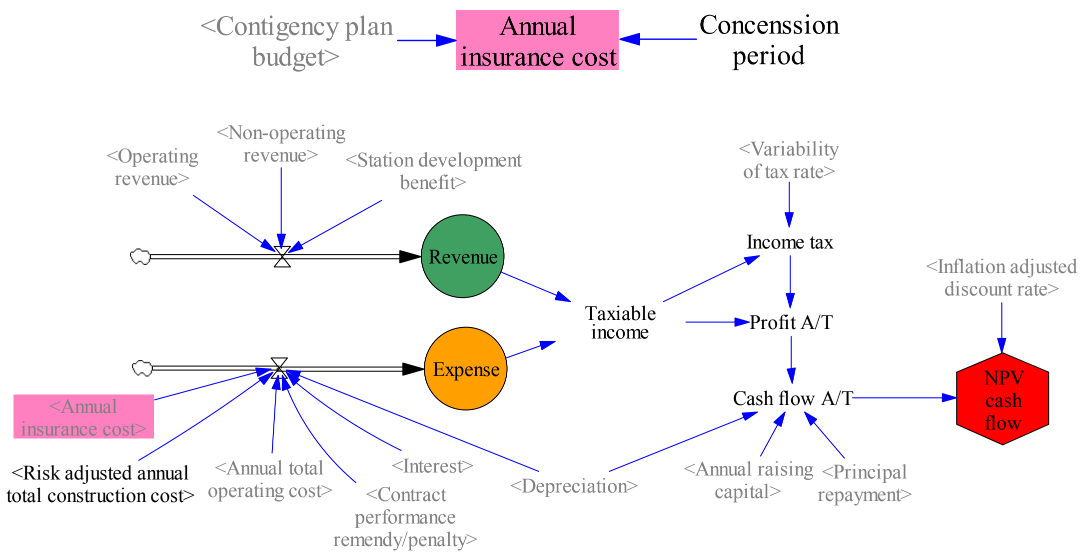


Figure VII27 The SD Model for 'Insurance Increases' Risk Effect

VII28. RCN for 'Contractual Disputes' on THSR

Based on the scenario statements described in Section VI28, Section VI6 and the Figure VI28, the direct causes for 'contract breach' and 'latent defect', and the direct consequence is 'design changes (remedy to solve contractual disputes).' Therefore, the linear multiple-regression model used to address the direct cause relationship in the SD model illustrated in Figure VII28 was:

$$RD_k\,(cd) = \beta_{0k} + \beta_{1k} * RD_k(cb) + \beta_{2k} * RD_k(ld) + \varepsilon_k,\ k = c, o$$

where

RD_k: random variable for the expected risk effect;
k: time period, c (construction stage); o (operation stage);
cd: risk event 'contractual disputes';
cb: risk event 'contractual breach';
ld: risk event 'latent defect'.
β_{0k}: the constant term for the multiple regression model;
β_{1k}, β_{2k}: the relational coefficients for the independent risk variables;

ε_k: *the random error for the multiple regression model;*

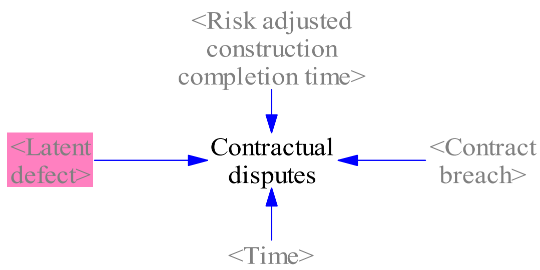


Figure VII28 The SD Model for 'Contractual Disputes' Risk Effect

VII29. RCN for 'Inflexible Contract Arrangements' on THSR

Based on the scenario statements described in Section VI29 and the Figure VI29, the direct cause for 'inflexible contract changes' is 'unsuitable regulatory policy', and the direct consequences are ''delay in contract change negotiation' and 'mis-pricing'. Therefore, the linear multiple-regression model used to address the direct cause relationship in the SD model illustrated in Figure VII29 was:

$$RD_k\ (ica) = \beta_{0k} + \beta_{1k} * RD_k(urp) + \varepsilon_k,\ k = c, o$$

where

RD_k: *random variable for the expected risk effect;*
k: time period, c (construction stage); o (operation stage);
ica: risk event 'inflexible contract changes';
urp: risk event 'unsuitable regulatory policy';
β_{0k}: *the constant term for the multiple regression model;*
β_{1k}: *the relational coefficients for the independent risk variables;*
ε_k: *the random error for the multiple regression model;*

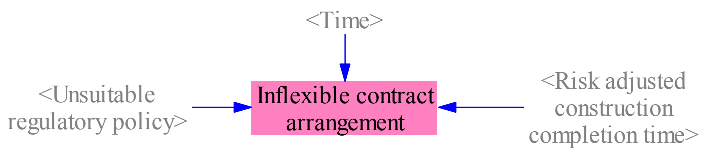


Figure 6.2.29 The SD Model for 'Inflexible Contract Arrangement' Risk Effect

VII30. RCN for 'Delay in Contract Change Negotiation' on THSR

Based on the scenario statements described in Section VI30 and the Figure VI31, the direct causes for 'delay in contract negotiation' are 'inflexible contract arrangement' and 'approval delay', and the direct consequence is 'construction delay'. Therefore, the linear multiple-regression model used to address the direct cause irelationship in the SD model illustrated in Figure VII30 was:

$$RD_k\ (dccn) = \beta_{0k} + \beta_{1k} * RD_k(ica) + \beta_{2k} * RD_k(ad) + \varepsilon_k,\ k = c, o$$

where

RD_k: *random variable for the expected risk effect;;*
k: time period, c (construction stage); o (operation stage);
dccn: risk event 'delay in contract negotiation';
ica: risk event 'inflexible contract arrangement';
ad: risk event 'approval delay';
β_{0k}: *the constant term for the multiple regression model;*
$\beta_{1k,}\beta_{2k}$: *the relational coefficients for the independent risk variables;*
ε_k: *the random error for the multiple regression model;*

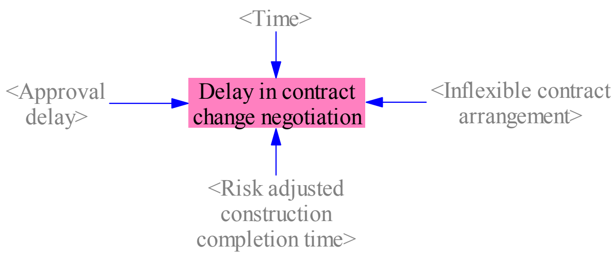


Figure VII30 The SD Model for 'Delay in Contract Change Negotiation' Risk Effect

VII31. 6.2.31 RCN for 'Contract Breach' on THSR

Based on the scenario statements described in Section VI31 and the Figure VI31, the direct causes for 'contract breach' are 'performance unavailable' 'failed commission tests' 'insolvency of contractor' and 'law/policy changes'; the direct consequences are 'contractual disputes' and 'termination liabilities.' Therefore, the linear multiple-regression model used to address the direct cause relationship in the SD model illustrated in Figure VII31 was:

$$RD_k\ (cb) = \beta_{0k} + \beta_{1k} * RD_k(fct) + \beta_{2k} * RD_k(ioc) + \beta_{3k} * RD_k(lpc) + \varepsilon_k,\ k=c;$$
$$RD_k\ (cb) = \beta_{0k} + \beta_{1k} * RD_k(pu) + \beta_{2k} * RD_k(ioc) + \beta_{3k} * RD_k(lpc) + \varepsilon_k,\ k=o$$

Where

RD_k: random variable for the expected risk effect;
k: time period, c (construction stage); o (operation stage);
cb: risk event 'contractual breach';
fct: risk event 'failed commission tests';
ioc: risk event 'insolvency of contractor';
lpc: risk event 'law/policy changes';
pu: risk event 'performance unavailable';
β_{0k}: the constant term for the multiple regression model;
$\beta_{1k}, \beta_{2k}, \beta_{3k}$: the relational coefficients for the independent risk variables;
ε_k: the random error for the multiple regression model;

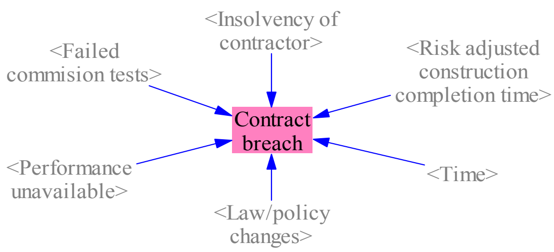


Figure VII31 The SD Model for 'Contract Breach' Risk Effect

VII32. RCN for 'Contract Remedies/Penalties' on THSR

Based on the scenario statements described in Section VI32, and Figure VI32, the 'performance unavailable' and 'accidents and safety issues' would lead to 'contract remedies/penalties' which would lead to 'revenue losses.' As described in Section VII3 and VII18, these remedies and penalties include 'capacity losses', 'on-time delay refund' and 'expected accident damage.' Therefore, the variable 'contract performance remedy/penalty' illustrated in Figure VII32 was:

$$CPP = CL + ODR + EASL$$

where

CPP: contract performance remedy/penalty;
CL: capacity loss;
ODR: on-time delay refund;
EASL: expected accident and safety loss

Then, as illustrated in Figure VII32, the variable 'contract performance remedy/penalty' will be one of the 'revenue loss' that it is linked with the Project Cash Flow model and added into the variable 'expense.'

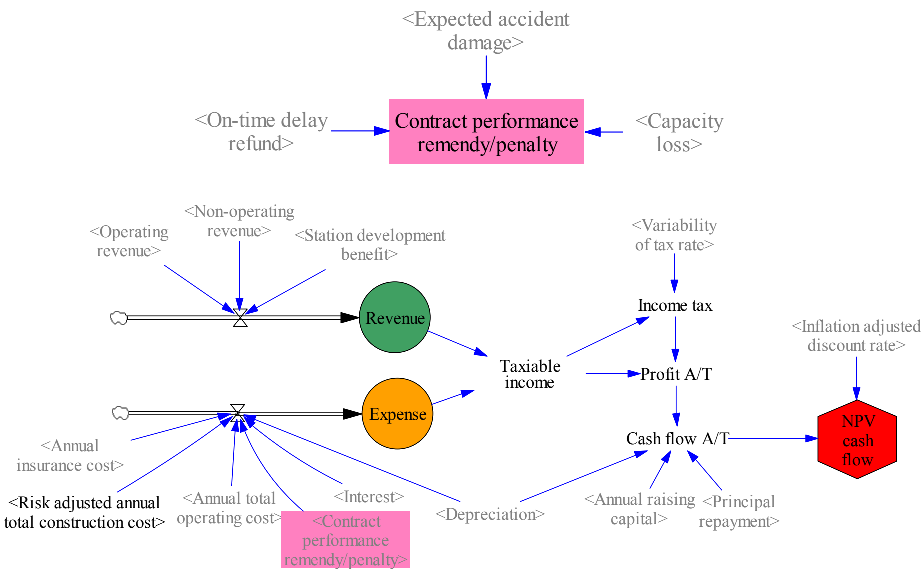


Figure VII32 The SD Model for 'Contract Remedies/Penalties' Risk Effect

VII33. RCN for 'Default of Subcontractors' on THSR

Based on the scenario statements described in Section VI33 and the Figure V33, the 'default of subcontractor' is an independent risk variable that has no the direct causes. It was:

$$RD_k(ds),\ k=c,\ o$$

Where

RD_k: random variable for the expected risk effect;;
k: time period, c (construction stage); o (operation stage);
ds: risk event 'default of subcontractor';

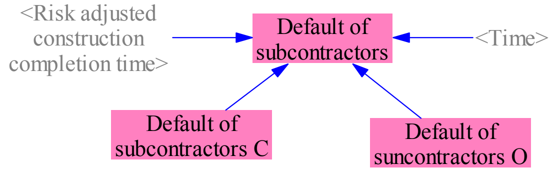


Figure VII33 The SD Model for 'Default of Subcontractor' Risk Effect

VII34. RCN for 'Inspection and Testing Delay' on THSR

As described in Section VI34, the variable 'inspection and testing delay' has been included in 'construction delay.' So, this risk variable is removed from modelling.

VII35. RCN for 'Latent Defect' on THSR

Based on the scenario statements described in Section VI35 and the Figure VII35, the 'latent defect' is an independent risk variable that has no the direct causes. It was:

$$RD_k(ld),\ k=c,\ o$$

where

RD_k: random variable for the expected risk effect;
k: time period, c (construction stage); o (operation stage);
ld: risk event 'latent defect'
t: time;
RACST: risk-adjusted construction start time;
RACCT: risk-adjusted construction completion time

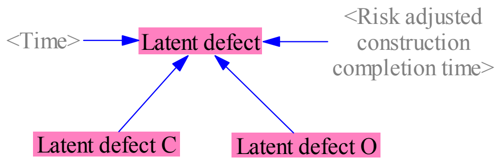


Figure VII35 The SD Model for 'Latent Defect' Risk Effect

VII36. RCN for 'Shorter Asset Life' on THSR

Based on the scenario statements described in Section VI36 and the Figure VI36, the direct causes for 'shorter asset life' are 'defective construction' and 'complex system interface/integration'; the direct consequences are 'less residual value' and 'performance unavailable' Therefore, the linear multiple-regression model used to address the direct cause relationship in the SD model illustrated in Figure VII36(a) was:

$$RD_k\ (sal) = \beta_{0k} + \beta_{1k} * RD_k(dc) + \beta_{2k} * RD_k(cii) + \varepsilon_k,\ k{=}o$$

where

RD_k: random variable for the expected risk effect;
k: time period, c (construction stage); o (operation stage);
sal: risk event 'shorter asset life';
dc: risk event 'defective construction';
cii: risk event 'complex system interface/integration';
β_{0k}: the constant term of for the multiple regression model;
$\beta_{1k,}\ \beta_{2k}$: the relational coefficients for the independent risk variables;
ε_k: the random error for the multiple regression model;

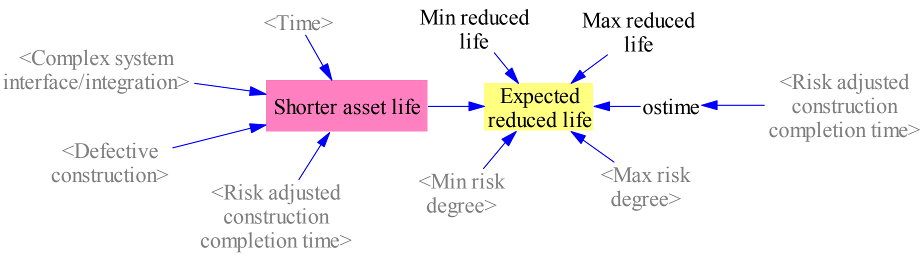


Figure VII36 The SD Model for 'Shorter Asset Life' Risk Effect

Assume the variable 'expected reduced life' is in linear proportion to the expected risk effect produced by 'shorter asset life' between the maximum consequence (maximum reduced life) and minimum consequence (minimum reduced life). Therefore, by using interpolation, the 'expected reduced life' was:

$$ERL = (RD_k\ (sal) - RD_{min})/(RD_{max} - RD_{min}) * (RL_{max} - RL_{min}) + RL_{min}$$

where

ERL: the expected reduce life;
RD_k: random variable for the expected risk effect;
sal: risk event 'shorter asset life';
RD_{max}: 25;
RD_{min}: 1;
RL_{max}: 10 years;
RL_{min}: 0 year;

VII37. RCN for 'Less Residual Values' on THSR

Based on the scenario statements described in Section VI36, VI37, the Figure VI36 and VI37, the direct causes for 'less residual value' is 'shorter asset life'; the direct consequence is 'revenue losses.' As shown in Figure VII37, the 'expected reduce life' is linked with 'Depreciation' sub-model (Figure 6.1.5) to make higher depreciation rate so that the residual value during 'expected reduced life' drop to 0. As described in Section 6.1.5, the fraction of the book balance α would be changed to *α'*:

$$\alpha' = \lambda(100\%/(L\text{-}ERL))$$

$$D'_n = \alpha BB_{n-1} = \alpha C_{asset}(1-\alpha)^{n-1}$$

$$BB'_n = C_{asset}(1-\alpha)^n,\ n=1,...L\text{-}ERL$$

Where

α': the new fraction of the book balance;
λ: multiplier =1.5
D'_n: the new depreciation value at nth year;
C_{asset}: estimated cost of asset;
BB'_n: book balance or accounting value of asset after period n;
L: asset life time = 30 years
ERL: the expected reduce life

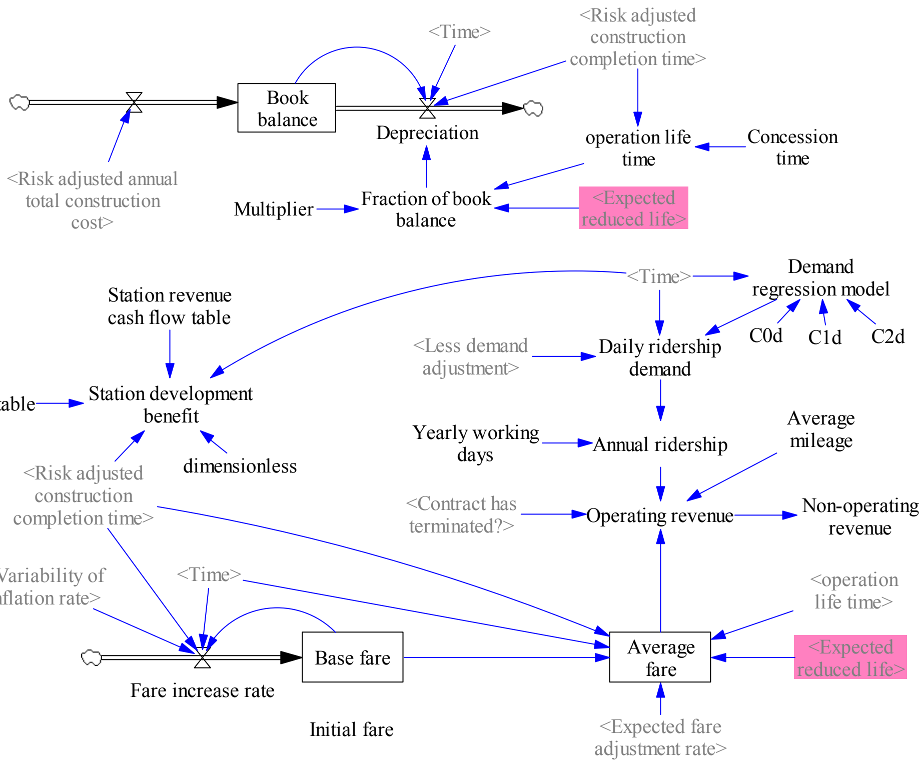


Figure VII37 The SD Model for 'Less Residual Value' Risk Effect

In addition, as shown in Figure VII37, the 'expected reduce life' is linked with 'Operation Revenue' sub-model (Figure 6.1.3) to make average fare =0 so that the revenue is 0 during the 'expected reduce life' was below:

$$AAF = 0,\ RACCT < t < RACCT+L\text{-}ERL$$

where

AAF: Annual average fare;
t: time;
RACCT: risk-adjusted construction completion time;
L: asset life time = 30 years;
ERL: the expected reduce life

VII38. RCN for 'Termination Liabilities' on THSR

Based on the scenario statements described in Section VI38 and the Figure V38, the 'termination liabilities' is caused under the worst circumstance of 'contract breach' and would lead to 'construction delay' at construction stage and 'revenue losses' at operation stage. Therefore, the risk variable 'contract has terminated?' is a binary variable that '1' means the contract has been terminated; '0' means the contract has not been terminated yet. It is modelled as below:

$$Cht = 1,\ RD(cb)=25;$$
$$= 0,\ RD(cb)<25$$

Where

Cht: risk variable 'contract has terminated?';
RD: random variable for the expected risk effect;
cb: risk event 'contract breach'

As for direct consequence on 'construction delay', it is described in Section VII8. As for consequence on 'revenue losses', the risk variable 'contract has terminated?' is linked with the 'Operation Revenue sub-model (Figure 6.1.3)' as shown in Figure VII38. The variable 'operating revenue' would turn to be 0 when binary variable 'contract has terminated?'= 1 that means contract has been terminated so that the operation is stop. Therefore, the annual operating revenue is modified as:

$$AOR' = (1-Cht)*AOR$$

Where

AOR: new annual operating revenue;
Cht: binary variable 'contract has terminated?'=0 or 1.

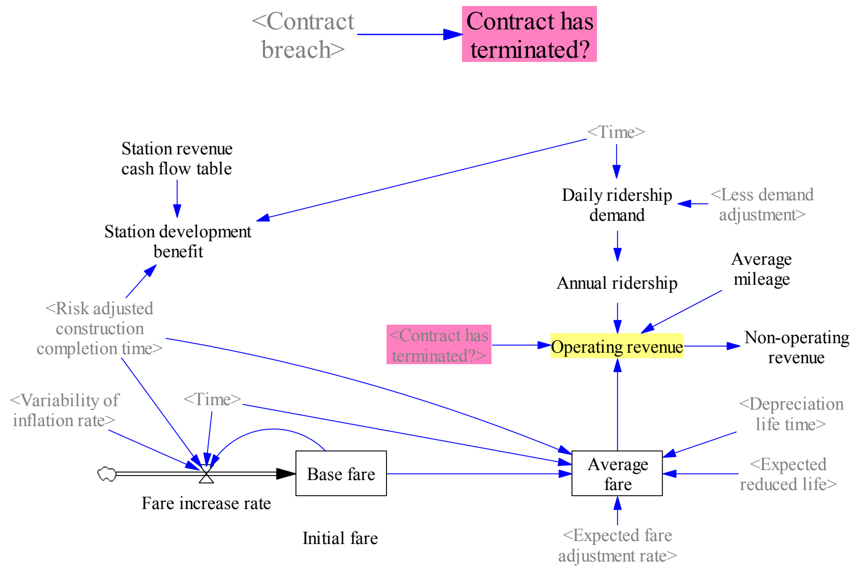


Figure VII38 The SD Model for 'Termination Liabilities' Risk Effect

VII39. RCN for 'Variability of Inflation Rate' on THSR

Based on the scenario statements described in Section VI39 and the Figure VI39, the 'variability of inflation rate' shown in Figure VII39 is an independent risk variable that has no the direct causes. According to DBAS(2000, 2007)'s data and the interview statement, the random variable for 'variability of inflation rate' was assumed to come from a triangular distribution that had a minimum value of 2%, a maximum value of 7% and the mean value of 3.69%.

$$r_{inf} = RANDOM\ TRIANGULAR(a, m, b)$$

where

r_{inf}: random variable for 'variability of inflation rate';
a: minimum value= 0.02;
b: maximum value=0.07;
*m: mode=3*mean-a-b=3*0.0369-0.02-0.07= 0.0207*

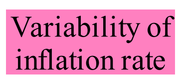
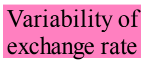


Figure VII39 The SD Model for 'Variability of Inflation Rate' Risk Effect

VII40. RCN for ‘Variability of Exchange Rate’ on THSR

Based on the scenario statements described in Section VI40 and the Figure VI40, the ‘variability of exchange rate’ shown in Figure VII40 is an independent risk variable that has no the direct causes, but has direct effects on construction costs and operation costs. According to CEPD (2005)’s data, the random variable for ‘variability of exchange rate’ during the past twenty years was assumed to come from a normal distribution that had a mean value of 30.73 and a standard deviation of 3.34, which was:



$$r_{ex} = RANDOM\ NORMAL(\mu, \sigma)$$

where

r_{ex}: *random variable for ‘variability of exchange rate’;*
μ: *mean=30.73;*
σ: *standard deviation = 3.34*

Then, as illustrated in Figure VII40, the ‘variability of exchange rate’ is linked with the ‘Construction Cost’ and ‘Operation Cost’ sub-models to replace ‘exchange rate (the risk-free exchange rate)’ so that we can evaluate the additional costs due to higher exchange rate than the reference interest rate.

