

DISSERTATION

THE BIDS-EVALUATION DECISION MODEL DEVELOPMENT AND APPLICATION FOR  
PPP TRANSPORT PROJECTS: A PROJECT RISKS MODELING FRAMEWORK

Submitted by

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WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY GUAN-WEI JANG ENTITLED THE BIDS-EVALUATION DECISION MODEL DEVELOPMENT AND APPLICATION FOR PPP TRANSPORT PROJECTS: A PROJECT RISKS MODELING FRAMEWORK BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

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## ABSTRACT OF DISSERTATION

### THE BIDS-EVALUATION DECISION MODEL DEVELOPMENT AND APPLICATION FOR PPP TRANSPORT PROJECTS: A PROJECT RISKS MODELING FRAMEWORK

Public-private partnership (PPP) infrastructure projects play a key role in economic growth. Value for money (VFM), a core objective when conducting PPP projects, is defined as the optimal combination of whole life costs and benefits of the project to meet user requirements. The PPP infrastructure projects are generally very complex and have highly dynamic, interdependent risks and uncertainties that occur over the life cycle of a project. By using PPP arrangements, experts transfer and allocate risks to the party who is most capable of managing them in a cost effective manner. This requires the optimization of risk allocation between the public and private sectors in order to achieve the best VFM. Risk assessment is a critical element when selecting a project partner and examining projected VFM performance. Unfortunately, the current contractor selection methods used in the industry do not address interdependently dynamic and non-linear risk interactions. Such methods are unable to address unstructured or even semi-structured real world problems. By using these methods, experts often lack the global perspectives of project life cycles and ignore the uncertainty of project performance outcomes. This researcher developed a theoretical approach which applied hybrid techniques to a bidding proposal selection model from the public perspective. Using System Dynamics modeling and relevant statistical techniques, the dynamic risk interactions and interdependencies over project construction and operation phases were addressed and quantified. By employing Monte Carlo simulation, this researcher estimated the probability distribution of the overall project net present value (NPV) with compounding both

downside and beneficial effects over project construction and operation phases. By applying appropriate decision making methods to compare the probability distribution of NPV among the bidding proposals, a capable contractor can be selected.

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# Table of Contents

Chapter 1 Introduction.....	1
1.1 Research Background.....	1
1.2 Research Issues.....	4
1.3 Research Objective.....	7
1.4 Research Structure.....	7
Chapter 2 Literature Review.....	9
2.1 Introduction to Public-Private Partnerships.....	9
2.2 The Mechanisms of PPP.....	14
2.2.1 Value for Money (VFM).....	14
2.2.2 Risk Sharing (RS).....	17
2.2.3 Long-term Contract (LC).....	18
2.2.4 Special Purpose Vehicle (SPV).....	19
2.2.5 Private Financing (PF).....	19
2.2.6 Output Specifications (OS).....	20
2.2.7 Performance Based Payment (PBP).....	21
2.3 PPP Risk Management and Procurement.....	22
2.3.1 Project Risk Management (PRM).....	22
2.3.2 PRM and PPP Procurement.....	23
2.4 Issues of VFM-based Bids Evaluation.....	26
2.4.1 Critics on VFM Assessment Approaches.....	26
2.4.2 Critics on Need of the PSC.....	31
2.4.3 Critics on Choice of the Discount Rate.....	34
2.4.4 Critics on Uncertainty and Optimism Bias.....	39
2.4.5 Critics on the Bids Comparison.....	44
2.5 Issues of Computer-aid Systems.....	49
Chapter 3 Research Methodology.....	54
3.1 Research Questions.....	55
3.2 Research Strategy.....	60
3.2.1 Multi-Strategy Research.....	60
3.2.2 Questions Oriented Strategies.....	62
3.3 Theoretical Approach and Assumption.....	66
3.4 The State-of-the-Art.....	70
3.4.1 System Dynamics.....	71
3.4.2 The Hybrid Techniques.....	74
3.4.2.1 Risk Rating Matrix.....	75