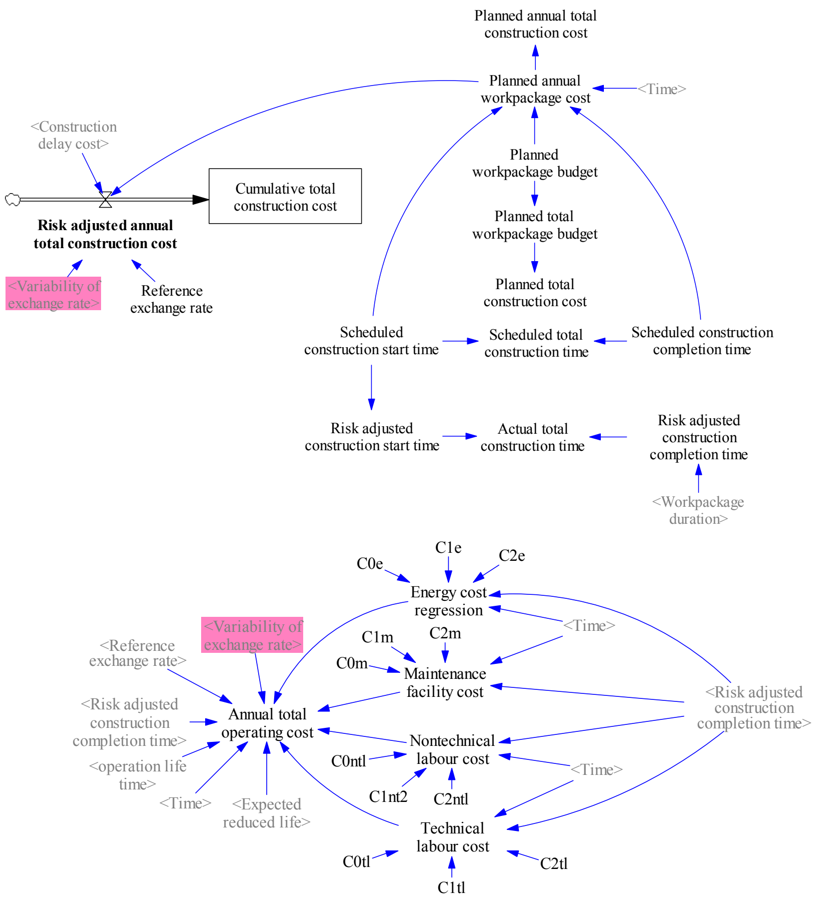


Figure VII40 The SD Model for ‘Variability of Exchange Rate’ Risk Effect

VII41. RCN for ‘Variability of Interest Rate’ on THSR

Based on the scenario statements described in Section VI41 and the Figure VI41, the ‘variability of interest rate’ shown in Figure VII41 is an independent risk variable that has no the direct causes, but has direct effects on construction expense and operation expense. According to Central Bank (2005)’s data and the interviewing statement, the random variable for interest rates during the past 10 years was assumed to come from a triangular distribution that had a minimum value of 1.75%, a maximum value of 9% and a mean value of 4.2%, which was:

r_{int}= *RANDOM TRIANGULAR(a, m, b)*

Where

r_{int}: random variable for 'variability of interest rate';
a: minimum value= 0.0175;
b: maximum value=0.09;
*m: mode=3*mean-a-b=3*0.042-0.0175-0.09= 0.0185*

Then, as illustrated in Figure VII41, the 'variability of interest rate' is linked with the Project Finance sub-model to replace 'interest rate (the risk-free interest)' so that we can evaluate the additional interest payment due to higher interest than the reference interest rate.

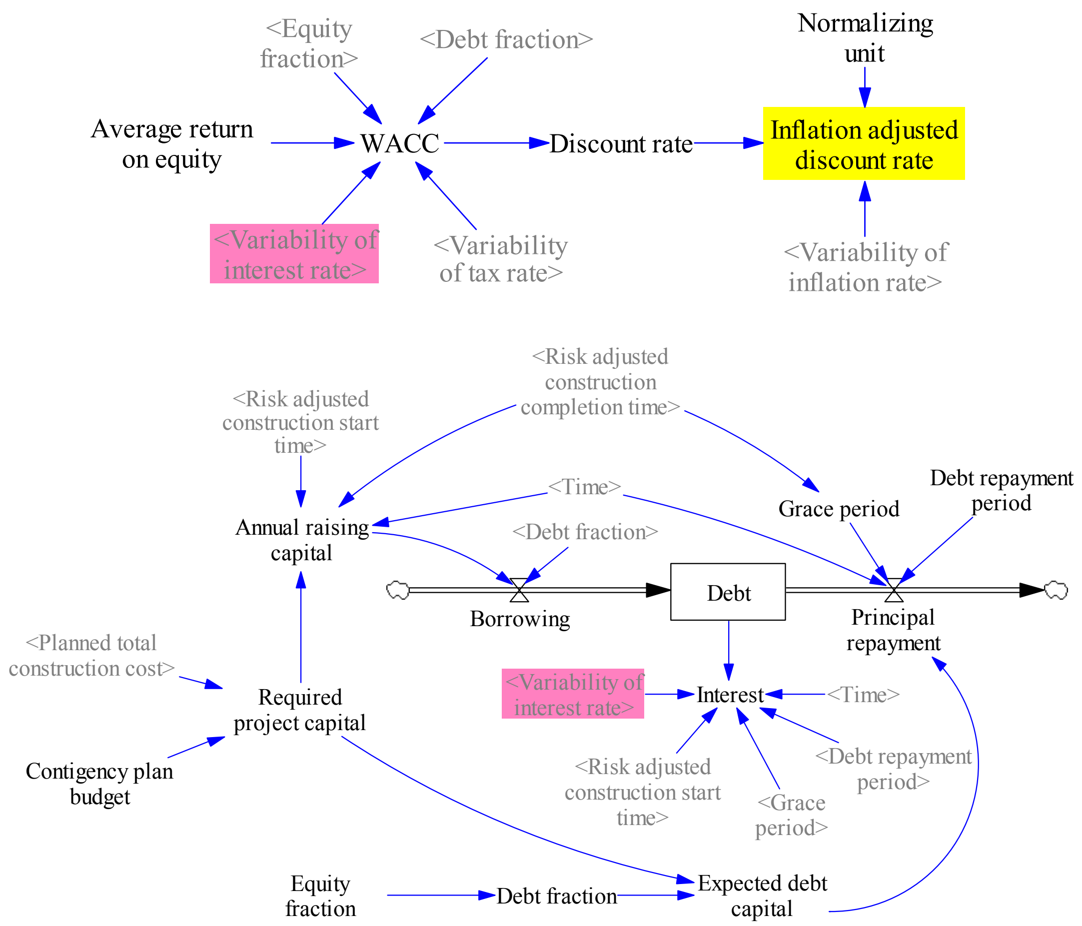


Figure VII41 The SD Model for 'Variability of Interest Rate' Risk Effect

VII42. RCN for 'Variability of Less Demand' on THSR

Based on the scenario statements described in Section VI42 and the Figure VI42, the 'variability of less demand' shown in Figure VII42 is an independent risk variable that has no the direct causes but has direct effects on 'revenue loss' which has impact on cash flow. As mentioned by interviewees, for THSR case, there is no a triggered event for 'variability of demand'. Therefore, the research evaluates the probability distribution for the 'variability of less demand' risk event based on the current research reports on ridership demand for THSR. The risk-free ridership demand described in Section 6.1.3 is based on BHSR's report (Hsu, 2000). To minimise the evaluation bias for ridership demand, the research take both the differences among different reports and optimal bias into account. There are seven research reports (THSR, 2002) for ridership demand forecasting, which include Sofrerail (1991), Transmark (1993), MVA(1993), Chen-Da(1995), NSA(1997), TRI(1998), and THSR(2000). The average difference of percentage of ridership demand between these reports and Hus(2000) was assumed to come from a normal distribution that had that had a mean value of 0.166, a standard deviation of 0.32, a minimum value of -0.13 and maximum value of 0.71. According to a statistics report conducted by Flyvbjerb et al.(2003) for the optimism bias for 27 rail projects around the world, it indicated that the average inaccuracy of rail passenger forecasts was assumed to come form a normal distribution that had that had a mean value of -0.39, a standard deviation of 0.52, a minimum value of -0.80 and maximum value of 0.20. As illustrated in Figure VII42, the ‘less demand adjustment’ is the sum of ‘variability of less demand’ variable and ‘optimism bias’ variable, which was:

$$LDA = VarLd + OptBias;$$
$$VarLd = RANDOM\ NORMAL(a_1, b_1, \mu_1, \sigma_1);$$
$$OptBias = RANDOM\ NORMAL(a_2, b_2, \mu_2, \sigma_2)$$

Where

LDA: random variable for ‘less demand adjustment’;
VarLd: random variable for ‘variability of less demand’;
OptBias: random variable for ‘optimism bias’;
a_1*: minimum value of ‘variability of less demand’= -0.13;*
b_1*: maximum value of ‘variability of less demand’= 0.71;*
μ_1*: mean value of ‘variability of less demand’=0.166;*
σ_1*: standard deviation of ‘variability of less demand’= 0.32;*
a_2*: minimum value of ‘optimism bias’= -0.8;*
b_2*: maximum value of ‘optimism bias’= 0.2;*
μ_2*: mean value of ‘optimism bias’=-0.39;*
σ_2*: standard deviation of ‘optimism bias’= 0.52*

Then ‘less demand adjustment’ is linked with Operation Revenue sub-model so that the daily ridership demand (DRD) is adjusted as:

$$DRD' = DRD*(1+LDA)$$

where

DRD’: adjusted daily ridership demand;
DRD: daily ridership demand

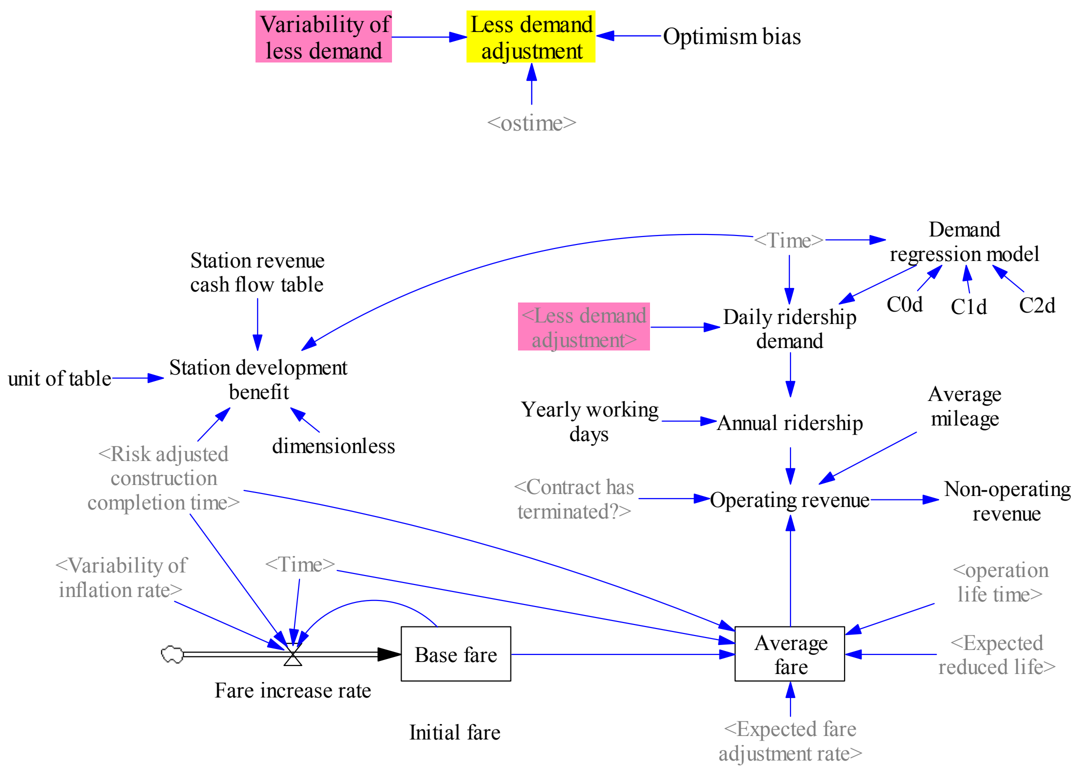


Figure VII42 The SD Model for ‘Variability of Less Demand’ Risk Effect

VII43. RCN for 'Higher Competition' on THSR

As described in Section VI42, there is no 'higher competition' risk for THSR project.

VII44. RCN for 'Downside Economic Events' on THSR

Based on the scenario statements described in Section VI44 and the Figure VI44, the 'downside economic events' is an independent risk variable that has no the direct causes. It was:

$$RD_k(dee),\ k=c,\ o$$

Where

RD_k: random variable for the expected risk effect;
k: time period, c (construction stage); o (operation stage);
dee: risk event 'downside economic events'

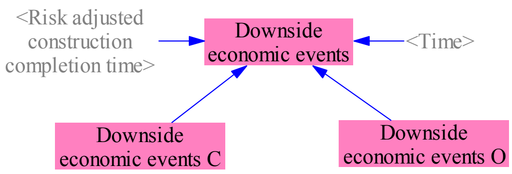


Figure VII44 The SD Model for 'Downside Economic Events' Risk Effect

VII45. RCN for 'Political Interference' on THSR

Based on the scenario statements described in Section VI45 and the Figure VI45, the 'political interference' is an independent risk variable that has no the direct causes. It was:

$$RD_k(pi),\ k=c,\ o$$

Where

RD_k: random variable for the expected risk effect;
k: time period, c (construction stage); o (operation stage);
pi: risk event 'political interference'

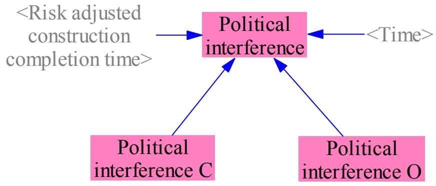


Figure VII45 The SD Model for 'Political Interference' Risk Effect

VII46. RCN for 'Unsuitable Regulatory Policy' on THSR

Based on the scenario statements described in Section VI46 and the Figure VI46, the direct cause for 'unsuitable regulatory policy' is 'political interference', and the direct consequences are 'financial unavailable' 'inflexible contract arrangement' 'approval delay' and 'industrial disputes'. Therefore, the linear multiple-regression model used to address the direct cause relationship in the SD model illustrated in Figure VII46 was:

$$RD_k\ (urp) = \beta_{0k} + \beta_{1k} * RD_k(pi) + \varepsilon_k,\ k=c,\ o$$

Where

RD_k: random variable for the expected risk effect;
k: time period, c (construction stage); o (operation stage);
urp: risk event 'unsuitable regulatory policy';
pi: risk event 'political interference';
β_{0k}: the constant term for the multiple regression model;
β_{1k}: the relational coefficients for the independent risk variables;
ε_k: the random error for the multiple regression model;

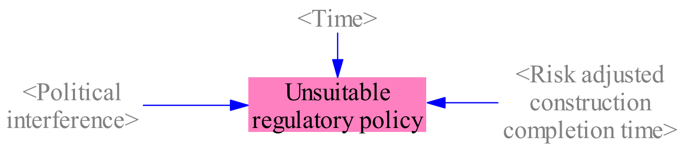


Figure VII46 The SD Model for 'Unsuitable Regulatory policy' Risk Effect

VII47. RCN for 'Approval Delay' on THSR

Based on the scenario statements described in Section VI47 and the Figure VI47, the direct cause for 'approval delay' is 'unsuitable regulatory policy', and the direct consequences are 'land unavailable' 'ownership change delay' and 'delay in contract change negotiation'. Therefore, the linear multiple-regression model used to address the direct cause relationship in the SD model illustrated in Figure VII47 was:

$$RD_k\,(ad) = \beta_{0k} + \beta_{1k} * RD_k(urp) + \varepsilon_k,\; k=c,\, o$$

where

RD_k: *random variable for the expected risk effect;*
k: time period, c (construction stage); o (operation stage);
ad: risk event 'approval delay';
urp: risk event 'unsuitable regulatory policy';
β_{0k}: *the constant term for the multiple regression model;*
β_{1k}: *the relational coefficients for the independent risk variables;*
ε_k: *the random error for the multiple regression model;*

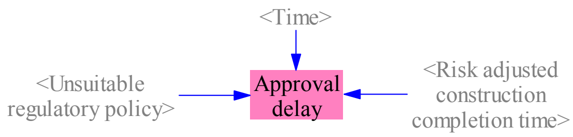


Figure VII47 The SD Model for 'Approval Delay' Risk Effect

VII48. RCN for 'Law/Policy' on THSR

Based on the scenario statements described in Section VI48 and the Figure VI48, the direct causes for 'law/policy changes' are 'downside economic events' 'political interference' 'industrial disputes' and 'Force Majeure', and the direct consequences are 'scope change' and 'contract breach' Therefore, the linear multiple-regression model used to address the direct cause relationship in the SD model illustrated in Figure VII9 was:

$$RD_k\,(lpc) = \beta_{0k} + \beta_{1k} * RD_k(dee) + \beta_{2k} * RD_k(pi) + \beta_{3k} * RD_k(id) + \beta_{4k} * RD_k(fm) + \varepsilon_k,\; k=c,\, o$$

where

RD_k: *random variable for the expected risk effect;*
k: time period, c (construction stage); o (operation stage);
lpc: risk event 'law/policy changes';
dee: risk event 'downside economic events';
pi: risk event 'political interference';
id: risk event 'industrial disputes';
fm: risk event 'Force Majeure';
β_{0k}: *the constant term for the multiple regression model;*
$\beta_{1k}, \beta_{2k}, \beta_{3k}, \beta_{4k}$: *the relational coefficients for the independent risk variables;*
ε_k: *the random error for the multiple regression model;*

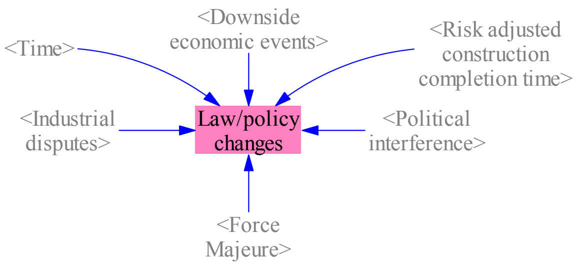


Figure VII48 The SD Model for 'Approval Delay' Risk Effect

VII49. RCN for 'Unforeseen Site Conditions' on THSR

Based on the scenario statements described in Section VI49 and the Figure VI49, the 'unforeseen site conditions' is an independent risk variable that has no the direct causes. It was:

$$RD_k(usc),\ k=c$$

where

RD_k: random variable for the expected risk effect;

k: time period, c (construction stage); o (operation stage);

usc: risk event 'unforeseen site conditions'

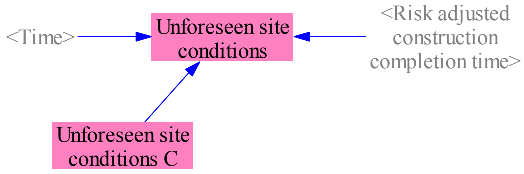


Figure VII49 The SD Model for 'Unforeseen Site Conditions' Risk Effect

VII50. RCN for 'Greater Environmental Expectation' on THSR

Based on the scenario statements described in Section VI50 and the Figure VI50, the 'greater environmental expectation' is an independent risk variable that has no the direct causes. It was:

$$RD_k(gee),\ k=c,\ o$$

where

RD_k: random variable for the expected risk effect;

k: time period, c (construction stage); o (operation stage);

gee: risk event 'greater environmental expectation'

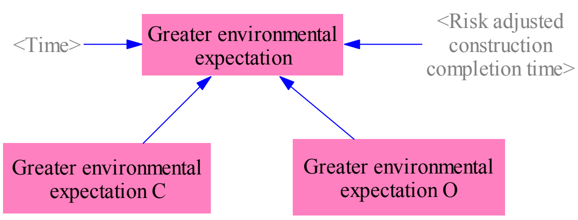


Figure VII50 The SD Model for 'Greater Environmental Expectation' Risk Effect

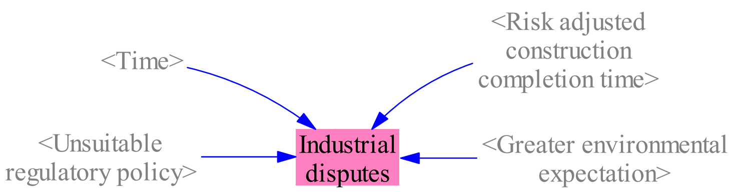
VII51. RCN for 'Industrial Disputes' on THSR

Based on the scenario statements described in Section VI51 and the Figure VI51, the direct causes for 'industrial disputes' are 'unsuitable regulatory policy' and 'higher environmental protection expectation', and the direct consequences are 'land unavailable' 'resources unavailable' and 'law/policy changes'. Therefore, the linear multiple-regression model used to address the direct cause relationship in the SD model illustrated in Figure VII51 was:

$$RD_k\ (id) = \beta_{0k} + \beta_{1k} * RD_k(urp) + \beta_{2k} * RD_k(gee),\ k=c,\ o$$

where

RD_k: *random variable for the expected risk effect;*
k: time period, c (construction stage); o (operation stage);
id: risk event 'industrial disputes';
urp: risk event 'unsuitable regulatory policy';
gee: risk event 'greater environmental expectation';
β_{0k}: *the constant term for the multiple regression model;*
$\beta_{1k,}\ \beta_{2k}$: *the relational coefficients for the independent risk variables;*
ε_k: *the random error for the multiple regression model;*



<u>Figure VII51 The SD Model for 'Industrial Disputes' Risk Effect</u>

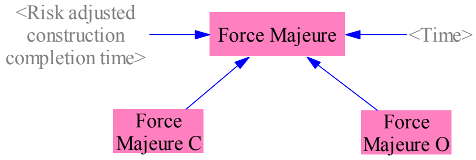
VII52. RCN for 'Force Majeure' on THSR

Based on the scenario statements described in Section VI52 and the Figure VI52, the 'Force Majeure' is an independent risk variable that has no the direct causes. It was:

$$RD_k(fm),\ k=c,\ o$$

Where

RD_k: *random variable for the expected risk effect;*
k: time period, c (construction stage); o (operation stage);
fm: risk event 'Force Majeure'



<u>Figure VII52 The SD Model for 'Force Majeure' Risk Effect</u>

Appendix VIII Multiple-Regression Models

Estimated Regression Coefficients for land unavailable

Term	Coef	SE Coef	T	P
Constant	4.3862	0.15511	28.278	0.000
industrial disputes	0.5250	0.01288	40.751	0.000
approval delay	0.1819	0.01251	14.537	0.000

S = 0.0338242 PRESS = 0.0477128
R-Sq = 98.84% R-Sq(pred) = 98.58% R-Sq(adj) = 98.77%

Analysis of Variance for land unavailable

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	2	3.31806	3.31806	1.65903	1450.11	0.000
Linear	2	3.31806	3.31806	1.65903	1450.11	0.000
Residual Error	34	0.03890	0.03890	0.00114		
Total	36	3.35696				

Estimated Regression Coefficients for resource unavailable

Term	Coef	SE Coef	T	P
Constant	10.9449	0.594646	18.406	0.000
default of subcontractor	0.1548	0.007249	21.357	0.000
Force Majeure	0.1027	0.005392	19.054	0.000
industrial disputes	0.1427	0.057126	2.498	0.018
finance unavailable	0.0990	0.006691	14.791	0.000

S = 0.159302   PRESS = 1.21205
R-Sq = 96.80% R-Sq(pred) = 95.22% R-Sq(adj) = 96.40%

Analysis of Variance for resource unavailable

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	4	24.5624	24.5624	6.14060	241.98	0.000
Linear	4	24.5624	24.5624	6.14060	241.98	0.000
Residual Error	32	0.8121	0.8121	0.02538		
Total	36	25.3745				

Estimated Regression Coefficients for scope change

Term	Coef	SE Coef	T	P
Constant	11.5664	0.22542	51.311	0.000
law/policy change	0.4979	0.01470	33.870	0.000

S = 0.151106   PRESS = 0.905771
R-Sq = 97.04% R-Sq(pred) = 96.64% R-Sq(adj) = 96.95%

Analysis of Variance for scope change

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	1	26.1941	26.1941	26.1941	1147.21	0.000
Linear	1	26.1941	26.1941	26.1941	1147.21	0.000
Residual Error	35	0.7992	0.7992	0.0228		
Total	36	26.9933				

Estimated Regression Coefficients for defective design

Term	Coef	SE Coef	T	P
Constant	3.61059	0.376221	9.597	0.000
default of subcontractor	0.09693	0.004830	20.069	0.000
resource unavailable	0.16386	0.021758	7.531	0.000

S = 0.0948642 PRESS = 0.376288
R-Sq = 96.00% R-Sq(pred) = 95.08% R-Sq(adj) = 95.76%

Analysis of Variance for defective design

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	2	7.33797	7.33797	3.66899	407.70	0.000
Linear	2	7.33797	7.33797	3.66899	407.70	0.000
Residual Error	34	0.30597	0.30597	0.00900		
Total	36	7.64395				

Estimated Regression Coefficients for design changes

Term	Coef	SE Coef	T	P
Constant	-0.3466	0.48629	-0.713	0.481
scope change	0.4972	0.02326	21.380	0.000
contractual disputes	0.2742	0.01353	20.260	0.000

S = 0.120655   PRESS = 0.599094
R-Sq = 96.43% R-Sq(pred) = 95.67% R-Sq(adj) = 96.22%

```
Analysis of Variance for design changes
Source          DF   Seq SS   Adj SS   Adj MS       F      P
Regression       2  13.3519  13.3519  6.67596  458.59  0.000
  Linear         2  13.3519  13.3519  6.67596  458.59  0.000
Residual Error  34   0.4950   0.4950  0.01456
Total           36  13.8469

Estimated Regression Coefficients for defective construction
Term                            Coef   SE Coef       T      P
Constant                      6.5782  0.815954   8.062  0.000
default of subcontractor      0.1186  0.005293  22.411  0.000
resource unavailable          0.1475  0.023740   6.211  0.000
poor cooperation/coordination  0.3137  0.083858   3.741  0.001
S = 0.103307   PRESS = 0.431655
R-Sq = 96.52%  R-Sq(pred) = 95.73%  R-Sq(adj) = 96.20%

Analysis of Variance for defective construction
Source          DF   Seq SS   Adj SS   Adj MS       F      P
Regression       3   9.7585  9.75855  3.25285  304.79  0.000
  Linear         3   9.7585  9.75855  3.25285  304.79  0.000
Residual Error  33   0.3522  0.35219  0.01067
Total           36  10.1107

Estimated Regression Coefficients for construction changes
Term               Coef  SE Coef       T      P
Constant        10.6535  0.53604  19.875  0.000
design changes   0.3646  0.03930   9.278  0.000
S = 0.146228   PRESS = 0.840976
R-Sq = 71.09%  R-Sq(pred) = 67.52%  R-Sq(adj) = 70.27%

Analysis of Variance for construction changes
Source          DF   Seq SS   Adj SS   Adj MS      F      P
Regression       1  1.84055  1.84055  1.84055  86.08  0.000
  Linear         1  1.84055  1.84055  1.84055  86.08  0.000
Residual Error  35  0.74840  0.74840  0.02138
Total           36  2.58894

Estimated Regression Coefficients for complex system interface/integr
Term                    Coef  SE Coef       T      P
Constant              8.8222  0.60390  14.609  0.000
complex technologies  0.3765  0.01565  24.062  0.000
defective design      0.1377  0.06462   2.132  0.040
S = 0.178124   PRESS = 1.29224
R-Sq = 94.45%  R-Sq(pred) = 93.36%  R-Sq(adj) = 94.13%

Analysis of Variance for complex system interface/integr
Source          DF   Seq SS   Adj SS   Adj MS       F      P
Regression       2  18.3731  18.3731  9.18656  289.54  0.000
  Linear         2  18.3731  18.3731  9.18656  289.54  0.000
Residual Error  34   1.0788   1.0788  0.03173
Total           36  19.4519

Estimated Regression Coefficients for low operating productivity
Term                              Coef  SE Coef      T      P
Constant                      0.98599  0.77428  1.273  0.212
resource unavailable          0.09524  0.01877  5.075  0.000
construction changes          0.19599  0.05017  3.907  0.000
system breakdown              0.14498  0.02494  5.813  0.000
accidents and safety issues   0.09239  0.01482  6.235  0.000
poor cooperation/coordination  0.15299  0.03312  4.619  0.000
S = 0.0619201  PRESS = 0.163599
R-Sq = 96.77%  R-Sq(pred) = 95.55%  R-Sq(adj) = 96.24%

Analysis of Variance for low operating productivity
Source          DF   Seq SS   Adj SS    Adj MS       F      P
Regression       5  3.55689  3.55689  0.711379  185.54  0.000
  Linear         5  3.55689  3.55689  0.711379  185.54  0.000
Residual Error  31  0.11886  0.11886  0.003834
Total           36  3.67575

Estimated Regression Coefficients for system breakdown
Term                      Coef  SE Coef       T      P
Constant                9.3599  0.32184  29.083  0.000
defective construction  0.5831  0.02330  25.024  0.000
S = 0.149170   PRESS = 0.876975
R-Sq = 94.71%  R-Sq(pred) = 94.04%  R-Sq(adj) = 94.56%
```

Analysis of Variance for system breakdown

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	1	13.9337	13.9337	13.9337	626.18	0.000
Linear	1	13.9337	13.9337	13.9337	626.18	0.000
Residual Error	35	0.7788	0.7788	0.0223		
Total	36	14.7125				

Estimated Regression Coefficients for high maintenance frequency

Term	Coef	SE Coef	T	P
Constant	2.5632	1.05995	2.418	0.021
defective construction	0.3822	0.02636	14.498	0.000
complex system interface/integr	0.2932	0.05930	4.944	0.000

S = 0.167267 PRESS = 1.07790
R-Sq = 88.37% R-Sq(pred) = 86.82% R-Sq(adj) = 87.68%

Analysis of Variance for high maintenance frequency

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	2	7.22643	7.22643	3.61321	129.14	0.000
Linear	2	7.22643	7.22643	3.61321	129.14	0.000
Residual Error	34	0.95126	0.95126	0.02798		
Total	36	8.17769				

Estimated Regression Coefficients for accidents and safety issues

Term	Coef	SE Coef	T	P
Constant	5.92910	0.067784	87.471	0.000
resource unavailable	0.09712	0.003007	32.300	0.000
defective construction	0.25295	0.002887	87.610	0.000
complex system interface/integr	0.10434	0.003760	27.754	0.000
Force Majeure	0.20018	0.000518	386.300	0.000

S = 0.0104998 PRESS = 0.00460871
R-Sq = 99.99% R-Sq(pred) = 99.99% R-Sq(adj) = 99.99%

Analysis of Variance for accidents and safety issues

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	4	46.7531	46.7531	11.6883	106019.16	0.000
Linear	4	46.7531	46.7531	11.6883	106019.16	0.000
Residual Error	32	0.0035	0.0035	0.0001		
Total	36	46.7566				

Estimated Regression Coefficients for complex technologies

Term	Coef	SE Coef	T	P
Constant	6.8154	0.056344	120.961	0.000
political interference	0.3412	0.003510	97.234	0.000

S = 0.117190 PRESS = 0.541080
R-Sq = 99.63% R-Sq(pred) = 99.58% R-Sq(adj) = 99.62%

Analysis of Variance for complex technologies

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	1	129.845	129.845	129.845	9454.52	0.000
Linear	1	129.845	129.845	129.845	9454.52	0.000
Residual Error	35	0.481	0.481	0.014		
Total	36	130.325				

Estimated Regression Coefficients for poor cooperation/coordination

Term	Coef	SE Coef	T	P
Constant	4.7294	0.21579	21.917	0.000
complex system interface/integr	0.2670	0.01484	17.990	0.000

S = 0.0654666 PRESS = 0.166271
R-Sq = 90.24% R-Sq(pred) = 89.18% R-Sq(adj) = 89.96%

Analysis of Variance for poor cooperation/coordination

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	1	1.38715	1.38715	1.38715	323.66	0.000
Linear	1	1.38715	1.38715	1.38715	323.66	0.000
Residual Error	35	0.15001	0.15001	0.00429		
Total	36	1.53715				

Estimated Regression Coefficients for insolvency of contractor

Term	Coef	SE Coef	T	P
Constant	1.7040	0.100109	17.022	0.000
finance unavailable	0.8422	0.005442	154.775	0.000

S = 0.136496 PRESS = 0.732217
R-Sq = 99.85% R-Sq(pred) = 99.84% R-Sq(adj) = 99.85%

Analysis of Variance for insolvency of contractor

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	1	446.312	446.312	446.312	23955.18	0.000
Linear	1	446.312	446.312	446.312	23955.18	0.000
Residual Error	35	0.652	0.652	0.019		
Total	36	446.964				

Estimated Regression Coefficients for ownership change delay

Term	Coef	SE Coef	T	P
Constant	5.4909	0.21988	24.972	0.000
approval delay	0.7397	0.01733	42.683	0.000

S = 0.0517507 PRESS = 0.105321
R-Sq = 98.12% R-Sq(pred) = 97.88% R-Sq(adj) = 98.06%

Analysis of Variance for ownership change delay

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	1	4.87912	4.87912	4.87912	1821.84	0.000
Linear	1	4.87912	4.87912	4.87912	1821.84	0.000
Residual Error	35	0.09373	0.09373	0.00268		
Total	36	4.97286				

Estimated Regression Coefficients for contractual disputes

Term	Coef	SE Coef	T	P
Constant	5.9944	0.167275	35.836	0.000
latent defect	0.3820	0.002383	160.311	0.000
contract breach	0.3197	0.012288	26.014	0.000

S = 0.0554044 PRESS = 0.128020
R-Sq = 99.87% R-Sq(pred) = 99.84% R-Sq(adj) = 99.86%

Analysis of Variance for contractual disputes

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	2	79.6256	79.6256	39.8128	12969.81	0.000
Linear	2	79.6256	79.6256	39.8128	12969.81	0.000
Residual Error	34	0.1044	0.1044	0.0031		
Total	36	79.7300				

Estimated Regression Coefficients for contract change negotiation

Term	Coef	SE Coef	T	P
Constant	3.9919	0.15358	25.992	0.000
inflexible contract arrangement	0.4145	0.02042	20.294	0.000

S = 0.151346   PRESS = 0.878953
R-Sq = 92.17% R-Sq(pred) = 91.41% R-Sq(adj) = 91.94%

Analysis of Variance for delay in contract change negoti

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	1	9.4336	9.43363	9.43363	411.85	0.000
Linear	1	9.4336	9.43363	9.43363	411.85	0.000
Residual Error	35	0.8017	0.80170	0.02291		
Total	36	10.2353				

Estimated Regression Coefficients for contract breach

Term	Coef	SE Coef	T	P
Constant	7.0160	0.307568	22.811	0.000
performance unavailable	0.1684	0.029040	5.800	0.000
insolvency of contractor	0.2910	0.005001	58.183	0.000
law/policy change	0.1905	0.010637	17.911	0.000

S = 0.0484001 PRESS = 0.0991878
R-Sq = 99.35% R-Sq(pred) = 99.17% R-Sq(adj) = 99.29%

Analysis of Variance for contract breach

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	3	11.8732	11.8732	3.95774	1689.49	0.000
Linear	3	11.8732	11.8732	3.95774	1689.49	0.000
Residual Error	33	0.0773	0.0773	0.00234		
Total	36	11.9505				

Estimated Regression Coefficients for contract breach

Term	Coef	SE Coef	T	P
Constant	2.39314	2.30459	1.038	0.307
insolvency of contractor	0.62804	0.12382	5.072	0.000
law/policy change	0.58273	0.13932	4.183	0.000
insolvency of contractor* law/policy change	-0.01985	0.00747	-2.656	0.012

S = 0.0624275 PRESS = 0.159171
R-Sq = 98.92% R-Sq(pred) = 98.67% R-Sq(adj) = 98.83%

Analysis of Variance for contract breach

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	3	11.8219	11.821925	3.940642	1011.15	0.000
Linear	2	11.7944	0.333986	0.166993	42.85	0.000
Interaction	1	0.0275	0.027496	0.027496	7.06	0.012
Residual Error	33	0.1286	0.128607	0.003897		
Total	36	11.9505				

Estimated Regression Coefficients for law/policy change

Term	Coef	SE Coef	T	P
Constant	2.5020	0.296874	8.428	0.000
downside economic events	0.2011	0.003446	58.348	0.000
political interference	0.1949	0.002754	70.754	0.000
industrial disputes	0.2445	0.031820	7.684	0.000
Force Majeure	0.2068	0.002704	76.485	0.000

S = 0.0815858 PRESS = 0.287675

R-Sq = 99.80% R-Sq(pred) = 99.73% R-Sq(adj) = 99.77%

Analysis of Variance for law/policy change

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	4	105.459	105.459	26.3647	3960.89	0.000
Linear	4	105.459	105.459	26.3647	3960.89	0.000
Residual Error	32	0.213	0.213	0.0067		
Total	36	105.672				

Estimated Regression Coefficients for industrial disputes

Term	Coef	SE Coef	T	P
Constant	6.15515	0.225146	27.338	0.000
unsuitable regulatory policy	0.14523	0.013871	10.470	0.000
greater environmental expectati	0.07903	0.002640	29.934	0.000

S = 0.0819708 PRESS = 0.265238

R-Sq = 96.98% R-Sq(pred) = 96.49% R-Sq(adj) = 96.80%

Analysis of Variance for industrial disputes

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	2	7.32457	7.32457	3.66229	545.05	0.000
Linear	2	7.32457	7.32457	3.66229	545.05	0.000
Residual Error	34	0.22845	0.22845	0.00672		
Total	36	7.55302				

Appendix IX A Statistical Analysis on “Univariate”and “Multivariate” Approaches

1. The problems

The “univariate” approach was originally proposed in the submitted PhD thesis that it used a risk matrix for the conversion of the 2 dimensional measures of likelihood and impact into a single measure of risk. This approach has the following technical limitations:

1. Using a risk matrix for conversion is arbitrary and arguable.

Since the expert judgment regarding risk effect measurement is very subjective, the observation and interpretation of the same risk factors may be inconsistent among different project experts. In addition, the risks involved in PPP projects are unique (Li & Zou, 2008). There may be the same type of risk factors among different projects, but different likelihood and impact exist. A clear definition of risk likelihood-impact scales are designed and tailored to reflect the specific risk characteristics of a particular project that may be helpful to reduce risk measurement bias. Therefore, the risk matrix used in this thesis research originally intended to provide the consistent definition of categorized scales with the corresponding numerical scales for risk likelihood-impact measures to reduce potential subjective bias when the project experts measured risk effects (see Appendix IV).

However, using a risk matrix for converting two-dimension categorical data to one-dimension ordinal numerical data for risk effect rating seems arbitrary and arguable. For example, there will be a question about why is LOW PROBABILITY MEDIUM IMPACT (numerical rating: 10) in the risk matrix worse than VERY HIGH LIKELIHOOD LOW IMPACT (numerical rating: 11)? Even though the numerical ranking depends on “RF values” calculation which depends on the “numerical weights” which are tailored to suit a particular project (see Appendix IV), the settings of “numerical weights” are arbitrary and also difficult to be justified according to the project characteristics.

2. Using a risk matrix to produce ordinal data for regression analysis is unreliable.

There are fundamental issues in using ordinal data for regression analysis. First, in general it implies the data must be interval in nature if regression analysis is used. There has been a continuing debate about whether it is legitimate to use ordinal data in parametric statistical procedures in the literature (see Appendix IXG). Second, the “rankings” of the ordinal values in the risk matrix are sensitive to the numerical scales. The different sets of numerical scales produce different weights which produce different rankings in the risk matrix (see Section 2.1, Appendix IX). Since the ordinal values produced by the risk matrix are critical input to the regression analysis, there will be a fundamental error in the analytical process for the use of regression.

Most of the literature simply used the two-dimensional risk matrix for prioritising or categorising the importance of risk factors only. It seems to be unsupported by any extensive literature or research that using a risk matrix for the conversion of the 2 dimensional measures of likelihood and impact into a single measure of risk, especially the issue that impact and probability are not commensurate dimensions. Thus, a “multivariate (bivariate)” approach using a two-dimensional independent set of values for probability and impact is undertaken to examine if it can resolve some of the concerns about the use of ordinal nature of data for regression.

2. Introduction to the statistical analysis

A statistical analysis is performed to examine the reliability and appropriateness of “univariate” and “multivariate (bivariate)” approaches in the use of regression by testing the sensitivity of risk relationships (including both ordinal and ratio relationships) to the numerical scales. It was performed from two different perspectives: “single-observed data” and “multiple-observed data”, because this provided us with an insight to clarify and justify reliability and appropriateness in using both approaches for regression analysis. “Single-observed data” means that the risk factors are measured by a project expert only (sample size / number of project experts = 1), and “multiple-observed data” means that the risk factors are measured by a group of experts (sample size / number of project experts = 37 in this PhD thesis research). The data characteristics in terms of mean and standard deviation were calculated for comparison. The hypothesis tests using “Two-Sample T-Test” were also performed to examine the consistency of expected risk effect values (mean values), ordinal and ratio relationships among different sets of numerical scales. An interpretation was presented to explain the results of statistical analysis.

2. The statistical analysis for “univariate” approach

2.1 Single-observed data (sample size / number of project experts = 1)

Four different sets of numerical scales including Original scale, Scale 1, Scale 2 and Scale 3 are used as examples to test the reliability of “univariate approach”. They are:

Original scale: (Originally proposed in this PhD thesis)
Impact: 5, 20, 100, 700, 1000
Likelihood: 1, 2, 5, 7, 9
Scale 1: (Adopting a simple linear scale for likelihood)
Impact: 5, 20, 100, 700, 1000
Likelihood: 1, 2, 3, 4, 5
Scale 2: (Retaining the likelihood scale but adopting a different scale for impact)
Impact: 5, 20, 100, 300, 500
Likelihood: 1, 2, 5, 7, 9
Scale 3: (Exchanging the impact and likelihood numerical scales)
Impact: 1, 2, 5, 7, 9
Likelihood: 5, 20, 100, 300, 500

This test is based on "single-observed data (sample size / number of project experts = 1)". Assume after an individual judgment, the impact and probability for Risk A and Risk B are given as:

Risk A: Impact (I) = High (H) and Likelihood (L) = Low (L);
Risk B: Impact (I) = Low (L) and Likelihood (L) = High (H)

Then we can obtain a rating value as the risk effect from risk matrix for Risk A and Risk B by Original scale, Scale 1, Scale 2 and Scale respectively (The data are illustrated in Appendix IXA). We compare "ordinal relationship" and "ratio relationship" between Risk A and Risk B among different numerical scales (Table IX1).

Obviously, Table IX1 illustrates that the both the "ordinal relationship" and "ratio relationship" between Risk A and Risk B change among different sets of numerical scales. Especially there is a radical change in numerical scales between Scale 3 and others. For example, changing numerical scale from Original scale to Scale 3, then ordinal relationship changes from "Risk A > Risk B" to "Risk A < Risk B" and ratio relationship changes from "Risk A = 1.8 Risk B" to "Risk A = 0.63 Risk B". Using different numerical scale values will change the ordinal and ratio relationships which are the critical inputs to the regression analysis. Since the rankings of the ordinal values in the risk matrix are very sensitive to the numerical scales, the "UNIVARIATE" approach is UNRELIABLE in the use of regression if the data are based on "SINGLE-OBSERVED DATA (sample size /number of project experts = 1)".