3.4.2.2 Expert Judgment .....	75
3.4.2.3 Multiple Regress Analysis .....	76
3.4.2.4 Probability Fitting .....	77
3.4.2.5 Monte Carlo Simulation .....	78
3.4.3 Ranking Decision Rules.....	78
3.5 Research Reliability and Validity .....	78
Chapter 4 Risk Factors and Causal Loop Diagrams .....	83
4.1 Literature Reviews for Risk Factors .....	83
4.2 Risk Causal Loop Diagrams .....	92
4.2.1 Land unavailable.....	94
4.2.2 Resources unavailable.....	96
4.2.3 Performance unavailable.....	98
4.2.4 Design changes .....	101
4.2.5 Construction cost overrun .....	102
4.2.6 Construction delay .....	104
4.2.7 Defective construction .....	106
Chapter 5 Taiwan High Speed Rail Project Risks .....	109
5.1 The Background of THSR.....	109
5.2 Risk Scenarios of THSR Project.....	111
5.2.1 ‘Land Unavailable’ on THSR .....	111
5.2.2 ‘Resources Unavailable’ on THSR.....	113
5.2.3 ‘Performance Unavailable’ on THSR.....	116
5.2.4 ‘Scope Changes’ on THSR.....	119
5.2.5 ‘Defective Design’ on THSR.....	120
Chapter 6 Risk Network Modeling and Simulation .....	123
6.1 Project NPV Cash Flow Modeling .....	125
6.1.1 Construction Cost Sub-model.....	125
6.1.2 Project Financing Sub-model.....	128
6.1.3 Operating Revenue Sub-model .....	130
6.1.4 Operating Cost Sub-model.....	135
6.1.5 Depreciation Sub-model .....	137
6.1.6 Discount Rate Sub-model .....	137
6.1.7 Project NPV Cash Flow Model.....	139
6.2 System Dynamics for Risk Network Modeling .....	142
6.2.1 RCN for ‘Land Unavailable’ on THSR .....	142
6.2.2 RCN for ‘Resource Unavailable’ on THSR.....	143
6.2.3 RCN for ‘Performance Unavailable’ on THSR .....	144

6.2.4 RCN for ‘Construction Cost Overrun’ on THSR.....	146
6.2.5 RCN for ‘Construction Delay’ on THSR.....	147
6.2.6 RCN for ‘Mis-pricing’ on THSR.....	149
6.2.7 RCN for ‘Accidents and Safety Issues’ on THSR.....	150
6.2.8 RCN for ‘Price Escalation’ on THSR.....	152
6.2.9 RCN for ‘Finance Unavailable’ on THSR.....	156
6.3 The Sample Data Analysis.....	158
6.3.1 An Example for Multiple-regression Analysis.....	159
6.3.2 An Example for Probability Fitting.....	170
6.4 Monte Carol Simulation for Risk Compounding Effects.....	171
Chapter 7 Bidding Proposal Modeling and Simulation.....	174
7.1 System Dynamics for Bidding Proposal Modeling.....	174
7.1.1 The Structure of Bidding Proposals.....	174
7.1.2 Risk Control Schemes Modeling.....	178
7.2 Monte Carlo Simulation for Bidding Proposals.....	190
7.3 Comparison Methods for Bids Competition.....	192
7.3.1 Mean-variance and Mean-Semivariance.....	193
7.3.2 Stochastic Dominance.....	196
7.3.3 The Expected-Loss ratio.....	197
CHAPTER 8 MODEL VALIDATION.....	200
8.1 Boundary Adequacy Tests.....	200
8.2 Structure Assessment Tests.....	195
8.3 Dimensional Consistency Tests.....	198
8.4 Parameter Assessment Tests.....	199
8.5 Extreme Condition Analysis.....	205
8.6 Integration Error Tests.....	209
8.7 Behavior Reproduction Tests.....	213
8.8 Sensitivity Analysis.....	217
CHAPTER 9 CONCLUSIONS.....	225
9.1 Summary of Research Findings.....	225
9.2 Contributions.....	233
9.3 Limitations.....	235
9.4 Future Work.....	235
References.....	237
Appendix.....	257
Appendix I Risk Factors Collected from Literature Survey.....	257
Appendix II Interview Survey Plan.....	271

Appendix III SD Model Variables and Parameters .....	274
Appendix IV Questionnaire Survey Plan .....	276
Appendix V The Analysis of CLD .....	292
Appendix VI Analysis of THSR Risks.....	338
Appendix VII Analysis of The Risk Network Models .....	359
Appendix VIII ANOVA List for Multiple-Regression Models.....	396
Appendix VIII Acronyms .....	402