Table IX1 Reliability of "univariate" approach (single-observed data, sample size = 1)

Testing scales	Numerical scales	Rating values (Expected risk effect values)	Ordinal relationships	Ratio relationships
Original	Impact: 5, 20, 100, 700, 1000 Likelihood:1, 2, 5, 7, 9	Risk A(I, L)=(H, L)=18	Risk A > Risk B	Risk A = 1.8 Risk B
		Risk B(I, L)=(H, L)=10		
Scale 1	Impact: 5, 20, 100, 700, 1000 Likelihood:1, 2, 3, 4, 5	Risk A(I, L)=(H, L)=18	Risk A > Risk B	Risk A = 2 Risk B
		Risk B(I, L)=(H, L)=9		
Scale 2	Impact: 5, 20, 100, 300, 500 Likelihood:1, 2, 5, 7, 9	Risk A(I, L)=(H, L)=16	Risk A > Risk B	Risk A = 1.6 Risk B
		Risk B(I, L)=(H, L)=10		
Scale 3	Impact: 1, 2, 5, 7, 9 Likelihood:5, 20, 100, 300, 500	Risk A(I, L)=(H, L)=10	Risk A < Risk B	Risk A = 0.63 Risk B
		Risk B(I, L)=(H, L)=16		

2.2 Multiple-observed data (sample size /number of project experts = 37)

This PhD thesis research used a "univariate" approach with a risk matrix for the conversion of the 2 dimensional measures of likelihood and impact into a single measure of risk. A group of experts were asked to make their judgments to rate the risk effect values by the use of the risk matrix which specified impact and likelihood scales separately. We originally obtained "multiple-observed data" that the sample size was equal to 37. The original data produced by Original scale are converted to other 3 sets of data by Scale 1, Scale 2, and Scale 3 respectively (The data are illustrated in Appendix IXB). Three risk factors including "Force Majeure (FM)", "unforeseen site conditions (USC)" and "political interference (PI)" are randomly chosen to demonstrate the tests.

Table IX2 Statistics of "univariate" approach (multiple-observed data, sample size = 37)

Numerical Scales	Original	Scale 1	Scale 2	Scale 3	Original	Scale 1	Scale 2	Scale 3	Original	Scale 1	Scale 2	Scale 3
Risk factors	FM	FM	FM	FM	USC	USC	USC	USC	PI	PI	PI	PI
Mean (μ)	18.23	18.27	18.19	16.81	11.97	11.97	12.22	12.68	15.09	15.03	15.03	14.22
SD	5.04	4.83	5.07	6.23	3.13	3.35	3.58	5.56	5.57	5.47	5.50	6.43
Change of Mean %	0.00%	0.22%	-0.22%	-7.79%	0.00%	0.00%	2.09%	5.93%	0.00%	-0.40%	-0.40%	-5.77%
Two-Sample T-Test for Means	Ho: μ (Scale 1)- μ (Original) = 0 (don't reject) Ho: μ (Scale 2)- μ (Original) = 0 (don't reject) Ho: μ (Scale 3)- μ (Original) = 0 (don't reject) Ho: μ (Scale 1)- μ (Scale 2) = 0 (don't reject) Ho: μ (Scale 1)- μ (Scale 3) = 0 (don't reject) Ho: μ (Scale 2)- μ (Scale3) = 0 (don't reject)				Ho: μ (Scale 1)- μ (Original) = 0 (don't reject) Ho: μ (Scale 2)- μ (Original) = 0 (don't reject) Ho: μ (Scale 3)- μ (Original) = 0 (don't reject) Ho: μ (Scale 1)- μ (Scale 2) = 0 (don't reject) Ho: μ (Scale 1)- μ (Scale 3) = 0 (don't reject) Ho: μ (Scale 2)- μ (Scale3) = 0 (don't reject)				Ho: μ (Scale 1)- μ (Original) = 0 (don't reject) Ho: μ (Scale 2)- μ (Original) = 0 (don't reject) Ho: μ (Scale 3)- μ (Original) = 0 (don't reject) Ho: μ (Scale 1)- μ (Scale 2) = 0 (don't reject) Ho: μ (Scale 1)- μ (Scale 3) = 0 (don't reject) Ho: μ (Scale 2)- μ (Scale3) = 0 (don't reject)			
	Expected risk effect value μ(FM) at α = 0.05 $\mu(FM)_{Original} = \mu(FM)_{Scale1} = \mu(FM)_{Scale2} = \mu(FM)_{Scale3}$				Expected risk effect value μ(USC) at α = 0.05 $\mu(USC)_{Original} = \mu(USC)_{Scale1} = \mu(USC)_{Scale2} = \mu(USC)_{Scale3}$				Expected risk effect value μ(PI) at α = 0.05 $\mu(PI)_{Original} = \mu(PI)_{Scale1} = \mu(PI)_{Scale2} = \mu(PI)_{Scale3}$			
Note: FM: risk factor "Force Majeure"; USC: risk factor "unforeseen site conditions; PI: risk factor "political interference."												

Table IX3 Reliability of "univariate" approach (multiple-observed data, sample size = 37)

Testing scales	Numerical scales	Expected risk effect values, μ	Ordinal relationships	Ratio relationships
Original	Impact: 5, 20, 100, 700, 1000 Likelihood: 1, 2, 5, 7, 9	μ(FM) = 18.23	μ(FM) > μ(PI) > μ(USC)	μ(FM) = 1.52 μ(USC)
		μ(USC) = 11.97		μ(USC) = 0.79 μ(PI)
		μ(PI) = 15.09		μ(PI) = 0.83 μ(FM)
Scale 1	Impact: 5, 20, 100, 700, 1000 Likelihood: 1, 2, 3, 4, 5	μ(FM) = 18.27	μ(FM) > μ(PI) > μ(USC)	μ(FM) = 1.53 μ(USC)
		μ(USC) = 11.97		μ(USC) = 0.80 μ(PI)
		μ(PI) = 15.03		μ(PI) = 0.82 μ(FM)
Scale 2	Impact: 5, 20, 100, 300, 500 Likelihood: 1, 2, 5, 7, 9	μ(FM) = 18.19	μ(FM) > μ(PI) > μ(USC)	μ(FM) = 1.49 μ(USC)
		μ(USC) = 12.22		μ(USC) = 0.81 μ(PI)
		μ(PI) = 15.03		μ(PI) = 0.83 μ(FM)
Scale 3	Impact: 1, 2, 5, 7, 9 Likelihood: 5, 20, 100, 300, 500	μ(FM) = 16.81	μ(FM) > μ(PI) > μ(USC)	μ(FM) = 1.33 μ(USC)
		μ(USC) = 12.68		μ(USC) = 0.89 μ(PI)
		μ(PI) = 14.22		μ(PI) = 0.85 μ(FM)
Reliability	There is no statistically significant difference in the expected risk effect values (mean values) among different sets of numerical scales at α = 0.05, i.e. μ(Scale 1) = μ(Scale 2) = μ(Scale 3) = μ(Original). Thus, there is no statistically significant difference in both ordinal and ratio relationships between different sets of numerical scales at 95% confidence level. We can draw a conclusion that the "UNIVARIATE" APPROACH with adequate MULTIPLE-OBSERVED DAT is RELIABLE in the use of regression, since both ordinal and ratio relationships remain CONSISTENT among different sets of numerical scales.			

Table IX2 indicates that the data characteristics in terms of the mean (μ) and "standard deviation (SD)" values only slightly change between different sets of numerical scales. For example, the expected risk effect values (mean values) for risk factor "Force Majeure (FM)" produced by Scale 1, Scale 2 and Scale 3 are 18.27, 18.19, and 16.81 respectively, which change between ±0.00% and ±7.79% only from the values produced by Original scale. Moreover, a stricter statistics in "Two-Sample T-Test" (Appendix IXC) is applied to test the difference of mean values between two independent samples produced by different sets of numerical scales. Table IX2 indicates that there are no statistically significant differences in the expected risk effect values among four different sets of numerical scales at 95% confidence level. Especially, there are no statistically significant differences in the sample means between Scale 3 and others even if there is a radical change in numerical scales between Scale 3 and others. For example, the "Two-Sample T-Test" on "Scale 3 vs. Original scale" for risk factor "Force Majeure (FM)" is:

Two-sample T for Original vs Scale 3

Ho: μ (Scale 3)- μ (Original) = 0
Ha: μ (Scale 3)- μ (Original) ≠ 0

	N	Mean	StDev	SE Mean
Original	37	18.23	5.04	0.83
Scale 3	37	16.81	6.23	1.0

Difference = mu (Original) - mu (Scale 3)
Estimate for difference: 1.42
95% CI for difference: (-1.21, 4.04)
T-Test of difference = 0 (vs not =): T-Value = 1.07 P-Value = 0.286 DF = 72
Both use Pooled StDev = 5.6678

It indicates that a 95% confidence interval is (-1.21, 4.04), which includes zero. Thus, it suggests that there is no statistically significant difference in mean values between Scale 3 and Original scale. In addition, the hypothesis test statistic is 1.07 with *p*-value of 0.286. Since the *p*-value is greater than *α*-level (0.05), there is no evidence for a difference in the expected risk effect values between Scale 3 and Original scale.

Table IX3 illustrates the expected risk effect values, ordinal relationship and ratio relationship among four different sets of numerical scales. It appears that there is no difference in ordinal relationship and a slight difference only in ratio relationship among different sets of numerical scales. However, the "Two-Sample T-Test" indicates there is no evidence for a difference in the expected risk effect values among different sets of numerical scales at α-level (0.05), i.e. μ(Scale 1) = μ(Scale 2) = μ(Scale 3) = μ(Original). Thus, there is no statistically significant difference in both ordinal and ratio relationships between different sets of numerical scales at 95% confidence level. We can draw a conclusion that the proposed "UNIVARIATE" approach with adequate "MULTIPLE-OBSERVED DATA (sample size /number of project experts = 37)" is RELIABLE in the use of regression since both ordinal and ratio relationships remain consistent among different sets of numerical scales.

3. The statistical analysis for "multivariate (bivariate)" approach

3.1 Single-observed data (sample size /number of project experts = 1)

The different sets of numerical scales including "Scale 1 (linear scale)", "Scale 2 (linear scale)", "Scale 3 (nonlinear scale)", "Scale 4 (nonlinear scale)", "Scale 5 (nonlinear and normalised scale)" and "Scale 6 (nonlinear and normalised scale)" are used as examples to test the reliability of "multivariate (bivariate)" approach. They are:

Scale 1: (linear)
Impact: 1, 2, 3, 4, 5
Likelihood: 0.1, 0.3, 0.5, 0.7, 0.9
Scale 2: (linear)
Impact: 1, 3, 5, 7, 9
Likelihood: 0.1, 0.3, 0.5, 0.7, 0.9
Scale 3: (non-linear)
Impact: 1, 5, 9, 15, 25
Likelihood: 0.1, 0.3, 0.5, 0.7, 0.9
Scale 4: (non-linear)
Impact: 1, 5, 9, 15, 25
Likelihood: 0.01, 0.1, 0.4, 0.6, 1
Scale 5: (non-linear and normalised)
Impact: 5, 20, 100, 700, 1000 (normalised: 0.0027, 0.0109, 0.0547, 0.3835, 0.5479)
Likelihood: 1, 2, 5, 7, 9 (normalised: 0.0416, 0.0833, 0.2083, 0.2916, 0.3750)
Scale 6: (non-linear and normalised)
Impact: 5, 20, 100, 300, 500 (normalised: 0.0054, 0.022, 0.1081, 0.3243, 0.5405)
Likelihood: 1, 2, 5, 7, 9 (normalised: 0.0416, 0.0833, 0.2083, 0.2916, 0.3750)

This test is based on "single-observed data (sample size / number of project experts = 1)". Assume after an individual judgment, the impact and probability for Risk A and Risk B are given as:

Risk A: Impact (I) = High (H) and Likelihood (L) = Low (L);
Risk B: Impact (I) = Low (L) and Likelihood (L) = High (H)

Then we can respectively calculate the expected risk effect values for Risk A and Risk B:

Expected risk effect value = impact (I) × Likelihood (L)

The data are illustrated in Appendix IXD. Table IX4 illustrates the ordinal and ratio relationships between Risk A and Risk B among different numerical scales. Obviously, it appears that the both ordinal relationship and ratio relationship between Risk A and Risk B change very much among different sets of numerical scales if the "multivariate (bivariate)" approach is used. Since ordinal and ration relationships are very sensitive to the numerical scales, the "MULTIVARIATE (BIVARIATE)" approach is UNRELIABLE in the use of regression if the data are based on "SINGLE-OBSERVED DATA (sample size /number of project experts = 1)".

3.2 Multiple-observed data (sample size / number of project experts = 37)

We use the same two-dimensional scales (Scale 1-6) as illustrated in Section 3.1/ Appendix IX to test the reliability of "multivariate (bivariate) approach" based on "multiple-observed data " that the risk factors are measured by a group of experts (group judgment). Three risk factors including "Force Majeure (FM)", "unforeseen site conditions (USC)" and "political interference (PI)" are randomly chosen to demonstrate the tests. Based on the originally collected data (sample size /number of project experts = 37) in this PhD thesis research, the two-dimensional independent set of values for probability and impact set in the Scale 1-6 are used to calculate the expected risk effect value for each observed data (The data are illustrated in Appendix IXE):

Expected risk effect value = impact (I) × Likelihood (L)

Table IX4 Reliability of "multivariate (bivariate) Approach" (single-observed data, sample size = 1)

Testing scales	Numerical scales	Expected risk effect values	Ordinal relationships	Ratio relationships
Scale 1	Impact: 1, 2, 3, 4, 5 Likelihood: 0.1, 0.3, 0.5, 0.7, 0.9	Risk A(I, L)= 4×0.3= 1.2 Risk B(I, L)= 2×0.7= 1.4	Risk A < Risk B	Risk A = 0.86 Risk B
Scale 2	Impact: 1, 3, 5, 7, 9 Likelihood: 0.1, 0.3, 0.5, 0.7, 0.9	Risk A(I, L)= 7×0.3= 2.1 Risk B(I, L)= 3×0.7= 2.1	Risk A = Risk B	Risk A = 1.0 Risk B
Scale 3	Impact: 1, 5, 9, 15, 25 Likelihood: 0.1, 0.3, 0.5, 0.7, 0.9	Risk A(I, L)= 15×0.3= 4.5 Risk B(I, L)= 5×0.7= 3.5	Risk A > Risk B	Risk A = 1.29 Risk B
Scale 4	Impact: 1, 5, 9, 15, 25 Likelihood: 0.01, 0.1, 0.4, 0.6, 1	Risk A(I, L)= 15×0.1= 1.5 Risk B(I, L)= 5×0.6= 3.0	Risk A < Risk B	Risk A = 0.50 Risk B
Scale 5	Impact: 0.0027, 0.0109, 0.0547, 0.3835, 0.5479 Likelihood: 0.0416, 0.0833, 0.2083, 0.2916, 0.3750	Risk A(I, L)= 0.38×0.08= 0.031 Risk B(I, L)= 0.01×0.29= 0.003	Risk A > Risk B	Risk A = 10.0 Risk B
Scale 6	Impact: 0.0054, 0.022, 0.1081, 0.3243, 0.5405 Likelihood: 0.0416, 0.0833, 0.2083, 0.2916, 0.3750	Risk A(I, L)= 0.33×0.08= 0.027 Risk B(I, L)= 0.02×0.3= 0.006	Risk A > Risk B	Risk A = 4.5 Risk B

Table IX5 indicates that the expected risk effect values (mean values) largely change between different sets of numerical scales, which range between ±32% and ±296% from the values produced by Scale 1. Moreover, Table IX5 appears almost all of the "Two-Sample T-Tests" (Appendix IXF) have statistically significant differences in mean values among different sets of numerical scales at 95% confidence level. Especially, there are statistically significant differences in mean values between Scale 5 and Scale 6 even if these two numerical scales have been normalised to reduce data variation as a result of numerical scales. For example, the "Two-Sample T-Test" for "Scale 5 vs. Scale 6" for risk factor "unforeseen site conditions (USC)" is:

```
Two-sample T for Scale 5 vs Scale 6

Ho: μ (Scale 5)- μ (Scale 6) = 0
Ha: μ (Scale 5)- μ (Scale 6) ≠ 0

          N    Mean    StDev    SE Mean
Scale 5   37   0.00974  0.00977  0.0016
Scale 6   37   0.0246   0.0350   0.0057

Difference = mu (Scale 5) - mu (Scale 6)
Estimate for difference:  -0.01491
95% CI for difference:  (-0.02681, -0.00301)
T-Test of difference = 0 (vs not =): T-Value = -2.50  P-Value = 0.015  DF = 72
Both use Pooled StDev = 0.0257
```

It indicates that a 95% confidence interval is (-0.02681, -0.00301), which excludes zero. Thus, it suggests that there is statistically significant difference in mean values. In addition, the hypothesis test statistic is -2.50 with p-value of 0.015. Since the p-value is less than α-level (0.05), there is strong evidence for a difference in mean values between Scale 5 and Scale 6.

Table IX5 Statistics of multivariate (bivariate) approach (multiple-observed data, sample size = 37)

Numerical Scales	Scale 1	Scale 2	Scale 3	Scale 4	Scale 5	Scale 6	Scale 1	Scale 2	Scale 3	Scale 4	Scale 5	Scale 6	Scale 1	Scale 2	Scale 3	Scale 4	Scale 5	Scale 6
Observation No(Sample Size = 37)	FM	FM	FM	FM	FM	FM	USC	USC	USC	USC	USC	USC	PI	PI	PI	PI	PI	PI
Mean	2.20	3.86	8.71	7.81	0.07	0.07	1.51	2.00	3.54	2.51	0.01	0.03	1.56	2.64	5.86	4.54	0.04	0.04
SD	1.04	1.90	5.53	5.62	0.06	0.05	1.72	1.00	1.95	2.08	0.01	0.04	1.04	1.87	4.65	5.35	0.05	0.05
Change of Mean %	0%	75%	296%	255%	-97%	-97%	0%	32%	134%	66%	-99%	-98%	0%	69%	276%	191%	-97%	-97%
Two-Sample T-Test for Sample Means	Ho: μ (Scale 1)- μ (Scale 2) = 0 (reject) Ho: μ (Scale 1)- μ (Scale 3) = 0 (reject) Ho: μ (Scale 1)- μ (Scale 4) = 0 (reject) Ho: μ (Scale 1)- μ (Scale 5) = 0 (reject) Ho: μ (Scale 1)- μ (Scale 6) = 0 (reject) Ho: μ (Scale 2)- μ (Scale 3) = 0 (reject) Ho: μ (Scale 2)- μ (Scale 4) = 0 (reject) Ho: μ (Scale 2)- μ (Scale 5) = 0 (reject) Ho: μ (Scale 2)- μ (Scale 6) = 0 (reject) Ho: μ (Scale 3)- μ (Scale 4) = 0 (don't reject) Ho: μ (Scale 3)- μ (Scale 5) = 0 (reject) Ho: μ (Scale 3)- μ (Scale 6) = 0 (reject) Ho: μ (Scale 4)- μ (Scale 5) = 0 (reject) Ho: μ (Scale 4)- μ (Scale 6) = 0 (reject) Ho: μ (Scale 5)- μ (Scale 6) = 0 (don't reject)						Ho: μ (Scale 1)- μ (Scale 2) = 0 (don't reject) Ho: μ (Scale 1)- μ (Scale 3) = 0 (reject) Ho: μ (Scale 1)- μ (Scale 4) = 0 (reject) Ho: μ (Scale 1)- μ (Scale 5) = 0 (reject) Ho: μ (Scale 1)- μ (Scale 6) = 0 (reject) Ho: μ (Scale 2)- μ (Scale 3) = 0 (reject) Ho: μ (Scale 2)- μ (Scale 4) = 0 (don't reject) Ho: μ (Scale 2)- μ (Scale 5) = 0 (reject) Ho: μ (Scale 2)- μ (Scale 6) = 0 (reject) Ho: μ (Scale 3)- μ (Scale 4) = 0 (reject) Ho: μ (Scale 3)- μ (Scale 5) = 0 (reject) Ho: μ (Scale 3)- μ (Scale 6) = 0 (reject) Ho: μ (Scale 4)- μ (Scale 5) = 0 (reject) Ho: μ (Scale 4)- μ (Scale 6) = 0 (reject) Ho: μ (Scale 5)- μ (Scale 6) = 0 (reject)						Ho: μ (Scale 1)- μ (Scale 2) = 0 (reject) Ho: μ (Scale 1)- μ (Scale 3) = 0 (reject) Ho: μ (Scale 1)- μ (Scale 4) = 0 (reject) Ho: μ (Scale 1)- μ (Scale 5) = 0 (reject) Ho: μ (Scale 1)- μ (Scale 6) = 0 (reject) Ho: μ (Scale 2)- μ (Scale 3) = 0 (reject) Ho: μ (Scale 2)- μ (Scale 4) = 0 (reject) Ho: μ (Scale 2)- μ (Scale 5) = 0 (reject) Ho: μ (Scale 2)- μ (Scale 6) = 0 (reject) Ho: μ (Scale 3)- μ (Scale 4) = 0 (don't reject) Ho: μ (Scale 3)- μ (Scale 5) = 0 (reject) Ho: μ (Scale 3)- μ (Scale 6) = 0 (reject) Ho: μ (Scale 4)- μ (Scale 5) = 0 (reject) Ho: μ (Scale 4)- μ (Scale 6) = 0 (reject) Ho: μ (Scale 5)- μ (Scale 6) = 0 (don't reject)					

Table IX6 illustrates the expected risk effect value (mean), ordinal relationship and ratio relationship among six different sets of numerical scales. Since there is strong evidence for a difference in the expected risk effect values among different sets of numerical scales at α-level (0.05) and hence the ordinal and ratio relationships among different sets of numerical scales are very inconsistent. We further use "Two-Sample T-Test" to test if the expected risk effect values are the same between different factors within the same scales. We find out that the expected risk effect values are not significantly different between risk factors "unforeseen site conditions (USC)" and "political interference (PI)" at α-level (0.05) as Scale 1, Scale 2 and Scale 6 are applied, but they are significantly different as the rest of scales are used (Table IX6). These tests further confirm that the expected risk effect values, ordinal and ratio relationships among different sets of numerical scales are very inconsistent at α-level (0.05) as the "multivariate (bivariate)" approach with "multiple-observed data" are applied to measure risk. Since ordinal and ration relationships are sensitive to the numerical scales, the "MULTIVARIATE (BIVARIATE)" approach is UNRELIABLE in the use of regression if the data are based on "MULTIPLE-OBSERVED DATA (sample size /number of project experts = 37)".

4. Interpretation of results

We summarise the results of statistical analysis for "univariate vs. multivariate(bivariate)" approaches in Table IX7. When data are based on "single-observed data (sample size = 1)", the statistical analysis appears that the expected risk effect values, ordinal and ratio relationships are very sensitive to the numerical scales regardless of which approaches are used to measure risks. That is because the individual outcomes are easily subject to the numerical scales. Using different sets of numerical scales will change both ordinal and ratio relationships of risk factors. From the perspective of "single-observed data (sample size/number of project experts = 1)", both "univariate" and "multivariate (bivariate)" approaches are inappropriate in the use of regression.