## List of Tables

Table 1 The Expected Annual Investment Needs for Year 2005-2010 .....	2
Table 2.1.1 Risk Responsibilities of the PPP Delivery Options.....	11
Table 2.4.1 Broad Risk Bands for PPP Projects.....	37
Table 2.4.2 Recommended Adjustment Ranges for Different Categories of Projects.....	43
Table 2.4.3 Recommended Adjustment Ranges for Transport Projects.....	43
Table 3.1.1 The Issues Learned from the Literature and Their Corresponding Argumentation, Research Gaps, and Research Questions.....	57
Table 3.2.1 Fundamental Differences between Quantitative and Qualitative Research Strategies .....	61
Table 3.2.2 Relevant Situations for Different Research Strategies .....	63
Table 3.2.3 Research Strategies for Each Research Question .....	64
Table 3.4.1 The Reference Matrix for Rating Risk Degree.....	76
Table 3.5 Criteria and Actions to Ensure Research Quality .....	80
Table 4.1.1 Risk Data Sources from the Empirical Studies.....	84
Table 4.1.2 Risk Data Sources from the Official Publications .....	84
Table 4.1.3 The Generic Risk Factors for Case Study .....	86
Table 6.1.4.1 The Regression Models for the Cost Elements of Operating Costs.....	136
Table 7.1 The Cost Components of Bidding Proposals.....	175
Table 7.1.1 The ‘Default of Subcontractors (DOS)’ Control Scheme.....	178
Table 7.1.2 The Rating for ‘DOS Risk Control Schemes’ Effects .....	182
Table 7.1.3 The Probability Distribution of the Expected Effects of Risk Control Schemes Addressed in Bidding Proposals.....	183
Table 7.1.4 An Example: the Percentage of Risk Premium Transferred to the Private Sector for Bid A ...	189
Table 7.2.1 The Price of Bidding Proposals.....	191
Table 7.3.1 the Expected-Loss Ratio for Bids Benchmarking .....	199
Table 8.1 Measures of Performance.....	192
Table 8.1.1 Model Boundary Chart for a Long-Term NPV Model of Risk Interactions.....	195
Table 8.2 The Partial Display of The Loop List for ‘Default of Subcontractor’ Risk Variable .....	197
Table 8.4 The Comparison of Regression Models ‘With Suspect Outliers’ and ‘Without Suspect Outliers’ .....	203
Table 8.6.1 The Integration Tests on Time Step .....	211
Table 9.1 The Research Results for 7-Research Questions.....	228

## List of Figures

Figure 1 The Typical Structure of BOT Projects Modified from .....	5
Figure 2.1.1 Risk Allocation for the PPP Delivery Options, modified from.....	11
Figure 2.1.2 PPP Delivery System Choice .....	13
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 .....	13
Figure 2.2.1 The Key Mechanisms of PPP.....	15
Figure 2.2.2 Value for Money (VFM) Demonstration .....	17
Figure 2.3.1 The Risk Management and PPP Process.....	25
Figure 2.4.1 Payback Period Compared for Two Bids .....	29
Figure 2.4.2 Dimensions of Project Complexity .....	31
Figure 2.4.3 Discount Rate Calculation: Net Cash Inflows to Government.....	38
Figure 2.4.4 Discount Rate Calculation: Net Cash Outflows to Government .....	39
Figure 2.4.5 Torpedo Diagram Concerning Risk Analysis and Management.....	42
Figure 2.4.6 The PSC Distribution and PPP Bid Price.....	46
Figure 2.4.7 Mean-variance Plot for Bid Comparisons .....	46
Figure 2.4.8 The NPV Cumulative-probability Distribution Curves for Two Bids Comparison .....	47
Figure 2.4.9 : The Intersected Curves of Cumulative-probability Distribution for Two Bids.....	48
Figure 2.4.10 The Display of the Expected –Loss Ratio .....	49
Figure 3.1 Research Framework.....	54
Figure 3.3.1 The Theoretical Approach and Presumption for PPP Project Bid- Selection .....	69
Figure 3.4.1 The Major Risk Analysis Techniques .....	70
Figure 3.4.2 System Dynamics Feedback Loops (Left) and Go-seeking Feedback Loop (Right) .....	72
Figure 3.4.3 Patterns of System Behavior .....	74
Figure 4.2 (1) Causal Loop Diagram for ‘Land Unavailable’ Risk Event.....	95
Figure 4.2 (2) Causal Loop Diagram for ‘Resources Unavailable’ Risk Event .....	96
Figure 4.2 (3) Cause Loop Diagram for ‘Performance Unavailable’ Risk Event.....	99
Figure 4.2 (4) Cause Loop Diagram for “Design Changes” Risk Event .....	101
Figure 4.2 (5) Cause Loop Diagram for ‘Construction Cost Overrun’ Risk Event.....	103
Figure 4.2 (6) Cause Loop Diagram for ‘Construction Delay’ Risk Event .....	104
Figure 4.2 (7) Cause Loop Diagram for “Defective Construction” Risk Event .....	106
Figure 5.1.1 The THSR Network, 700T Train and Shingchu Station .....	110
Figure 5.1.2 Tunnels and Viaducts on The THSR Network.....	110
Figure 5.2.1 The Direct Cause and Consequence for ‘Land Unavailable’ .....	113

Figure 5.2.3 The Modified Direct Cause and Consequence for ‘Performance Unavailable’ .....	119
Figure 5.2.4 The Modified Direct Cause and Consequence for ‘Scope Changes’ .....	120
Figure 5.2.5 The Modified Direct Cause and Consequence for ‘Defective Design’ .....	122
Figure 6.1 The NPV Cash flow Model with Its Six Sub-models .....	124
Figure 6.1.1 The SD Model for Total Construction Cost and Its Outputs.....	127
Figure 6.1.2 The SD Model for Project Finance and Its Outputs .....	129
Figure 6.1.3 The SD Model for Operating Revenue and Its Outputs .....	132
Figure 6.1.3.1 The Regression Model for the Estimated Daily Ridership.....	133
Figure 6.1.4 The SD Model for Operating Cost and Its Outputs.....	135
Figure 6.1.5 The SD Model for Depreciation and Its Outputs .....	138
Figure 6.1.6 The Discount Rate SD Model and Outputs.....	139
Figure 6.1.7 The Project Cash Flow Model and Outputs .....	140
Figure 6.1.8 The Project Cash Flow Model Including Risk Budget.....	141
Figure 6.2.1 The SD Model for ‘Land Unavailable’ Risk Effect .....	143
Figure 6.2.2 The SD Model for ‘Resources Unavailable’ Risk Effect .....	144
Figure 6.2.3 The SD Model for ‘Performance Unavailable’ Risk Effect.....	146
Figure 6.2.4 The SD Model for ‘Construction Cost Overrun’ Risk Effect.....	146
Figure 6.2.5 The SD Model for ‘Construction Delay’ and Construction Delay Cost.....	149
Figure 6.2.6 The SD Model for ‘Mis-pricing’ Risk Effect.....	150
Figure 6.2.7 The SD Model for ‘Accident and Safety Issues’ Risk Effect.....	152
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.....	154
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....	155
Figure 6.2.9 The SD Model for ‘Finance Unavailable’ Risk Effect.....	158
Figure 6.3.1 The Fitted Probability Distribution for the Expected Risk Effect of ‘Political Interference’ At Construction and Operation Phases .....	171
Figure 6.4.1 The Comparison of Project NPV .....	172
Figure 6.4.2 The Probability Distribution of the Expected Project NPV in Year 2036.....	173
Figure 7.1.1 The Exogenous Variables, Risk Network and NPV Model .....	175
Figure 7.1.2 The Cause-effect Tree of Exogenous Risk Variable ‘Default of Subcontractors’ .....	177
Figure 7.1.3 The ‘Goal Seeking’ Structure and Behavior .....	179
Figure 7.1.4 The Positive (Reinforce) and Negative (Balance) Feedback Loops of DOS Causal Loop Diagram.....	181
Figure 7.1.5 The SD Modeling for DOS Risk Control Scheme .....	181