When data are based on "multiple-observed data (sample size/number of project experts = 37)", the statistical analysis appears the data characteristics in terms of expected risk effect values (mean values), ordinal and ratio relationships among different sets of numerical scales remain consistent at α=0.05 significance (95% confidence level) if the "univariate" approach is used. On the other hand, when data (sample size /number of project experts = 37)", the statistical analysis appears the data characteristics in terms of expected risk effect values (mean values), ordinal and ratio relationships among different sets of numerical scales are inconsistent at α=0.05 significance (95% confidence level) if "multivariate (bivariate)" approach is used. Therefore, the "univariate" approach based on "multiple-observed data (sample size /number of project experts = 37)" is reliable and appropriate in the use of regression. On the contrast, "multivariate (bivariate)" approach based on "multiple-observed data" is unreliable in the use of regression.

Why can "univariate" approach with "multiple-observed data (sample size /number of project experts = 37)" remain consistency of risk relationships among different sets of numerical scales, but "multivariate (bivariate)" approach can not? There are two contributors to reduce the sensitivity of risk relationships to the numerical scale values:

Table IX6 Reliability of multivariate (bivariate) approach (multiple-observed data, sample size = 37)

Testing scales	Numerical scales	Expected risk effect values	Ordinal relationships	Ratio relationships
Scale 1	Impact: 1, 2, 3, 4, 5 Likelihood: 0.1, 0.3, 0.5, 0.7, 0.9	μ(FM) = 2.20	μ(FM) > μ(USC) = μ(PI) Ho: μ (USC)- μ (PI) = 0 (don't reject)	μ(FM) = 1.46 μ(USC)
		μ(USC) = 1.51		μ(USC) = 0.96 μ(PI)
		μ(PI) = 1.56		μ(PI) = 0.71 μ(FM)
Scale 2	Impact: 1, 3, 5, 7, 9 Likelihood: 0.1, 0.3, 0.5, 0.7, 0.9	μ(FM) = 3.86	μ(FM) > μ(USC) = μ(PI) Ho: μ (USC)- μ (PI) = 0 (don't reject)	μ(FM) = 1.93 μ(USC)
		μ(USC) = 2.00		μ(USC) = 0.76 μ(PI)
		μ(PI) = 2.64		μ(PI) = 0.68 μ(FM)
Scale 3	Impact: 1, 5, 9, 15, 25 Likelihood: 0.1, 0.3, 0.5, 0.7, 0.9	μ(FM) = 8.71	μ(FM) > μ(PI) > μ(USC)	μ(FM) = 2.46 μ(USC)
		μ(USC) = 3.54		μ(USC) = 0.60 μ(PI)
		μ(PI) = 5.86		μ(PI) = 0.67 μ(FM)
Scale 4	Impact: 1, 5, 9, 15, 25 Likelihood: 0.01, 0.1, 0.4, 0.6, 1	μ(FM) = 7.81	μ(FM) > μ(PI) > μ(USC)	μ(FM) = 3.11 μ(USC)
		μ(USC) = 2.51		μ(USC) = 0.55 μ(PI)
		μ(PI) = 4.54		μ(PI) = 0.58 μ(FM)
Scale 5	Impact: 0.0027, 0.0109, 0.0547, 0.3835, 0.5479 Likelihood: 0.0416, 0.0833, 0.2083, 0.2916, 0.3750	μ(FM) = 0.07	μ(FM) > μ(PI) > μ(USC)	μ(FM) = 7.40 μ(USC)
		μ(USC) = 0.01		μ(USC) = 0.25 μ(PI)
		μ(PI) = 0.04		μ(PI) = 0.55 μ(FM)
Scale 6	Impact: 0.0027, 0.0109, 0.0547, 0.3835, 0.5479 Likelihood: 0.0054, 0.0216, 0.1081, 0.3243, 0.5405	μ(FM) = 0.07	μ(FM) > μ(USC) = μ(PI) Ho: μ (USC)- μ (PI) = 0 (don't reject)	μ(FM) = 2.87 μ(USC)
		μ(USC) = 0.03		μ(USC) = 0.75 μ(PI)
		μ(PI) = 0.04		μ(PI) = 0.57 μ(FM)
Reliability	There is almost statistically significant difference in the expected risk effect values (mean values), ordinal and ratio relationships between different sets of numerical scales at 95% confidence level. We can draw a conclusion that the "MULTIVARIATE" APPROACH with adequate MULTIPLE-OBSERVED DAT is UNRELIABLE in the use of regression, since both ordinal and ratio relationships remain INCONSISTENT among different sets of numerical scales.			

Table IX7 Summary of "univariate" vs. "multivariate(bivariate)" approaches

Approaches	Univariate	Univariate	Multivariate (bivariate)	Multivariate (bivariate)
Sample size, N	N=1	N=37	N=1	N=37
Are the ordinal and ratio relationships of risk factors consistent among different sets of numerical scales?	No	Yes	No	No
Is it reliable and appropriate in the use of regression?	No	Yes	No	No

First, the "multiple-observed data (sample size /number of project experts = 37)" will greatly contribute to reduction of the sensitivity of risk ordinal and ratio relationships to the numerical scales. A whole of "multiple-observed data" may consist of individual outcomes that can take on a wide range of values from extremely small (the minimum is 1 in 1-25 point scale values) to extremely large (the maximum is 25 in 1-25 point scale values) which will have an effect on the mean value (expected risk effect value). However, this effect is reduced because the value is averaged with other values in the "multiple-observed data." The standard error of the mean σ_m is equal to the standard deviation in the population σ divided by the square root of the sample size n ($\sigma_m = \sigma/n^{1/2}$). As the sample size increases, the standard error of the mean decreases. Therefore, the mean values in the "multiple-observed data" are less variable than the individual values in the "single-observed data." The greater sample size (number of project experts) for "multiple-observed data" is used to measure risk effect, the less standard error of mean (the expected risk effect value) is produced to provide more possibility of remaining ordinal and ratio relationships of risk factors unchanged among different sets of numerical scales. The sample size used to measure risk effect in this PhD thesis research is 37. Apparently it is adequate to the use of regression in risk relationship modelling, because this statistical analysis illustrates that it helps to reduce sensitivity of risk relationships to the numerical scales when using whatever the “univariate” or “multivariate (bivariate)” approach.

Second, “single and normalised numerical scale values” will greatly contribute to reduction of the sensitivity of risk ordinal and ratio relationships to numerical scales. That is because “single and normalised numerical scale values” will produce less data variation arisen from numerical scale values. This implies that there is less amount of dispersion of risk effect rating values away from a central point in a data set and hence mean values (expected risk effect values) are less variable to reduce sensitivity of risk relationships to the numerical scales. The “univariate” approach proposed in this PhD thesis employs a risk matrix for the conversion of two scale values (impact and likelihood values) into “single and normalised numerical scale values.” They are standardised to 1-25 point scale values which continuously and symmetrically spread from the minimum extreme category (VL, VL; level 1) through the middle category (M, M; level 13) to the maximum extreme category (VH, VH; level 25) (p. 222 in the submitted thesis). This format of numerical scale makes consistency of the expected risk effect values among different sets of numerical scales by reducing amount of dispersion of risk effect rating values away from mean values. It ensures there is less data variation to make risk relationships insensitive to the measurement scales. Thus, this statistical analysis has illustrated that the data based on “single and normalised numerical scale values” is reliable in the use of regression. On the other hand, this statistical analysis has illustrated that the mean values in the data sets based on “a two-dimensional independent set of values for probability and impact” are more variable than “single and normalised numerical scale values.” That is the result of compounding data variation respectively arisen from each of the two dimensional scales (“Impact” and “Likelihood” scale values) to become a greater amount of dispersion of risk effect values away from mean in a data set. The more dimensional scales are used to represent risk effect, the more data variations will cause more variable in the expected risk effect values. This explain why both ordinal and ratio relationships among different sets of numerical scales are still inconsistent in “multivariate (bivariate) approach” even if the numerical scales (Scale 5 and Scale 6) have been normalised to reduce data variation. Thus, the data based on “a two-dimensional independent set of values for probability and impact” is not reliable in the use of regression.

The “multiple-observed data” collected by the proposed “univariate” approach has proved to be valid in the use of regression in this PhD research. A set of residual plots including a histogram of residuals, a normality plot of residuals, residuals versus fits, and residuals versus order were conducted to test whether the data can meet the assumptions of regression procedure. All of these plots showed that the data well meet the assumptions on residuals are normally distributed, residuals have constant variance, and residuals are independent. Moreover, the analysis of variance indicates the p-value for regression was close to 0. It appeared that both coefficients and regression relationship between predictors and response are statistically significant at $\alpha = 0.05$. That is the model can fit the data extremely well. The small p-value ensures that there is a strong evidence to support using “univariate” approach with “multiple-observation data in the use of regression. This has been addressed in Section 8.4 and Appendix IXG.

In addition to regression modelling, the proposed “univariat”e approach based on “multiple-observation data” has also proved to be valid in System Dynamics modelling in this PhD research. Eight variant validation tests with 23 measures of performance from variant views were implemented to examine the SD model in Chapter 8. These tests include boundary adequacy tests, structure assessment tests, dimensional consistency tests, parameter assessment tests, extreme condition analysis, integration error tests, behaviour reproduction tests, and sensitivity analysis. All of the test results indicated that the developed SD model using “univariate” approach based on “multiple-observed data (sample size /number of project experts = 37)” is capable of reproducing real-world data. This has been addressed in Chapter 8.

5. Conclusions

From the results of this statistical analysis, we can draw the following conclusions:

1. Both the “univariate” and “multivariate (bivariate)” approaches are inappropriate in the use of regression in the circumstance of “single-observed data (sample size/number of project experts = 1)”. That is because the individual outcomes are easily subject to the numerical scales. Using different sets of numerical scales will change both ordinal and ratio relationships of risk factors.
2. The “univariate” approach is not supported by any extensive literature and has potential technical limitations on converting two conceptually distinct dimensions (Impact and Probability) into one single measure, but the results of this statistical analysis support the data are reliable in the use of regression in some circumstances. First, the data from conversion and expert judgment are arbitrary and arguable, but they have face validity. Second, using ordinal data in parametric statistical procedures has drawn much debate in the literature. However, this has received wide range of acceptance. It is used not only in psychology and marketing researches but also in other areas. Many researches have noted that the ordinal data can be treated as interval data in parametric statistical procedures under certain conditions. The “univariate” approach can generally meet these conditions for the use of regression (Appendix IXG). Third, the rankings of the ordinal values in the risk matrix are sensitive to the numerical scales, but the results of this statistical analysis appear that this effect will be reduced as sample size (number of project expects) increases. As the sample size increases, the standard error of the mean decreases and hence the data characteristics in terms of expected risk effect values (mean values), ordinal and ratio relationships among different sets of numerical scales remain consistent. Therefore, the “univariate” approach is reliable in the

use of regression in the circumstance of “multiple-observed data (sample size / number of project expert = 37 in this PhD thesis research)”.

3. The results of this statistical analysis have shown that the data characteristics in terms of expected risk effect values (mean values), ordinal and ratio relationships among different sets of numerical scales don’t come up with consistent results at $\alpha=0.05$ significance (95% confidence level) in the circumstance of “multiple-observed data (sample size / number of project expert = 37).” Because of the technical problem that impact and probability are not commensurate dimensions, the compounding data variation respectively arisen from each of the “Impact” and “Likelihood” scale values will become a greater data variation which have a great effect on mean values. As the sample size (number of project experts) increases, this doesn’t greatly contribute to reduction of the sensitivity of risk ordinal and ratio relationships to numerical scales. In addition, most of the literature simply used the two-dimensional scales (impact and probability) for prioritising or categorising the importance of risk factors, rather than for the use of regression. Therefore, the “multivariate (bivariate)” approach is not reliable and not recommended in the use of regression.
4. Due to some potential technical limitations in the proposed “univariate” approach, the System Dynamics (SD) model itself may well be based on some slightly suspect data, and so the conclusions this thesis research has drawn may not be 100% reliable. Since the SD model testing results (Chapter 8) are generally acceptable, the problems of the proposed “univariate” approach do not detract from the basic structural validity of the SD model or affect the fundaments of the methodology that are proposing in the rest of the thesis. This thesis research suggests that future researchers look into the numerical-scale problems concerning risk measurement and may attempt to solve problems for the legitimate use of ordinal data in parametric statistical procedures.

Appendix IXA Outcomes of "univariate" approach with "single-observed data (sample size = 1)"

Original scale: (Originally proposed in this PhD thesis, p.230)

Numerical scales	Impact	ranking					
1000	**VH**	17	19	22	24	25	
700	**H**	15	18	20	21	23	
100	**M**	9	12	13	14	16	
20	**L**	3	6	9	10	11	
5	**VL**	1	2	4	5	7	
		VL	**L**	**M**	**H**	**VH**	**Likelihood**
		1	2	5	7	9	Numerical scales

Scale 1: (Adopting a simple linear scale for likelihood)

Numerical scales	Impact	ranking					
1000	**VH**	17	19	22	24	25	
700	**H**	16	18	20	21	23	
100	**M**	11	12	13	14	15	
20	**L**	5	7	8	9	11	
5	**VL**	1	2	3	5	6	
		VL	**L**	**M**	**H**	**VH**	**Likelihood**
		1	2	3	4	5	Numerical scales

Scale 2: (Retaining the likelihood scale but adopting a different scale for impact)

Numerical scales	Impact	ranking					
500	**VH**	14	19	22	24	25	
300	**H**	13	16	20	21	23	
100	**M**	8	12	15	17	18	
20	**L**	3	6	9	10	11	
5	**VL**	1	2	4	5	7	
		VL	**L**	**M**	**H**	**VH**	**Likelihood**
		1	2	5	7	9	Numerical scales

Scale 3: (Exchanging the impact and likelihood numerical scales)

Numerical scales	Impact	ranking					
9	**VH**	7	11	18	23	25	
7	**H**	5	10	17	21	24	
5	**M**	4	9	15	20	22	
2	**L**	2	6	12	16	19	
1	**VL**	1	3	8	13	14	
		VL	**L**	**M**	**H**	**VH**	**Likelihood**
		5	20	100	300	500	Numerical scales

Appendix IXB Outcomes of "univariate" approach with "multiple-observed data (sample size = 37)"

Numerical Scales	Original	Scale 1	Scale 2	Scale 3	Original	Scale 1	Scale 2	Scale 3	Original	Scale 1	Scale 2	Scale 3
Observation No (Sample Size = 37)	Force Majeure	Force Majeure	Force Majeure	Force Majeure	unforeseen site conditions	unforeseen site conditions	unforeseen site conditions	unforeseen site conditions	political interference	political interference	political interference	political interference
1	21	21	21	21	6	7	6	6	5	5	5	13
2	14	14	17	20	12	12	12	9	20	20	20	17
3	19	19	19	11	7	6	7	14	12	12	12	9
4	20	20	20	17	14	14	17	20	17	15	18	22
5	21	21	21	21	12	12	12	9	21	21	21	21
6	22	22	22	18	13	13	15	15	15	16	13	5
7	19	19	19	11	18	18	16	10	22	22	22	18
8	22	22	22	18	11	11	11	19	19	19	19	11
9	24	24	24	23	12	12	12	9	13	13	15	15
10	17	15	18	22	17	15	18	22	16	17	14	7
11	18	18	16	10	14	14	17	20	8	8	9	12
12	21	21	21	21	14	14	17	20	11	11	11	19
13	17	15	18	22	14	14	17	20	18	18	16	10
14	19	19	19	11	12	12	12	9	22	22	22	18
15	23	23	23	24	11	11	11	19	23	23	23	24
16	16	17	14	7	15	16	13	5	20	20	20	17
17	24	24	24	23	13	13	15	15	10	9	10	16
18	16	17	14	7	13	13	15	15	10	9	10	16
19	23	23	23	24	8	8	9	12	18	18	16	10
20	11	11	11	19	15	16	13	5	20	20	20	17
21	13	13	15	15	16	17	14	7	6	7	6	6
22	20	20	20	20	15	16	13	5	9	11	8	4
23	25	25	25	25	11	11	11	19	8	8	9	12
24	20	20	20	17	19	19	19	11	19	19	19	11
25	23	23	23	24	12	12	12	9	15	16	13	5
26	13	13	15	15	4	3	4	8	14	14	17	20
27	20	20	20	17	13	13	15	15	17	15	18	22
28	16	15	13	7	11	11	11	19	14	14	17	20
29	14	14	17	20	10	9	10	16	2	2	2	3
30	22	22	22	18	8	8	9	12	12	12	12	9
31	11	11	8	19	10	9	10	16	23	23	23	24
32	24	24	24	23	10	9	10	16	13	13	15	15
33	3	5	3	2	9	11	8	4	11	11	11	19
34	18	18	16	10	10	9	10	16	25	25	25	25
35	24	24	24	23	9	11	8	4	15	16	13	5
36	15	16	13	5	13	13	15	15	16	17	14	7
37	8	8	9	12	9	11	8	4	17	15	18	22
Mean	**18.23**	**18.27**	**18.19**	**16.81**	**11.97**	**11.97**	**12.22**	**12.68**	**15.09**	**15.03**	**15.03**	**14.22**
SD	**5.04**	**4.83**	**5.07**	**6.23**	**3.13**	**3.35**	**3.58**	**5.56**	**5.57**	**5.47**	**5.50**	**6.43**

Appendix IXC "Two-Sample T-Test" for "univariate" approach with "multiple-observed data (sample size = 37)"

"Two-Sample T-Test" for risk factor "Force Majeure (FM)" between Original, Scale 1, Scale 2 and Scale 3	
Two-sample T for Original vs Scale 1 N Mean StDev SE Mean Original 37 18.23 5.04 0.83 Scale 1 37 18.27 4.83 0.79 Difference = mu (Original) - mu (Scale 1) Estimate for difference: -0.04 95% CI for difference: (-2.33, 2.25) T-Test of difference = 0 (vs not =): T-Value = -0.04 P-Value = 0.970 DF = 72 Both use Pooled StDev = 4.9393	Two-sample T for Original vs Scale 2 N Mean StDev SE Mean Original 37 18.23 5.04 0.83 Scale 2 37 18.27 4.83 0.79 Difference = mu (Original) - mu (Scale 2) Estimate for difference: -0.04 95% CI for difference: (-2.33, 2.25) T-Test of difference = 0 (vs not =): T-Value = -0.04 P-Value = 0.970 DF = 72 Both use Pooled StDev = 4.9393
Two-sample T for Original vs Scale 3 N Mean StDev SE Mean Original 37 18.23 5.04 0.83 Scale 3 37 16.81 6.23 1.0 Difference = mu (Original) - mu (Scale 3) Estimate for difference: 1.42 95% CI for difference: (-1.21, 4.04) T-Test of difference = 0 (vs not =): T-Value = 1.07 P-Value = 0.286 DF = 72 Both use Pooled StDev = 5.6678	Two-sample T for Scale 1 vs Scale 2 N Mean StDev SE Mean Scale 1 37 18.27 4.83 0.79 Scale 2 37 18.27 4.83 0.79 Difference = mu (Scale 1) - mu (Scale 2) Estimate for difference: 0.00 95% CI for difference: (-2.24, 2.24) T-Test of difference = 0 (vs not =): T-Value = 0.00 P-Value = 1.000 DF = 72 Both use Pooled StDev = 4.8342
Two-sample T for Scale 1 vs Scale 3 N Mean StDev SE Mean Scale 1 37 18.27 4.83 0.79 Scale 3 37 16.81 6.23 1.0 Difference = mu (Scale 1) - mu (Scale 3) Estimate for difference: 1.46 95% CI for difference: (-1.13, 4.04) T-Test of difference = 0 (vs not =): T-Value = 1.13 P-Value = 0.264 DF = 72 Both use Pooled StDev = 5.5765	Two-sample T for Scale 2 vs Scale 3 N Mean StDev SE Mean Scale 2 37 18.27 4.83 0.79 Scale 3 37 16.81 6.23 1.0 Difference = mu (Scale 2) - mu (Scale 3) Estimate for difference: 1.46 95% CI for difference: (-1.13, 4.04) T-Test of difference = 0 (vs not =): T-Value = 1.13 P-Value = 0.264 DF = 72 Both use Pooled StDev = 5.5765

"Two-Sample T-Test" for risk factor "unforeseen site conditions (USC)" between Original, Scale 1, Scale 2 and Scale 3	
Two-sample T for Original vs Scale 1 N Mean StDev SE Mean Original 37 11.97 3.13 0.51 Scale 1 37 11.97 3.35 0.55 Difference = mu (Original) - mu (Scale 1) Estimate for difference: -0.002 95% CI for difference: (-1.506, 1.502) T-Test of difference = 0 (vs not =): T-Value = -0.00 P-Value = 0.998 DF = 72 Both use Pooled StDev = 3.2444	Two-sample T for Original vs Scale 2 N Mean StDev SE Mean Original 37 11.97 3.13 0.51 Scale 2 37 12.22 3.58 0.59 Difference = mu (Original) - mu (Scale 2) Estimate for difference: -0.245 95% CI for difference: (-1.805, 1.314) T-Test of difference = 0 (vs not =): T-Value = -0.31 P-Value = 0.755 DF = 72 Both use Pooled StDev = 3.3648
Two-sample T for Original vs Scale 3 N Mean StDev SE Mean Original 37 11.97 3.13 0.51 Scale 3 37 12.68 5.56 0.91 Difference = mu (Original) - mu (Scale 3) Estimate for difference: -0.70 95% CI for difference: (-2.80, 1.39) T-Test of difference = 0 (vs not =): T-Value = -0.67 P-Value = 0.504 DF = 72 Both use Pooled StDev = 4.5139	Two-sample T for Scale 1 vs Scale 2 N Mean StDev SE Mean Scale 1 37 11.97 3.35 0.55 Scale 2 37 12.22 3.58 0.59 Difference = mu (Scale 1) - mu (Scale 2) Estimate for difference: -0.243 95% CI for difference: (-1.852, 1.365) T-Test of difference = 0 (vs not =): T-Value = -0.30 P-Value = 0.764 DF = 72 Both use Pooled StDev = 3.4706
Two-sample T for Scale 1 vs Scale 3 N Mean StDev SE Mean Scale 1 37 11.97 3.35 0.55 Scale 3 37 12.68 5.56 0.91 Difference = mu (Scale 1) - mu (Scale 3) Estimate for difference: -0.70 95% CI for difference: (-2.83, 1.43) T-Test of difference = 0 (vs not =): T-Value = -0.66 P-Value = 0.513 DF = 72 Both use Pooled StDev = 4.5933	Two-sample T for Scale 2 vs Scale 3 N Mean StDev SE Mean Scale 2 37 12.22 3.58 0.59 Scale 3 37 12.68 5.56 0.91 Difference = mu (Scale 2) - mu (Scale 3) Estimate for difference: -0.46 95% CI for difference: (-2.63, 1.71) T-Test of difference = 0 (vs not =): T-Value = -0.42 P-Value = 0.674 DF = 72 Both use Pooled StDev = 4.6791