Figure 7.1.6 The DOS Effect/Cost Ratio for A Risk Control Scheme between Bids During Project Construction and Operation Phases .....	185
Figure 7.1.7 The ‘Default of Subcontractors’ Risk Effect Reduction over Project Construction and Operation Phases among Bids .....	186
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 .....	187
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 .....	190
Figure 7.2.1 The NPV Probability Distribution of Base Case and Bidding Proposals .....	192
Figure 7.2.2 The Boxplot with Mean and 95% Confidence Interval for the Expected NPV of Base Case and Bidding Proposals .....	193
Figure 7.3.1 The Mean-Variance Plot for Bids Comparison .....	194
Figure 7.3.2 The Mean-Semivariance Plot for Bids Comparison .....	195
Figure 7.3.3 The Empirical CDF of Base Case and Bidding Proposals .....	197
Figure 7.3.4 The Empirical CDF for the Base Case and Bidding Proposals with the Expected Loss .....	198
Figure 8.1.1 The Cause Tree for Risk Variable ‘Default of Subcontractors C’ .....	201
Figure 8.1.2 The Use Tree for Risk Variable ‘Default of Subcontractors C’ .....	201
Figure 8.2.1 The Vensim’ Message Window of ‘Check Model’ .....	196
Figure 8.2.2 The Cash Flow Pattern to Test Model Structure .....	198
Figure 8.3 The Vensim’s Message Window of ‘Unit Check’ .....	198
Figure 8.4.1 Residuals versus Predictors .....	201
Figure 8.4.2 Four Types of Residual Plots for Response ‘Resources Unavailable’ .....	201
Figure 8.4.3 the Residual Plots for ‘Design Changes’ Regression Model with Suspect Outliers .....	204
Figure 8.4.4 The Probability Plot, Q-Q and P-P Plot for Response ‘Political Interference’ .....	205
Figure 8.5.1 The Risk Degree for Endogenous Risk Variables When the Risk Degree for Exogenous Risk Variables Have A Maximum Value 25 .....	208
Figure 8.5.2 The Risk Degree for Endogenous Risk Variables When the Risk Degree for Exogenous Risk Variables Have A Minimum Value 1 .....	208
Figure 8.6.1 The Integration Tests for NPV Changes by Time Step for Risk .....	210
Figure 8.6.2 The Integration Tests on NPV Changes by Time Step for Bidding Proposals Model .....	212
Figure 8.7 The Forecast Error .....	213
Figure 8.7.1 Discrepancy between Simulated and Real Data for Construction Cost Overrun Percentage ..	215
Figure 8.7.2 Discrepancy between Simulated and Real Data for Construction Delay Percentage .....	215
Figure 8.7.3 Discrepancy between Simulated and Real Data for Average Daily Ridership Demand in Year 2007 .....	216
Figure 8.8.1 The Multivariate Sensitivity Analysis for The Project NPV of Risk Network Model .....	220

Figure 8.8.2 The Multivariate Sensitivity Analysis for The Project NPV of Bidding Proposal Model .....	220
Figure 8.8.3 The Pareto Chart for the Relative Importance of Risk Effects on Project NPV.....	221
Figure 8.8.4 The Most Important Feedback Loop in SD Model and Causal Loop Diagram.....	222
Figure 8.8.5 Policy Sensitivity Analysis for Interest Rates .....	223

## 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
<b>By income group</b>						
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%
<b>Developing countries by region</b>						
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%
<b>All developing countries</b>	<b>233,139</b>	<b>2.74%</b>	<b>231,654</b>	<b>2.73%</b>	<b>464,793</b>	<b>5.47%</b>
<b>World</b>	<b>369,095</b>	<b>0.90%</b>	<b>479,624</b>	<b>1.17%</b>	<b>848,719</b>	<b>2.07%</b>

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.