"Two-Sample T-Test" for risk factor "political interference (PI)" between Original, Scale 1, Scale 2 and Scale 3	
Two-sample T for Original vs Scale 1 N Mean StDev SE Mean Original 37 15.09 5.57 0.91 Scale 1 37 15.03 5.47 0.90 Difference = mu (Original) - mu (Scale 1) Estimate for difference: 0.06 95% CI for difference: (-2.50, 2.62) T-Test of difference = 0 (vs not =): T-Value = 0.05 P-Value = 0.963 DF = 72 Both use Pooled StDev = 5.5177	Two-sample T for Original vs Scale 2 N Mean StDev SE Mean Original 37 15.09 5.57 0.91 Scale 2 37 15.03 5.50 0.91 Difference = mu (Original) - mu (Scale 2) Estimate for difference: 0.06 95% CI for difference: (-2.51, 2.63) T-Test of difference = 0 (vs not =): T-Value = 0.05 P-Value = 0.963 DF = 72 Both use Pooled StDev = 5.5353
Two-sample T for Original vs Scale 3 N Mean StDev SE Mean Original 37 15.09 5.57 0.91 Scale 3 37 14.22 6.43 1.1 Difference = mu (Original) - mu (Scale 3) Estimate for difference: 0.87 95% CI for difference: (-1.92, 3.66) T-Test of difference = 0 (vs not =): T-Value = 0.62 P-Value = 0.535 DF = 72 Both use Pooled StDev = 6.0108	Two-sample T for Scale 1 vs Scale 2 N Mean StDev SE Mean Scale 1 37 15.03 5.47 0.90 Scale 2 37 15.03 5.50 0.91 Difference = mu (Scale 1) - mu (Scale 2) Estimate for difference: 0.00 95% CI for difference: (-2.54, 2.54) T-Test of difference = 0 (vs not =): T-Value = 0.00 P-Value = 1.000 DF = 72 Both use Pooled StDev = 5.4873
Two-sample T for Scale 1 vs Scale 3 N Mean StDev SE Mean Scale 1 37 15.03 5.47 0.90 Scale 3 37 14.22 6.43 1.1 Difference = mu (Scale 1) - mu (Scale 3) Estimate for difference: 0.81 95% CI for difference: (-1.95, 3.58) T-Test of difference = 0 (vs not =): T-Value = 0.58 P-Value = 0.561 DF = 72 Both use Pooled StDev = 5.9666	Two-sample T for Scale 2 vs Scale 3 N Mean StDev SE Mean Scale 2 37 15.03 5.50 0.91 Scale 3 37 14.22 6.43 1.1 Difference = mu (Scale 2) - mu (Scale 3) Estimate for difference: 0.81 95% CI for difference: (-1.96, 3.58) T-Test of difference = 0 (vs not =): T-Value = 0.58 P-Value = 0.562 DF = 72 Both use Pooled StDev = 5.9829

Appendix IXD Outcomes of “multivariate (bivariate)” approach with “multiple-observed data (sample size = 37)”

Scale 1: (linear)

Numerical scales	Impact	ranking					
5	**VH**	0.5	1.5	2.5	3.5	4.5	
4	**H**	0.4	1.2	2	2.8	3.6	
3	**M**	0.3	0.9	1.5	2.1	2.7	
2	**L**	0.2	0.6	1	1.4	1.8	
1	**VL**	0.1	0.3	0.5	0.7	0.9	
		VL	**L**	**M**	**H**	**VH**	**Likelihood**
		0.1	0.2	0.3	0.4	0.5	Numerical scales

Scale 2: (linear)

Numerical scales	Impact	ranking					
9	**VH**	0.9	2.7	4.5	6.3	8.1	
7	**H**	0.7	2.1	3.5	4.9	6.3	
5	**M**	0.5	1.5	2.5	3.5	4.5	
3	**L**	0.3	0.9	1.5	2.1	2.7	
1	**VL**	0.1	0.3	0.5	0.7	0.9	
		VL	**L**	**M**	**H**	VH	**Likelihood**
		0.1	0.3	0.5	0.7	0.9	Numerical scales

Scale 3: (non-linear)

Numerical scales	Impact	ranking					
25	**VH**	2.5	7.5	12.5	17.5	22.5	
15	**H**	1.5	4.5	7.5	10.5	13.5	
9	**M**	0.9	2.7	4.5	6.3	8.1	
5	**L**	0.5	1.5	2.5	3.5	4.5	
1	**VL**	0.1	0.3	0.5	0.7	0.9	
		VL	L	M	H	VH	**Likelihood**
		0.1	0.3	0.5	0.7	0.9	Numerical scales

Scale 4: (non-linear)

Numerical scales	Impact	ranking					
25	**VH**	0.25	2.5	10	15	25	
15	**H**	0.15	1.5	6	9	15	
9	**M**	0.09	0.9	3.6	5.4	9	
5	**L**	0.05	0.5	2	3	5	
1	**VL**	0.01	0.1	0.4	0.6	1	
		VL	**L**	**M**	**H**	**VH**	**Likelihood**
		0.01	0.1	0.4	0.6	1	Numerical scales

Scale 5: (non-linear & normalised)

Normalised scales	Numerical scales	Impact	ranking					
0.547945	1000	**VH**	0.022831	0.045662	0.114155	0.159817	0.205479	
0.383562	700	**H**	0.015982	0.031963	0.079909	0.111872	0.143836	
0.054795	100	**M**	0.002283	0.004566	0.011416	0.015982	0.020548	
0.010959	20	**L**	0.000457	0.000913	0.002283	0.003196	0.00411	
0.00274	5	**VL**	0.000114	0.000228	0.000571	0.000799	0.001027	
			VL	**L**	**M**	**H**	**VH**	**Likelihood**
			1	2	5	7	9	Numerical scales
			0.041667	0.083333	0.208333	0.291667	0.375	Normalised scales

Scale 6: (non-linear & normalised)

Normalised scales	Numerical scales	Impact	ranking					
0.540541	500	**VH**	0.022523	0.045045	0.112613	0.157658	0.202703	
0.324324	300	**H**	0.013514	0.027027	0.067568	0.094595	0.121622	
0.108108	100	**M**	0.004505	0.009009	0.022523	0.031532	0.040541	
0.021622	20	**L**	0.000901	0.001802	0.004505	0.006306	0.008108	
0.005405	5	**VL**	0.000225	0.00045	0.001126	0.001577	0.002027	
			VL	**L**	**M**	**H**	**VH**	**Likelihood**
			1	2	5	7	9	Numerical scales
			0.041667	0.083333	0.208333	0.291667	0.375	Normalised scales

Appendix IXE Outcomes of “multivariate” approach with “multiple-observed data (sample size = 37)”

Numerical Scales	**Scale 1**	**Scale 2**	**Scale 3**	**Scale 4**	**Scale 5**	**Scale 6**
Observation No (Sample Size = 37)	Force Majeure	Force Majeure	Force Majeure	Force Majeure	Force Majeure	Force Majeure
1	2.80	4.90	10.50	9.00	0.112	0.095
2	2.10	3.50	6.30	5.40	0.016	0.032
3	1.50	2.70	7.50	2.50	0.046	0.045
4	2.00	3.50	7.50	6.00	0.080	0.095
5	2.80	4.90	10.50	9.00	0.112	0.095
6	2.50	4.50	12.50	10.00	0.114	0.113
7	1.50	2.70	7.50	2.50	0.046	0.045
8	2.50	4.50	12.50	10.00	0.114	0.113
9	3.50	6.30	17.50	15.00	0.160	0.158
10	2.70	4.50	8.10	9.00	0.021	0.041
11	1.20	2.10	4.50	1.50	0.032	0.027
12	2.50	4.50	10.50	10.00	0.112	0.095
13	2.70	4.50	8.10	9.00	0.021	0.041
14	1.50	2.70	7.50	2.50	0.046	0.045
15	3.60	6.30	13.50	15.00	0.144	0.122
16	0.50	0.90	2.50	9.00	0.023	0.023
17	3.50	6.30	17.50	15.00	0.160	0.158
18	2.70	4.50	2.50	9.00	0.023	0.023
19	3.60	6.30	13.50	15.00	0.144	0.122
20	1.80	2.70	4.50	5.00	0.004	0.008
21	1.50	2.50	4.50	3.60	0.011	0.023
22	2.00	3.50	7.50	6.00	0.080	0.068
23	4.50	8.10	22.50	25.00	0.205	0.203
24	2.00	3.50	7.50	6.00	0.080	0.068
25	3.60	6.30	13.50	15.00	0.144	0.122
26	1.50	2.50	4.50	3.60	0.011	0.023
27	2.00	4.90	7.50	6.00	0.080	0.068
28	0.50	0.70	2.50	0.25	0.023	0.023
29	2.10	3.50	6.30	5.40	0.016	0.032
30	2.50	4.50	12.50	10.00	0.114	0.113
31	1.80	2.70	4.50	5.00	0.004	0.008
32	3.50	6.30	17.50	15.00	0.160	0.158
33	0.20	0.30	0.50	0.05	0.000	0.009
34	1.20	2.10	4.50	1.50	0.032	0.027
35	3.50	6.30	17.50	15.00	0.160	0.158
36	0.40	0.70	1.50	0.15	0.016	0.014
37	1.00	1.50	2.50	2.00	0.002	0.005
Mean	**2.20**	**3.86**	**8.71**	**7.81**	**0.072**	**0.071**
SD	**1.04**	**1.90**	**5.33**	**5.62**	**0.060**	**0.054**

Numerical Scales	Scale 1	Scale 2	Scale 3	Scale 4	Scale 5	Scale 6
Observation No (Sample Size = 37)	unforeseen site conditions	unforeseen site conditions	unforeseen site conditions	unforeseen site conditions	unforeseen site conditions	unforeseen site conditions
1	0.6	0.9	1.5	0.5	0.001	0.002
2	0.9	1.5	2.7	0.9	0.005	0.009
3	0.9	0.9	0.9	1.0	0.001	0.002
4	2.1	3.5	6.3	5.4	0.016	0.032
5	0.9	1.5	2.7	0.9	0.005	0.009
6	1.5	2.5	4.5	3.6	0.011	0.023
7	1.2	2.1	4.5	1.5	0.032	0.027
8	1.8	2.7	4.5	5.0	0.004	0.008
9	0.9	1.5	2.7	0.9	0.005	0.009
10	2.7	4.5	8.1	9.0	0.021	0.041
11	2.1	3.5	6.3	5.4	0.016	0.032
12	2.1	3.5	6.3	5.4	0.016	0.032
13	2.1	3.5	6.3	5.4	0.016	0.032
14	0.9	1.5	2.7	0.9	0.005	0.009
15	1.8	2.7	4.5	0.9	0.005	0.008
16	0.4	0.7	1.5	0.1	0.021	0.134
17	1.5	2.5	4.5	3.6	0.011	0.023
18	1.5	2.5	4.5	3.6	0.011	0.023
19	1.0	1.5	2.5	2.0	0.002	0.005
20	0.4	0.7	1.5	0.1	0.016	0.134
21	0.5	0.9	2.5	0.3	0.023	0.023
22	0.4	0.7	1.5	0.1	0.016	0.134
23	11.0	2.7	4.5	5.0	0.004	0.008
24	1.5	2.7	7.5	2.5	0.046	0.045
25	0.9	1.5	2.7	0.9	0.005	0.009
26	0.7	0.7	0.5	0.6	0.001	0.001
27	1.5	2.5	4.5	3.6	0.011	0.023
28	1.8	2.7	4.5	3.0	0.004	0.008
29	1.4	2.1	3.5	3.0	0.003	0.006
30	1.0	1.5	2.5	2.0	0.002	0.005
31	1.4	2.1	3.5	3.0	0.003	0.006
32	1.4	2.1	3.5	3.0	0.003	0.006
33	1.4	2.1	0.9	3.0	0.002	0.005
34	1.4	2.1	3.5	3.0	0.003	0.006
35	0.3	0.5	0.9	0.1	0.002	0.005
36	1.5	2.5	4.5	3.6	0.011	0.023
37	0.3	0.5	0.9	0.1	0.002	0.005
Mean	**1.51**	**2.00**	**3.54**	**2.51**	**0.010**	**0.025**
SD	**1.72**	**1.00**	**1.95**	**2.08**	**0.010**	**0.035**

Numerical Scales	Scale 1	Scale 2	Scale 3	Scale 4	Scale 5	Scale 6
Observation No (Sample Size = 37)	political interference	political interference	political interference	political interference	political interference	political interference
1	0.70	0.70	0.70	0.60	0.001	0.002
2	2.00	3.50	7.50	6.00	0.080	0.068
3	0.90	1.50	2.70	0.90	0.004	0.009
4	1.20	2.10	8.10	1.50	0.020	0.041
5	2.80	4.90	10.50	9.00	0.111	0.095
6	0.40	0.70	1.50	0.15	0.016	0.014
7	2.50	4.50	12.50	10.00	0.114	0.113
8	1.50	2.70	7.50	2.50	0.050	0.045
9	1.50	2.50	4.50	3.60	0.011	0.023
10	0.50	0.90	2.50	0.25	0.022	0.023
11	1.00	1.50	2.50	2.00	0.002	0.005
12	1.80	2.70	4.50	5.00	0.004	0.008
13	1.20	2.10	4.50	1.50	0.032	0.027
14	2.50	4.50	12.50	10.00	0.114	0.113
15	3.60	6.30	13.50	15.00	0.144	0.122
16	2.00	3.50	7.50	6.00	0.080	0.068
17	1.40	2.10	3.50	3.00	0.003	0.006
18	1.40	2.10	3.50	3.00	0.003	0.006
19	1.20	2.10	4.50	1.50	0.040	0.027
20	2.00	3.50	7.50	6.00	0.080	0.068
21	0.60	0.90	1.50	0.50	0.001	0.002
22	0.30	0.50	0.90	0.09	0.002	0.005
23	1.00	1.50	2.50	2.00	0.002	0.005
24	1.50	2.70	7.50	2.50	0.046	0.045
25	0.40	0.70	1.50	0.15	0.016	0.014
26	2.10	3.50	6.30	5.40	0.016	0.032
27	2.70	4.50	8.10	9.00	0.021	0.041
28	0.30	0.30	6.30	0.10	0.016	0.032
29	0.30	0.30	0.30	0.10	0.000	0.000
30	0.90	1.50	2.70	0.90	0.005	0.009
31	3.60	6.30	13.50	15.00	0.144	0.122
32	2.10	3.50	4.50	5.40	0.011	0.023
33	1.80	2.70	4.50	5.00	0.004	0.008
34	4.50	8.10	22.50	25.00	0.205	0.203
35	0.40	0.70	1.50	0.15	0.016	0.014
36	0.50	0.90	2.50	0.25	0.023	0.023
37	2.70	4.50	8.10	9.00	0.021	0.041
Mean	**1.56**	**2.64**	**5.86**	**4.54**	**0.040**	**0.041**
SD	**1.04**	**1.87**	**4.65**	**5.35**	**0.051**	**0.045**

Appendix IXF "Two-Sample T-Test" for "multivariate" approach with "multiple-observed data (sample size = 37)"

"Two-Sample T-Test" for risk factor "Force Majeure (FM)" between Scale 1-6	
Two-sample T for Scale 1 vs Scale 2 N Mean StDev SE Mean Scale 1 37 2.20 1.04 0.17 Scale 2 37 3.86 1.90 0.31 Difference = mu (Scale 1) - mu (Scale 2) Estimate for difference: -1.659 95% CI for difference: (-2.370, -0.949) T-Test of difference = 0 (vs not =): T-Value = -4.66 P-Value = 0.000 DF = 72 Both use Pooled StDev = 1.5329	Two-sample T for Scale 1 vs Scale 3 N Mean StDev SE Mean Scale 1 37 2.20 1.04 0.17 Scale 3 37 8.71 5.33 0.88 Difference = mu (Scale 1) - mu (Scale 3) Estimate for difference: -6.514 95% CI for difference: (-8.294, -4.733) T-Test of difference = 0 (vs not =): T-Value = -7.29 P-Value = 0.000 DF = 72 Both use Pooled StDev = 3.8415
Two-sample T for Scale 1 vs Scale 4 N Mean StDev SE Mean Scale 1 37 2.20 1.04 0.17 Scale 4 37 7.81 5.62 0.92 Difference = mu (Scale 1) - mu (Scale 4) Estimate for difference: -5.612 95% CI for difference: (-7.484, -3.740) T-Test of difference = 0 (vs not =): T-Value = -5.98 P-Value = 0.000 DF = 72 Both use Pooled StDev = 4.0384	Two-sample T for Scale 1 vs Scale 5 N Mean StDev SE Mean Scale 1 37 2.20 1.04 0.17 Scale 5 37 0.0721 0.0597 0.0098 Difference = mu (Scale 1) - mu (Scale 5) Estimate for difference: 2.125 95% CI for difference: (1.783, 2.468) T-Test of difference = 0 (vs not =): T-Value = 12.37 P-Value = 0.000 DF = 72 Both use Pooled StDev = 0.7388
Two-sample T for Scale 1 vs Scale 6 N Mean StDev SE Mean Scale 1 37 2.20 1.04 0.17 Scale 6 37 0.0708 0.0539 0.0089 Difference = mu (Scale 1) - mu (Scale 6) Estimate for difference: 2.127 95% CI for difference: (1.784, 2.469) T-Test of difference = 0 (vs not =): T-Value = 12.38 P-Value = 0.000 DF = 72 Both use Pooled StDev = 0.7386	Two-sample T for Scale 2 vs Scale 3 N Mean StDev SE Mean Scale 2 37 3.86 1.90 0.31 Scale 3 37 8.71 5.33 0.88 Difference = mu (Scale 2) - mu (Scale 3) Estimate for difference: -4.854 95% CI for difference: (-6.709, -2.999) T-Test of difference = 0 (vs not =): T-Value = -5.22 P-Value = 0.000 DF = 72 Both use Pooled StDev = 4.0024
Two-sample T for Scale 2 vs Scale 4 N Mean StDev SE Mean Scale 2 37 3.86 1.90 0.31 Scale 4 37 7.81 5.62 0.92 Difference = mu (Scale 2) - mu (Scale 4) Estimate for difference: -3.953 95% CI for difference: (-5.895, -2.010) T-Test of difference = 0 (vs not =): T-Value = -4.06 P-Value = 0.000 DF = 72 Both use Pooled StDev = 4.1917	Two-sample T for Scale 2 vs Scale 5 N Mean StDev SE Mean Scale 2 37 3.86 1.90 0.31 Scale 5 37 0.0721 0.0597 0.0098 Difference = mu (Scale 2) - mu (Scale 5) Estimate for difference: 3.785 95% CI for difference: (3.162, 4.408) T-Test of difference = 0 (vs not =): T-Value = 12.11 P-Value = 0.000 DF = 72 Both use Pooled StDev = 1.3444
Two-sample T for Scale 2 vs Scale 6 N Mean StDev SE Mean Scale 2 37 3.86 1.90 0.31 Scale 6 37 0.0708 0.0539 0.0089 Difference = mu (Scale 2) - mu (Scale 6) Estimate for difference: 3.786 95% CI for difference: (3.163, 4.409) T-Test of difference = 0 (vs not =): T-Value = 12.11 P-Value = 0.000 DF = 72 Both use Pooled StDev = 1.3443	Two-sample T for Scale 3 vs Scale 4 N Mean StDev SE Mean Scale 3 37 8.71 5.33 0.88 Scale 4 37 7.81 5.62 0.92 Difference = mu (Scale 3) - mu (Scale 4) Estimate for difference: 0.90 95% CI for difference: (-1.64, 3.44) T-Test of difference = 0 (vs not =): T-Value = 0.71 P-Value = 0.481 DF = 72 Both use Pooled StDev = 5.4752
Two-sample T for Scale 3 vs Scale 5 N Mean StDev SE Mean Scale 3 37 8.71 5.33 0.88 Scale 5 37 0.0721 0.0597 0.0098 Difference = mu (Scale 3) - mu (Scale 5) Estimate for difference: 8.639 95% CI for difference: (6.891, 10.386) T-Test of difference = 0 (vs not =): T-Value = 9.86 P-Value = 0.000 DF = 72 Both use Pooled StDev = 3.7703	Two-sample T for Scale 3 vs Scale 6 N Mean StDev SE Mean Scale 3 37 8.71 5.33 0.88 Scale 6 37 0.0708 0.0539 0.0089 Difference = mu (Scale 3) - mu (Scale 6) Estimate for difference: 8.640 95% CI for difference: (6.893, 10.387) T-Test of difference = 0 (vs not =): T-Value = 9.86 P-Value = 0.000 DF = 72 Both use Pooled StDev = 3.7702
Two-sample T for Scale 4 vs Scale 5 N Mean StDev SE Mean Scale 4 37 7.81 5.62 0.92 Scale 5 37 0.0721 0.0597 0.0098 Difference = mu (Scale 4) - mu (Scale 5) Estimate for difference: 7.737 95% CI for difference: (5.897, 9.578) T-Test of difference = 0 (vs not =): T-Value = 8.38 P-Value = 0.000 DF = 72 Both use Pooled StDev = 3.9707	Two-sample T for Scale 4 vs Scale 6 N Mean StDev SE Mean Scale 4 37 7.81 5.62 0.92 Scale 6 37 0.0708 0.0539 0.0089 Difference = mu (Scale 4) - mu (Scale 6) Estimate for difference: 7.739 95% CI for difference: (5.898, 9.579) T-Test of difference = 0 (vs not =): T-Value = 8.38 P-Value = 0.000 DF = 72 Both use Pooled StDev = 3.9706

Two-sample T for Scale 5 vs Scale 6 N Mean StDev SE Mean Scale 5 37 0.0721 0.0597 0.0098 Scale 6 37 0.0708 0.0539 0.0089 Difference = mu (Scale 5) - mu (Scale 6) Estimate for difference: 0.0014 95% CI for difference: (-0.0250, 0.0277) T-Test of difference = 0 (vs not =): T-Value = 0.10 P-Value = 0.918 DF = 72 Both use Pooled StDev = 0.0569	

"Two-Sample T-Test" for risk factor "unforeseen site conditions (USC)" between Scale 1-6	
Two-sample T for Scale 1 vs Scale 2 N Mean StDev SE Mean Scale 1 37 1.51 1.72 0.28 Scale 2 37 2.003 0.995 0.16 Difference = mu (Scale 1) - mu (Scale 2) Estimate for difference: -0.496 95% CI for difference: (-1.146, 0.154) T-Test of difference = 0 (vs not =): T-Value = -1.52 P-Value = 0.133 DF = 72 Both use Pooled StDev = 1.4027	Two-sample T for Scale 1 vs Scale 3 N Mean StDev SE Mean Scale 1 37 1.51 1.72 0.28 Scale 3 37 3.54 1.95 0.32 Difference = mu (Scale 1) - mu (Scale 3) Estimate for difference: -2.031 95% CI for difference: (-2.882, -1.180) T-Test of difference = 0 (vs not =): T-Value = -4.76 P-Value = 0.000 DF = 72 Both use Pooled StDev = 1.8360
Two-sample T for Scale 1 vs Scale 4 N Mean StDev SE Mean Scale 1 37 1.51 1.72 0.28 Scale 4 37 2.51 2.08 0.34 Difference = mu (Scale 1) - mu (Scale 4) Estimate for difference: -1.006 95% CI for difference: (-1.890, -0.122) T-Test of difference = 0 (vs not =): T-Value = -2.27 P-Value = 0.026 DF = 72 Both use Pooled StDev = 1.9073	Two-sample T for Scale 1 vs Scale 5 N Mean StDev SE Mean Scale 1 37 1.51 1.72 0.28 Scale 5 37 0.00974 0.00977 0.0016 Difference = mu (Scale 1) - mu (Scale 5) Estimate for difference: 1.497 95% CI for difference: (0.934, 2.059) T-Test of difference = 0 (vs not =): T-Value = 5.31 P-Value = 0.000 DF = 72 Both use Pooled StDev = 1.2134
Two-sample T for Scale 1 vs Scale 6 N Mean StDev SE Mean Scale 1 37 1.51 1.72 0.28 Scale 6 37 0.0246 0.0350 0.0057 Difference = mu (Scale 1) - mu (Scale 6) Estimate for difference: 1.482 95% CI for difference: (0.919, 2.044) T-Test of difference = 0 (vs not =): T-Value = 5.25 P-Value = 0.000 DF = 72 Both use Pooled StDev = 1.2137	Two-sample T for Scale 2 vs Scale 3 N Mean StDev SE Mean Scale 2 37 2.003 0.995 0.16 Scale 3 37 3.54 1.95 0.32 Difference = mu (Scale 2) - mu (Scale 3) Estimate for difference: -1.535 95% CI for difference: (-2.252, -0.818) T-Test of difference = 0 (vs not =): T-Value = -4.27 P-Value = 0.000 DF = 72 Both use Pooled StDev = 1.5472
Two-sample T for Scale 2 vs Scale 4 N Mean StDev SE Mean Scale 2 37 2.003 0.995 0.16 Scale 4 37 2.51 2.08 0.34 Difference = mu (Scale 2) - mu (Scale 4) Estimate for difference: -0.510 95% CI for difference: (-1.266, 0.246) T-Test of difference = 0 (vs not =): T-Value = -1.35 P-Value = 0.183 DF = 72 Both use Pooled StDev = 1.6311	Two-sample T for Scale 2 vs Scale 5 N Mean StDev SE Mean Scale 2 37 2.003 0.995 0.16 Scale 5 37 0.00974 0.00977 0.0016 Difference = mu (Scale 2) - mu (Scale 5) Estimate for difference: 1.993 95% CI for difference: (1.667, 2.319) T-Test of difference = 0 (vs not =): T-Value = 12.18 P-Value = 0.000 DF = 72 Both use Pooled StDev = 0.7037
Two-sample T for Scale 2 vs Scale 6 N Mean StDev SE Mean Scale 2 37 2.003 0.995 0.16 Scale 6 37 0.0246 0.0350 0.0057 Difference = mu (Scale 2) - mu (Scale 6) Estimate for difference: 1.978 95% CI for difference: (1.652, 2.304) T-Test of difference = 0 (vs not =): T-Value = 12.08 P-Value = 0.000 DF = 72 Both use Pooled StDev = 0.7041	Two-sample T for Scale 3 vs Scale 4 N Mean StDev SE Mean Scale 3 37 3.54 1.95 0.32 Scale 4 37 2.51 2.08 0.34 Difference = mu (Scale 3) - mu (Scale 4) Estimate for difference: 1.025 95% CI for difference: (0.091, 1.959) T-Test of difference = 0 (vs not =): T-Value = 2.19 P-Value = 0.032 DF = 72 Both use Pooled StDev = 2.0159
Two-sample T for Scale 3 vs Scale 5 N Mean StDev SE Mean Scale 3 37 3.54 1.95 0.32 Scale 5 37 0.00974 0.00977 0.0016 Difference = mu (Scale 3) - mu (Scale 5) Estimate for difference: 3.528 95% CI for difference: (2.889, 4.167) T-Test of difference = 0 (vs not =): T-Value = 11.01 P-Value = 0.000 DF = 72 Both use Pooled StDev = 1.3780	Two-sample T for Scale 3 vs Scale 6 N Mean StDev SE Mean Scale 3 37 3.54 1.95 0.32 Scale 6 37 0.0246 0.0350 0.0057 Difference = mu (Scale 3) - mu (Scale 6) Estimate for difference: 3.513 95% CI for difference: (2.874, 4.152) T-Test of difference = 0 (vs not =): T-Value = 10.96 P-Value = 0.000 DF = 72 Both use Pooled StDev = 1.3782

Two-sample T for Scale 4 vs Scale 5 N Mean StDev SE Mean Scale 4 37 2.51 2.08 0.34 Scale 5 37 0.00974 0.00977 0.0016 Difference = mu (Scale 4) - mu (Scale 5) Estimate for difference: 2.503 95% CI for difference: (1.821, 3.185) T-Test of difference = 0 (vs not =): T-Value = 7.32 P-Value = 0.000 DF = 72 Both use Pooled StDev = 1.4715	Two-sample T for Scale 4 vs Scale 6 N Mean StDev SE Mean Scale 4 37 2.51 2.08 0.34 Scale 6 37 0.0246 0.0350 0.0057 Difference = mu (Scale 4) - mu (Scale 6) Estimate for difference: 2.488 95% CI for difference: (1.806, 3.170) T-Test of difference = 0 (vs not =): T-Value = 7.27 P-Value = 0.000 DF = 72 Both use Pooled StDev = 1.4717
Two-sample T for Scale 5 vs Scale 6 N Mean StDev SE Mean Scale 5 37 0.00974 0.00977 0.0016 Scale 6 37 0.0246 0.0350 0.0057 Difference = mu (Scale 5) - mu (Scale 6) Estimate for difference: -0.01491 95% CI for difference: (-0.02681, -0.00301) T-Test of difference = 0 (vs not =): T-Value = -2.50 P-Value = 0.015 DF = 72 Both use Pooled StDev = 0.0257	

"Two-Sample T-Test" for risk factor "political interference (PI)" between Scale 1-6	
Two-sample T for Scale 1 vs Scale 2 N Mean StDev SE Mean Scale 1 37 1.56 1.04 0.17 Scale 2 37 2.64 1.87 0.31 Difference = mu (Scale 1) - mu (Scale 2) Estimate for difference: -1.073 95% CI for difference: (-1.773, -0.373) T-Test of difference = 0 (vs not =): T-Value = -3.05 P-Value = 0.003 DF = 72 Both use Pooled StDev = 1.5111	Two-sample T for Scale 1 vs Scale 3 N Mean StDev SE Mean Scale 1 37 1.56 1.04 0.17 Scale 3 37 5.86 4.65 0.76 Difference = mu (Scale 1) - mu (Scale 3) Estimate for difference: -4.295 95% CI for difference: (-5.855, -2.734) T-Test of difference = 0 (vs not =): T-Value = -5.48 P-Value = 0.000 DF = 72 Both use Pooled StDev = 3.3677
Two-sample T for Scale 1 vs Scale 4 N Mean StDev SE Mean Scale 1 37 1.56 1.04 0.17 Scale 4 37 4.54 5.35 0.88 Difference = mu (Scale 1) - mu (Scale 4) Estimate for difference: -2.979 95% CI for difference: (-4.767, -1.192) T-Test of difference = 0 (vs not =): T-Value = -3.32 P-Value = 0.001 DF = 72 Both use Pooled StDev = 3.8561	Two-sample T for Scale 1 vs Scale 5 N Mean StDev SE Mean Scale 1 37 1.56 1.04 0.17 Scale 5 37 0.0400 0.0508 0.0084 Difference = mu (Scale 1) - mu (Scale 5) Estimate for difference: 1.522 95% CI for difference: (1.181, 1.863) T-Test of difference = 0 (vs not =): T-Value = 8.91 P-Value = 0.000 DF = 72 Both use Pooled StDev = 0.7350
Two-sample T for Scale 1 vs Scale 6 Two-sample T for Scale 1 vs Scale 6 N Mean StDev SE Mean Scale 1 37 1.56 1.04 0.17 Scale 6 37 0.0406 0.0454 0.0075 Difference = mu (Scale 1) - mu (Scale 6) Estimate for difference: 1.522 95% CI for difference: (1.181, 1.862) T-Test of difference = 0 (vs not =): T-Value = 8.91 P-Value = 0.000 DF = 72 Both use Pooled StDev = 0.7349	Two-sample T for Scale 2 vs Scale 3 N Mean StDev SE Mean Scale 2 37 2.64 1.87 0.31 Scale 3 37 5.86 4.65 0.76 Difference = mu (Scale 2) - mu (Scale 3) Estimate for difference: -3.222 95% CI for difference: (-4.863, -1.580) T-Test of difference = 0 (vs not =): T-Value = -3.91 P-Value = 0.000 DF = 72 Both use Pooled StDev = 3.5422
Two-sample T for Scale 2 vs Scale 4 N Mean StDev SE Mean Scale 2 37 2.64 1.87 0.31 Scale 4 37 4.54 5.35 0.88 Difference = mu (Scale 2) - mu (Scale 4) Estimate for difference: -1.906 95% CI for difference: (-3.765, -0.048) T-Test of difference = 0 (vs not =): T-Value = -2.05 P-Value = 0.044 DF = 72 Both use Pooled StDev = 4.0094	Two-sample T for Scale 2 vs Scale 5 N Mean StDev SE Mean Scale 2 37 2.64 1.87 0.31 Scale 5 37 0.0400 0.0508 0.0084 Difference = mu (Scale 2) - mu (Scale 5) Estimate for difference: 2.595 95% CI for difference: (1.983, 3.208) T-Test of difference = 0 (vs not =): T-Value = 8.45 P-Value = 0.000 DF = 72 Both use Pooled StDev = 1.3213
Two-sample T for Scale 2 vs Scale 6 N Mean StDev SE Mean Scale 2 37 2.64 1.87 0.31 Scale 6 37 0.0406 0.0454 0.0075 Difference = mu (Scale 2) - mu (Scale 6) Estimate for difference: 2.595 95% CI for difference: (1.982, 3.207) T-Test of difference = 0 (vs not =): T-Value = 8.45 P-Value = 0.000 DF = 72 Both use Pooled StDev = 1.3212	Two-sample T for Scale 3 vs Scale 4 N Mean StDev SE Mean Scale 3 37 5.86 4.65 0.76 Scale 4 37 4.54 5.35 0.88 Difference = mu (Scale 3) - mu (Scale 4) Estimate for difference: 1.32 95% CI for difference: (-1.01, 3.64) T-Test of difference = 0 (vs not =): T-Value = 1.13 P-Value = 0.263 DF = 72 Both use Pooled StDev = 5.0133

Two-sample T for Scale 3 vs Scale 5 N Mean StDev SE Mean Scale 3 37 5.86 4.65 0.76 Scale 5 37 0.0400 0.0508 0.0084 Difference = mu (Scale 3) - mu (Scale 5) Estimate for difference: 5.817 95% CI for difference: (4.293, 7.340) T-Test of difference = 0 (vs not =): T-Value = 7.61 P-Value = 0.000 DF = 72 Both use Pooled StDev = 3.2869	Two-sample T for Scale 3 vs Scale 6 N Mean StDev SE Mean Scale 3 37 5.86 4.65 0.76 Scale 6 37 0.0406 0.0454 0.0075 Difference = mu (Scale 3) - mu (Scale 6) Estimate for difference: 5.816 95% CI for difference: (4.293, 7.340) T-Test of difference = 0 (vs not =): T-Value = 7.61 P-Value = 0.000 DF = 72 Both use Pooled StDev = 3.2869
Two-sample T for Scale 4 vs Scale 5 N Mean StDev SE Mean Scale 4 37 4.54 5.35 0.88 Scale 5 37 0.0400 0.0508 0.0084 Difference = mu (Scale 4) - mu (Scale 5) Estimate for difference: 4.502 95% CI for difference: (2.747, 6.256) T-Test of difference = 0 (vs not =): T-Value = 5.11 P-Value = 0.000 DF = 72 Both use Pooled StDev = 3.7858	Two-sample T for Scale 4 vs Scale 6 N Mean StDev SE Mean Scale 4 37 4.54 5.35 0.88 Scale 6 37 0.0406 0.0454 0.0075 Difference = mu (Scale 4) - mu (Scale 6) Estimate for difference: 4.501 95% CI for difference: (2.746, 6.256) T-Test of difference = 0 (vs not =): T-Value = 5.11 P-Value = 0.000 DF = 72 Both use Pooled StDev = 3.7857
Two-sample T for Scale 5 vs Scale 6 N Mean StDev SE Mean Scale 5 37 0.0400 0.0508 0.0084 Scale 6 37 0.0406 0.0454 0.0075 Difference = mu (Scale 5) - mu (Scale 6) Estimate for difference: -0.0006 95% CI for difference: (-0.0229, 0.0217) T-Test of difference = 0 (vs not =): T-Value = -0.05 P-Value = 0.957 DF = 72 Both use Pooled StDev = 0.0482	

"Two-Sample T-Test" for Scale 1	
Two-sample T for FM vs USC N Mean StDev SE Mean FM 37 2.20 1.04 0.17 USC 37 1.51 1.72 0.28 Difference = mu (FM) - mu (USC) Estimate for difference: 0.691 95% CI for difference: (0.033, 1.349) T-Test of difference = 0 (vs not =): T-Value = 2.09 P-Value = 0.040 DF = 72 Both use Pooled StDev = 1.4200	Two-sample T for FM vs PI N Mean StDev SE Mean FM 37 2.20 1.04 0.17 PI 37 1.56 1.04 0.17 Difference = mu (FM) - mu (PI) Estimate for difference: 0.635 95% CI for difference: (0.153, 1.117) T-Test of difference = 0 (vs not =): T-Value = 2.63 P-Value = 0.011 DF = 72 Both use Pooled StDev = 1.0407
Two-sample T for USC vs PI N Mean StDev SE Mean USC 37 1.51 1.72 0.28 PI 37 1.56 1.04 0.17 Difference = mu (USC) - mu (PI) Estimate for difference: -0.056 95% CI for difference: (-0.713, 0.602) T-Test of difference = 0 (vs not =): T-Value = -0.17 P-Value = 0.867 DF = 72 Both use Pooled StDev = 1.4182	

"Two-Sample T-Test" for Scale 2	
Two-sample T for FM vs USC N Mean StDev SE Mean FM 37 3.86 1.90 0.31 USC 37 2.003 0.995 0.16 Difference = mu (FM) - mu (USC) Estimate for difference: 1.854 95% CI for difference: (1.151, 2.557) T-Test of difference = 0 (vs not =): T-Value = 5.26 P-Value = 0.000 DF = 72 Both use Pooled StDev = 1.5169	Two-sample T for FM vs PI N Mean StDev SE Mean FM 37 3.86 1.90 0.31 PI 37 2.64 1.87 0.31 Difference = mu (FM) - mu (PI) Estimate for difference: 1.222 95% CI for difference: (0.348, 2.095) T-Test of difference = 0 (vs not =): T-Value = 2.79 P-Value = 0.007 DF = 72 Both use Pooled StDev = 1.8842
Two-sample T for USC vs PI N Mean StDev SE Mean USC 37 2.003 0.995 0.16 PI 37 2.64 1.87 0.31 Difference = mu (USC) - mu (PI) Estimate for difference: -0.632 95% CI for difference: (-1.326, 0.061) T-Test of difference = 0 (vs not =): T-Value = -1.82 P-Value = 0.073 DF = 72 Both use Pooled StDev = 1.4965	

“Two-Sample T-Test” for Scale 3	
Two-sample T for FM vs USC N Mean StDev SE Mean FM 37 8.71 5.33 0.88 USC 37 3.54 1.95 0.32 Difference = mu (FM) - mu (USC) Estimate for difference: 5.173 95% CI for difference: (3.313, 7.033) T-Test of difference = 0 (vs not =): T-Value = 5.54 P-Value = 0.000 DF = 72 Both use Pooled StDev = 4.0140	Two-sample T for FM vs PI N Mean StDev SE Mean FM 37 8.71 5.33 0.88 PI 37 5.86 4.65 0.76 Difference = mu (FM) - mu (PI) Estimate for difference: 2.85 95% CI for difference: (0.54, 5.17) T-Test of difference = 0 (vs not =): T-Value = 2.45 P-Value = 0.017 DF = 72 Both use Pooled StDev = 5.0016
Two-sample T for USC vs PI N Mean StDev SE Mean USC 37 3.54 1.95 0.32 PI 37 5.86 4.65 0.76 Difference = mu (USC) - mu (PI) Estimate for difference: -2.319 95% CI for difference: (-3.971, -0.667) T-Test of difference = 0 (vs not =): T-Value = -2.80 P-Value = 0.007 DF = 72 Both use Pooled StDev = 3.5639	

“Two-Sample T-Test” for Scale 4	
Two-sample T for FM vs USC N Mean StDev SE Mean FM 37 7.81 5.62 0.92 USC 37 2.51 2.08 0.34 Difference = mu (FM) - mu (USC) Estimate for difference: 5.296 95% CI for difference: (3.334, 7.259) T-Test of difference = 0 (vs not =): T-Value = 5.38 P-Value = 0.000 DF = 72 Both use Pooled StDev = 4.2343	Two-sample T for FM vs PI N Mean StDev SE Mean FM 37 7.81 5.62 0.92 PI 37 4.54 5.35 0.88 Difference = mu (FM) - mu (PI) Estimate for difference: 3.27 95% CI for difference: (0.73, 5.81) T-Test of difference = 0 (vs not =): T-Value = 2.56 P-Value = 0.012 DF = 72 Both use Pooled StDev = 5.4859
Two-sample T for USC vs PI N Mean StDev SE Mean USC 37 2.51 2.08 0.34 PI 37 4.54 5.35 0.88 Difference = mu (USC) - mu (PI) Estimate for difference: -2.029 95% CI for difference: (-3.911, -0.146) T-Test of difference = 0 (vs not =): T-Value = -2.15 P-Value = 0.035 DF = 72 Both use Pooled StDev = 4.0615	

“Two-Sample T-Test” for Scale 5	
Two-sample T for FM vs USC N Mean StDev SE Mean FM 37 0.0721 0.0597 0.0098 USC 37 0.00974 0.00977 0.0016 Difference = mu (FM) - mu (USC) Estimate for difference: 0.06238 95% CI for difference: (0.04255, 0.08220) T-Test of difference = 0 (vs not =): T-Value = 6.27 P-Value = 0.000 DF = 72 Both use Pooled StDev = 0.0428	Two-sample T for FM vs PI N Mean StDev SE Mean FM 37 0.0721 0.0597 0.0098 PI 37 0.0400 0.0508 0.0084 Difference = mu (FM) - mu (PI) Estimate for difference: 0.0321 95% CI for difference: (0.0064, 0.0578) T-Test of difference = 0 (vs not =): T-Value = 2.49 P-Value = 0.015 DF = 72 Both use Pooled StDev = 0.0554
Two-sample T for USC vs PI N Mean StDev SE Mean USC 37 0.00974 0.00977 0.0016 PI 37 0.0400 0.0508 0.0084 Difference = mu (USC) - mu (PI) Estimate for difference: -0.03025 95% CI for difference: (-0.04722, -0.01329) T-Test of difference = 0 (vs not =): T-Value = -3.56 P-Value = 0.001 DF = 72 Both use Pooled StDev = 0.0366	

“Two-Sample T-Test” for Scale 6	
Two-sample T for FM vs USC N Mean StDev SE Mean FM 37 0.0708 0.0539 0.0089 USC 37 0.0246 0.0350 0.0057 Difference = mu (FM) - mu (USC) Estimate for difference: 0.0461 95% CI for difference: (0.0250, 0.0672) T-Test of difference = 0 (vs not =): T-Value = 4.36 P-Value = 0.000 DF = 72 Both use Pooled StDev = 0.0455	Two-sample T for FM vs PI N Mean StDev SE Mean FM 37 0.0708 0.0539 0.0089 PI 37 0.0406 0.0454 0.0075 Difference = mu (FM) - mu (PI) Estimate for difference: 0.0302 95% CI for difference: (0.0070, 0.0533) T-Test of difference = 0 (vs not =): T-Value = 2.60 P-Value = 0.011 DF = 72 Both use Pooled StDev = 0.0499
Two-sample T for USC vs PI N Mean StDev SE Mean USC 37 0.0246 0.0350 0.0057 PI 37 0.0406 0.0454 0.0075 Difference = mu (USC) - mu (PI) Estimate for difference: -0.01596 95% CI for difference: (-0.03473, 0.00282) T-Test of difference = 0 (vs not =): T-Value = -1.69 P-Value = 0.095 DF = 72 Both use Pooled StDev = 0.0405	

Appendix IXG The Conditions of using ordinal data for parametric statistical analysis

The popularity of Likert-type ordinal rating scale is not without controversy. Whether the ordinal rating data merely are ordered-categorical or relative to intervals has been a continuing and fierce debate (Wu & Tsai, 2007). A very common question is whether it is legitimate to use ordinal data in parametric statistical procedures that require interval data, such as linear regression, ANOVA, and factor analysis (Carifio & Perla, 2007; Jamieson, 2004).

Relative to the issue of the usage of ordinal rating scales, two opposing positions have been held by researchers. Some researchers maintain ordinal rating scales as ordered categories, the intervals between the scale values are not equal. Treating it as interval, or even ratio, is doubtful and unclear (Hodge & Gillespie, 2003). Any mean, correlation, or other numerical operation applied is invalid. Only non-parametric statistics such as frequencies, tabulation, chi-squared statistics, and Kruskall-Wallis can be used on ordinal data (Elene & Seaman, 2007; Hair et al., 2009). The other group of researchers maintains that while technically the ordinal rating scales are ordered, using them in parametric statistics is valid in some situations.

For example, Dawes (2008) found that the data obtained from the ordinal rating scales which have more than five points are approximately comparable in terms of mean score and various measures of variation and data shape. Dawes concluded that when using five response levels it clearly implies symmetry of response levels about a middle category; at the very least, such an item would fall between ordinal and interval-level measurement, and to treat it as merely ordinal would lose information. Lubke and Muthen (2004) found that it is possible to find true parameter values in factor analysis with ordinal data if assumptions about skewness, number of categories, and the like are met. Likewise, Glass et al. (1972) found that F tests in ANOVA could return accurate p-values on ordinal data under certain conditions.

However, the leading researchers in the social science area such as marketing and organizational and strategic management use ordinal data in parametric statistical analysis. Leading textbook authors also follow this approach (Carifio & Perla, 2007). A definitive answer is absent therefore the debate continues. Many researchers have noted that some conditions must be met when treating ordinal data as interval data in parametric statistical procedures (Dawes, 2008; Kerlinger & Lee, 2000; Lubke & Muthen, 2004):

1. ***The ordinal rating scales should be more than five points with symmetry of response levels about a middle category. The underlying concept is that the data are continuous, and that there is an indication that the intervals between points are approximately equal.***

   This is the preliminary condition to use ordinal data in parametric statistics like multiple-regression.

2. ***Regardless of equal intervals, assuring the data meets assumptions in parametric statistics.***

   In parametric statistics, assuring the data meets the assumptions is very important. For example, constant variance of error terms, independence of error terms and normality of the error term distribution are the assumptions in multiple regression analysis. To ensure that the resulting regression equations for expressing the functional relations of the dependent risk variable and independent risk variables are appropriately formulated, the ordinal numerical data must meet the assumptions underling multiple regression analysis.

3. ***Make sure a strong result is delivered before making claims.***

   This ensures that there is strong evidence to support the appropriateness of the resulting regression equations when using ordinal data. For example, the p-values of 0.001 are much stronger than that of 0.45, even if parameter estimates are slightly biased. It is when p-values are close to .05 that the effect of bending assumptions is unclear.

In the questionnaire survey, the 1 to 25 ordinal numerical scales were accompanied with the categorical scales for the survey questionnaire so that project experts could rate risk effects. As shown in Table IXG1, with more than five balance rating scales, 25 response levels symmetrically spread from the minimum extreme category (VL, VL; level 1) through the middle category (M, M; level 13) to the maximum extreme category (VH, VH; level 25). This meets the first condition addressed in point 1 that the ordinal numerical data are valid in parametric statistics.

The ordinal numerical data obtained from the questionnaire survey were used in two types of parametric statistical analysis. By fitting a set of theoretical distribution to the sample data collected from questionnaire survey, a fitted continuous probability distribution for the expected risk effect can be easily identified in risk network modelling and simulation to estimate the range values of project NPV. By the use of multiple-regression analysis, the functional relationships of the risk variables can be easily identified as well in risk network modelling. A set of plots were conducted to test whether the fitted probability distributions and multiple-regression models were adequate and the data assumptions were met. All of the results showed that all of the fitted probability distributions and regression models were adequate and the data assumptions were met. The ANOVA analysis had small *p*-values close to 0. (See point 3). They meet the second and third conditions addressed in point 2 and 3 that applying ordinal numerical data in the use of parametric statistical analysis.

Table IXG1 The corresponding relationship between categorized scales and ordinal numerical scales

Ordinal numerical scales (1-25)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Categorized Scales (Likelihood, Impact)	VL, VL	VL, L	L, VL	VL, M	VL, H	L, L	VL, VH	L, M	M, VL	L, H	L, VH	M, L	M, M	M, H	H, VL	M, VH	VH, VL	H, L	VH, L	H, M	VH, M	H, H	H, VH	VH, H	VH, VH

Appendix X The analysis of the remarkable low standard deviation in construction delay

Concerning construction delay, the actual construction delay percentage was approximately 18.59% (Bureau of High Speed Rail, 2007). The *SD* model outcome (Figure X1) reported the simulation result for construction delay percentage with 18.63% for mean, 0.08% for standard deviation, and (18.47%, 18.78%) for a 95% confidence interval. The forecast error was approximately 0.22% for construction delay, which represented a small discrepancy between the simulated and real data. This remarkable result on low estimation error casts doubt on the credibility of the *SD* modelling and this needs justification. In this section, this result was checked and analysed to find out why *SD* model reported a low standard deviation and low forecast error for the percentage of construction delay.

As stated in Section 6.2.5, the risk variable "construction delay" is calculated and depends on another variable "time delay effect" which is assumed to be in linear proportion to the expected risk effect between the maximum time delay effect $TCMAX_{ij}$ and minimum time delay effect $TCMIN_{ij}$ of a risk event on a work package:

$$TD_{ij} = (RD_i - RD_{min})/(RD_{max} - RD_{min}) * (TCMAX_{ij} - TCMIN_{ij}) + TCMIN_{ij}$$

where

TD_{ij}: *time delay effect for a risk event on a work package (in percentage);*

RD_i: *random variable for the expected risk effect;*

$TCMAX_{ij}$: *maximum time delay effect for a risk event in a work package (in percentage);*

$TCMIN_{ij}$: *minimum time delay effect for a risk event in a work package (in percentage);*

RD_{max}: *25;*

RD_{min}: *1;*

i: risk event index;

j: work package index

Table X1 shows the minimum and maximum values for the time delay effect of a risk variable on a work package. The original data from interview surveys for time delay units are *day* or *month*. All of time units used in the *SD* model are converted to *year*. The work packages for THSR project are civic work, track work, station construction, depot construction, core system, Taipei underground, and design and supervision. From interview survey, six risk variables including land unavailable, resource unavailable, contract change negotiation, construction change, site conditions, and ownership change would directly lead to construction delay (see Appendix VI8, VI1, VI2, VI10, VI25, VI30, VI49). In Table X1, the total time delay effect of all risk variables that would lead to construction delays on a work package of the THSR project are calculated. Table X2 shows a rough estimation for *SD* model outcome '% construction delay'. There are 7 major parallel paths for THSR project, including 'land+civic' (work package 'land acquisition' + work package 'civic work'. '+' means that the civic work depends on land acquisition.), 'land+track', 'land+station', 'land+depot', 'land+core system', 'Taipei undeground', and 'design+supervision'. The minimum and maximum time delay, minimum and maximum percentage of construction delay, and range of percentage of construction delay (the range between minimum and maximum percentage of construction) are calculated for each path. Since the path 'land+core' is the critical path, the time delay on this path is equal to the construction delay of the THSR project. As shown in Table X2, the minimum percentage construction delay is about 0.0311, the maximum percentage construction delay is about 0.2079, and the range of percentage construction delay is about 0.1768 for THSR project. Since *the range is the simplest measure of variation (Mendenball et al., 1993)*, the variance σ^2 is 0.1768. Thus, the rough estimating for standard deviation s is about: $s = \sqrt{\sigma^2} = \sqrt{0.1768} = 0.0884$. This is very close to the *S*D model outcome that the standard deviation is 0.0805 for percentage of construction delay. The maximum time delay effect $TCMAX_{ij}$ and the minimum time delay effect $TCMIN_{ij}$ are two of the key parameters that affect output values of risk variable "construction delay". The smaller range values between $TCMAX_{ij}$ and $TCMIN_{ij}$, the smaller variation in the output values of "construction delay". This interprets that the low standard deviation and low forecast error in the output values of "construction delay" are the result of tight range values between "the maximum time delay effect $TCMAX_{ij}$" and "the minimum time delay effect $TCMIN_{ij}$" obtained from interview survey.

In addition to using an Excel spreadsheet to calculate the approximate construction delay to find out why *SD* model reports a low standard deviation for the percentage of construction delay, a sensitivity analysis in the SD model will be performed to interpret the result in a low standard deviation for the percentage of construction delay. Figure X2 and Figure X3 show the spider plot and the tornado plot for sensitivity analysis, respectively, that measure the variability of "the percentage of construction delay" when the parameter values of an exogenous risk variable change. The *SD* model has 7 qualitative exogenous variables that affect output variable "construction delays", including "default of subcontractors", "Force Majeure", "unforeseen site conditions", "greater environment expectation", "latent defect", "political interference", and "downside economic events". Figure X2 and Figure X3 shows that the exogenous variables except for "political interference" are almost not sensitive to the variability of "the percentage of construction delay". Even for "political interference", it only leads to a small slope of relation line which is about 0.0008 in Figure X2 and a narrow range of "the percentage of construction delays" between 0.18 and 0.19 in Figure X3. These results are consistent with those of *SD* output shown in Figure X1 that the standard deviation is 0.08% and the range of "the percentage of construction delay" is between 18% and 19%. This means that the *SD* outcome "the percentage of construction delay" is not sensitive to all of the exogenous variables so that there is only a small standard deviation.

There are six risk variables that directly cause variable "time delay effect" which directly lead to output variable "construction delay", including "land unavailable", "resource unavailable", "contract change negotiation", "construction change", "site conditions", and "ownership change". From the causal loop diagrams we discovered that all of the exogenous variables but "political interference" lead to only one or two of six risk variables which would directly lead to "construction delay". The exogenous risk variable "political interference" can lead to five of the six risk variables which would directly lead to "construction delay". This explains why "the percentage of construction delay" is more sensitive to "political interference" than other exogenous variables shown in spider and tornado plots. It indicates that risk variable "political interference" is the major driver of "construction delay" in THSR project.

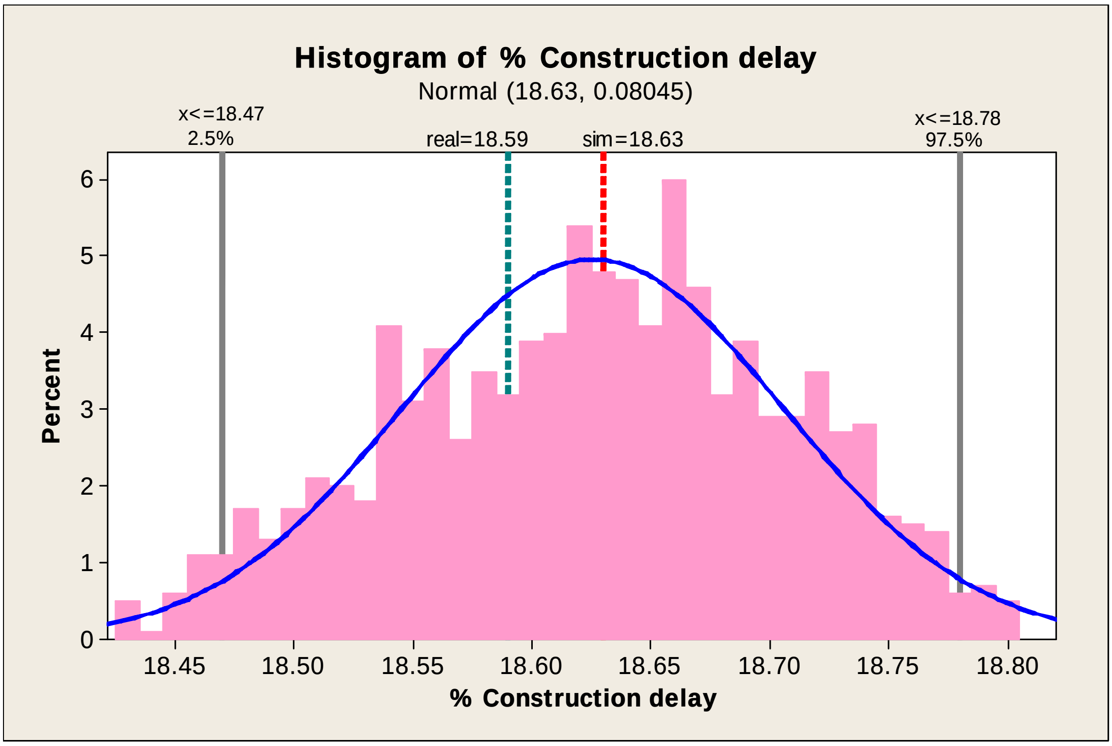


Figure X1 Discrepancy between Simulated and Real Data of Percentage of Construction Delay

Table X1 The Min. and Max. Time Delay Effect of the Risk Variables on the Work Packages

Work packages / Risk variables	Civic work	Track work	Station construction	Depot construction	Core system	Land acquisition	Taipei underground	Design & supervision
Land unavailable	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0.03, 0.13)	(0,0)	(0,0)
Resource unavailable	(0.026,0.007)	(0.037,0.1)	(0.037,0.1)	(0.028, 0.076)	(0.06,0.165)	(0,0)	(0,0)	(0,0)
Contract change negotiation	(0.0089,0.107)	(0.0125,0.15)	(0.125,0.15)	(0.0096,0.115)	(0.0209,0.25)	(0.0122,0.146)	(0.0062,0.074)	(0.0058,0.07)
Construction change	(0.01,0.15)	(0,0.03)	(0.01,0.15)	(0,0.01)	(0.1,0.3)	(0,0)	(0,0.01)	(0.05,0.25)
Site conditions	(0.1,0.3)	(0.05,0.15)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)
Ownership change	(0,0.214)	(0,0.3)	(0,0.3)	(0,0.23)	(0,0.5)	(0,0)	(0,0.148)	(0,0)
Total time effects	(0.0949,0.619)	(0.0995,0.73)	(0.0525,0.7)	(0.0376,0.431)	(0.1809,1.215)	(0.0422,0.276)	(0.0062,0.232)	(0.0558,0.32)

Note: (min, max), unit: year

Table X2 A Rough Estimation for the percentage of Construction Delay

Rough estimating for time delay on a project path	Min. delay effect	Max. delay effect	Min. % construction delay	Max. % construction delay	Range % construction delay
land+civic	0.1371	0.895	0.019121339	0.124825662	0.105704
land+track	0.1417	1.006	0.019762901	0.140306834	0.120544
land+station	0.0947	0.976	0.01320781	0.136122734	0.122915
land+depot	0.0798	0.707	0.011129707	0.0986053	0.087476
land+core system	0.2231	1.491	0.03111576	0.207949791	0.176834
Taipei underground	0.0062	0.232	0.000864714	0.032357043	0.031492
design & supervision	0.0558	0.32	0.007782427	0.044630404	0.036848

As shown in Table X2, the interviewees' statement led to the inference that the minimum percentage of construction delay was approximately 0.0311, the maximum percentage of construction delay was approximately 0.2079, and the range of the percentage of construction delay was about 0.1768 (0.08 for standard deviation) for THSR project. Since "political interference" causes five of the six risk variables that would directly lead to "construction delay", so the time delay effect caused by "political interference" would be close to the upper bound of approximately 0.2079. On the contrary, the other exogenous variables cause only one or two of six risk variables would directly lead to construction delay, so the time delay effect caused by other exogenous variables would be close to the lower bound around 0.03. As a result, a tight range between the maximum time delay effect $TCMAX_{ij}$ and the minimum time delay effect $TCMIN_{ij}$ set up by interviewees, the *SD* model produced a narrow range in percentage of "construction delay" between 0.18 and 0.19, which was close to 0.2079. All of above analyses can consistently interpret why the *SD* model outcome for "the percentage of construction delay" is so accurately with low standard deviation.

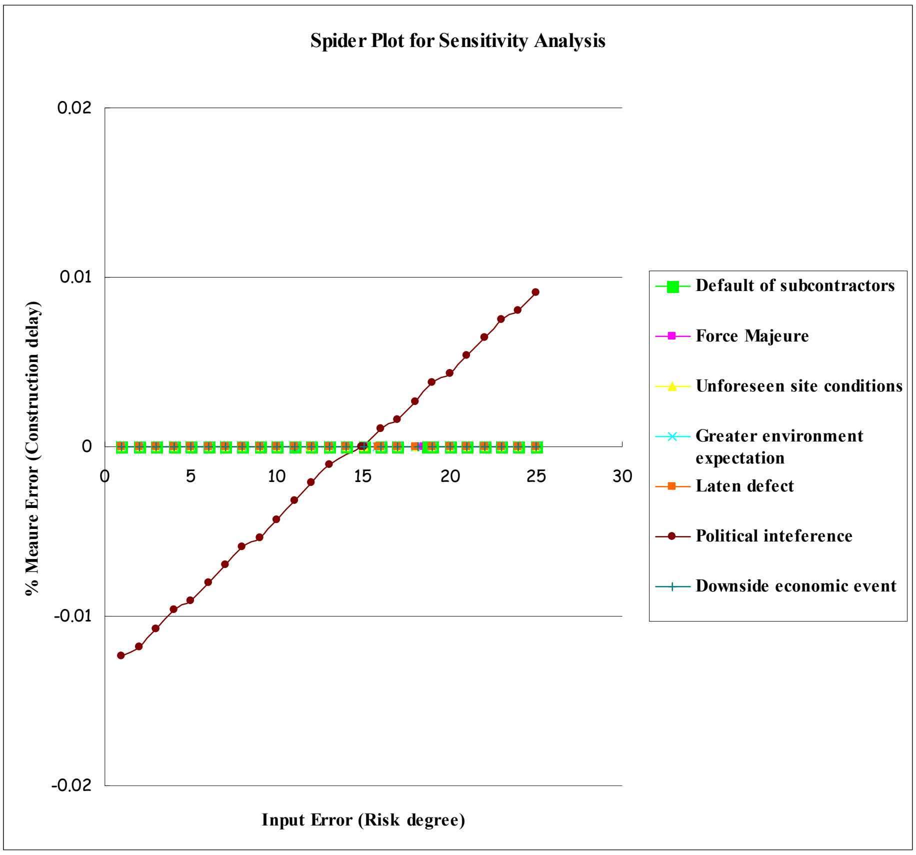


Figure X2 The Spider Plot for Sensitivity Analysis

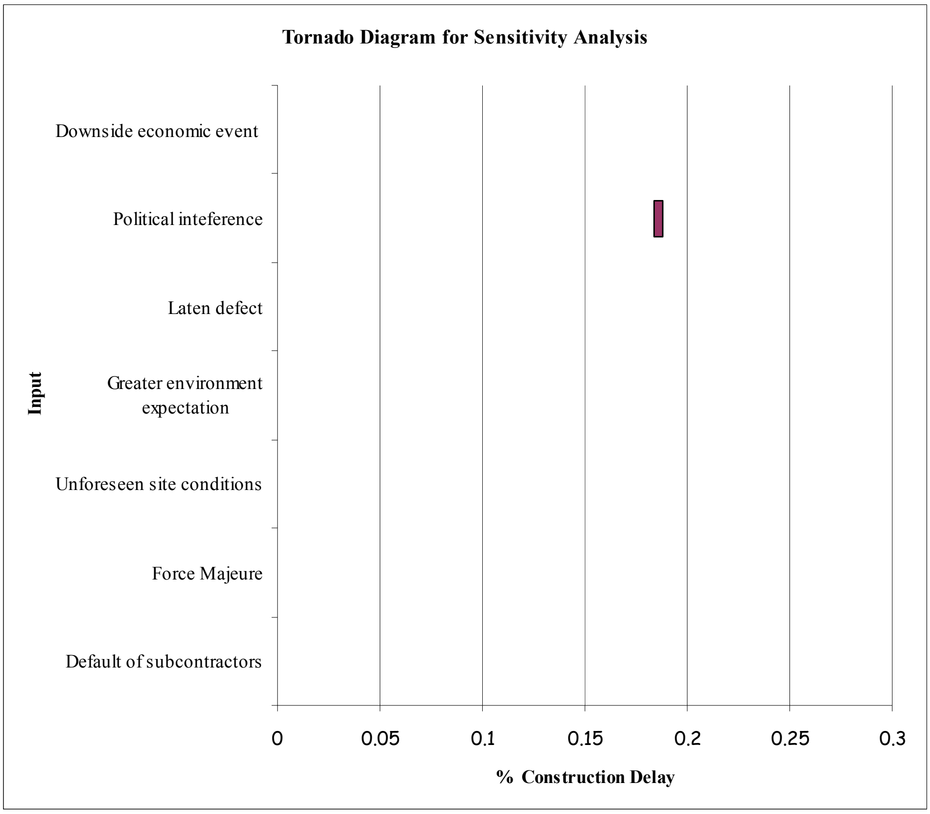


Figure X3 The Tornado Diagram for Sensitivity Analysis

A question may be raised, "Why could the interviewees set up a tight range between minimum and maximum values for construction delay?" The interviewees have wide experiences in project management of mass transit projects that are similar to THSR project. This might be the reason why the interviewees were confident in using their experiences or historic data from other similar projects to support their information on tight range values between $TCMAX_{ij}$ and $TCMIN_{ij.}$ For example, one of the interviewees, answered to this question as the following statement:

> "We have wide experiences and good record of achievement to manage mass transit projects that are similar to THSR project, like Taipei Metro system. The Nova and CoMET rail public transport benchmarking consortiums facilitated by the Railway and Transport Strategy Centre at Imperial College London have placed the Taipei Metro system first for reliability among the 26 other consortium members since year 2004. We believe that we are able to provide you with useful information for case study on public transit projects."

Since there were no real data in terms of qualitative risk effects, many parameter values in the *SD* model were heavily relied on the interviewees (the project experts). Thus the accuracy and error of *SD* model might be greatly subject to the interviewees. The remarkable low estimation error in "construction delay" reported in the *SD* model outcome is exactly the case. Because the maximum time delay effect $TCMAX_{ij}$ and the minimum time delay effect $TCMIN_{ij}$ of a qualitative risk factor on a work package are unknown, they need to be estimated by the interviewees. Due to the tight range values between the maximum time delay effect and the minimum time delay effect, the *SD* model produced a low estimation error in "construction delay". This case reflects that the effects of qualitative risk factors such as "resource unavailable" and "ownership change" have to depend on the interviewees' estimation and hence the model outcomes may greatly be constrained to reflect *SD* model's real forecasting capacity.

Appendix XI Acronyms

GDP: Gross Domestic Product

PPP: Public-private Partnership

VFM: Value for Money

NPV: Net Present Value

BOT: Build-operate-transfer

P3: Public-private Partnerships

PWF: Public Works Financing Projects

O&M: Operations and Maintenance

DB: Design, Build

LDO: Lease, Develop, Operate

DBOM: Design, Build, Operate, Maintain

DBFO: Design, Build, Finance, Operate

BOO: Build, Own, Operate

RS: Risk Sharing

LC: Long-term Contract

SPV: Special Purpose Vehicle

PF: Private Financing

OS: Output Specifications

PBP: Performance-based Payment

PSC: Public-sector Comparator

CBA: Cost Benefit Analysis

CEA: Cost-effectiveness Analysis

MCDA: Multi-criteria Decision Making

IRR: Internal Rate of Return

BC: Benefit-cost

WBS: Work Breakdown Structure

SD: System Dynamics

STPR: Social Time Preference Rate

CAPM: Capital Asset Pricing Model

MRP: Market Risk Premium

NPC: Net Present Cost

WSDOT: Washington Department of Transportation

MoD: Ministry of Defense

NAO: National Audit Office

ENPV: Expected Net Present Value

VNPV: Variance of Net Present Value

ELR: Expected-loss Ratio

DSS: Decision Support System

EEA: European Environmental Agency

SPARCS: Supply-chain Parameter Classification System

CLD: Causal Loop Diagram

PAC: Public Account Committee

THSR: Taiwan High Speed Rail

BHSR: Bureau of High Speed Rail

MOTC: Ministry of Transportation and Communications

CEVP: Cost Estimate Validation Process