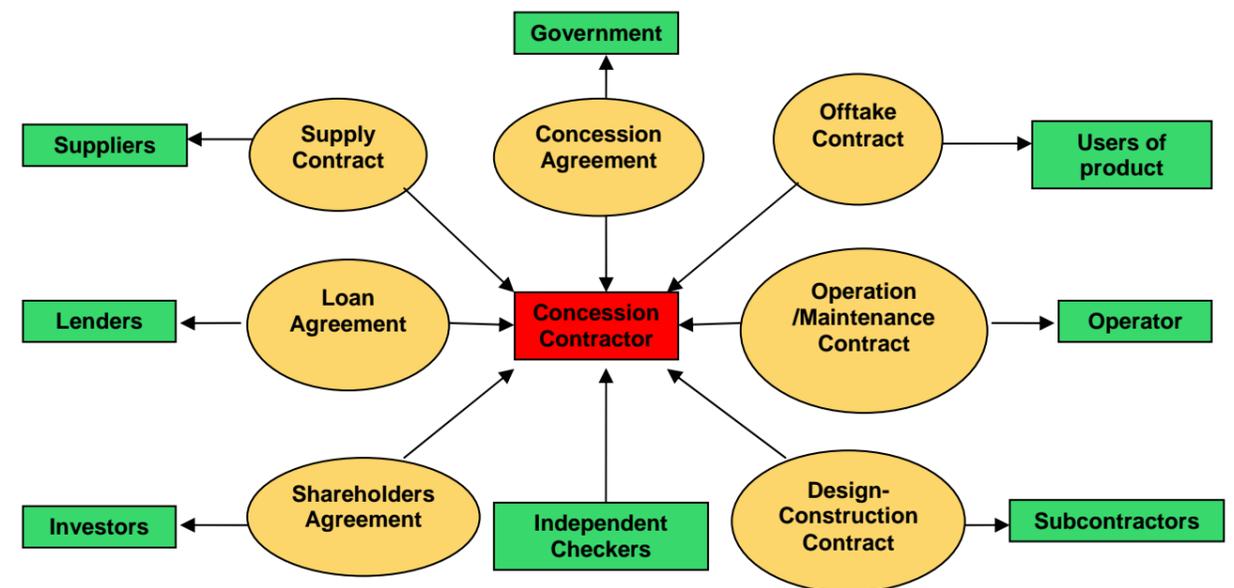
## 1.2 Research Issues

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, this researcher found that the major lessons learned from current contractor-selection literature could be summarized with the following points:

- ***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)



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

- *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 contractor-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 purpose of this research was to propose an approach that accounts for the issues related to the contractor/bidding proposal selection methods. This researcher focused on a decision support model that is used to assist the public sector officials in choosing a contractor/bidding proposal that can produce the desired long-term VFM.

### **1.4 Research Structure**

The research structure is outlined below:

- Chapter 1 Introduction: In this chapter, this 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, this researcher reviewed and discussed the characteristics of a PPP project and the PPP project contractor/bid selection.
- Chapter 3 Research Methodology: In this chapter, this researcher stated and identified the research questions, strategies and proposed methods.
- Chapter 4 Risk Factors and Causal Loop Diagrams: In this chapter, this 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, this researcher described the risk scenarios of the THSR project.

- Chapter 6 Risk Network Modeling: In this chapter, this researcher applied the System Dynamics technique to model risk effects, interactions, and feedback effects over project life.
- Chapter 7 Bidding Proposal Modeling: In this chapter, this 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, this researcher reviewed the simulation results and applied tests to measure model performance.
- Chapter 9: Conclusions: Finally, in this chapter, this 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.

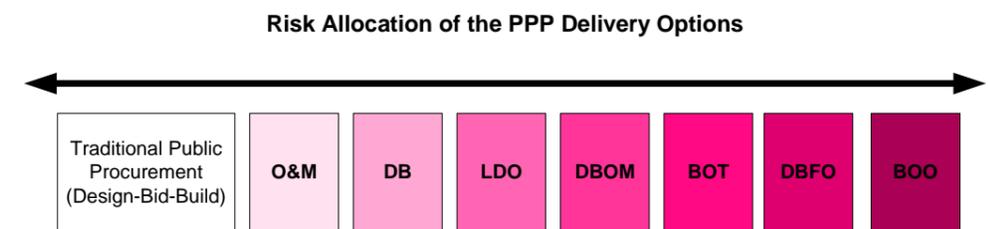
However, there is no single definition or model for a public-private partnership (Abadie & Howcroft, 2004; Davies & Eustice, 2005). “If a narrow definition is taken, this can result in legislation which only applies to a narrow range of project types or structures, which may be of limited practical value.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

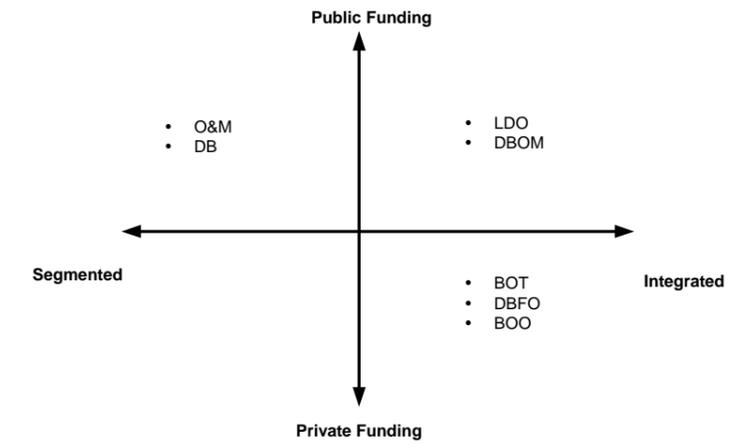
PPP Options	Design	Construction	Financing	Ownership	Operations	Maintenance	Marketing
<b>O&amp;M</b>	Public	Public	Public	Public	Private	Private or Public	Private or Public
<b>DB</b>	Private	Private	Public	Public	Public	Public	Public
<b>LDO</b>	Private	Private	Private then Public	Private or Public	Private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

In addition to data shown in Figure 2.1.2 (Pakkala, 2002), this 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. This 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:

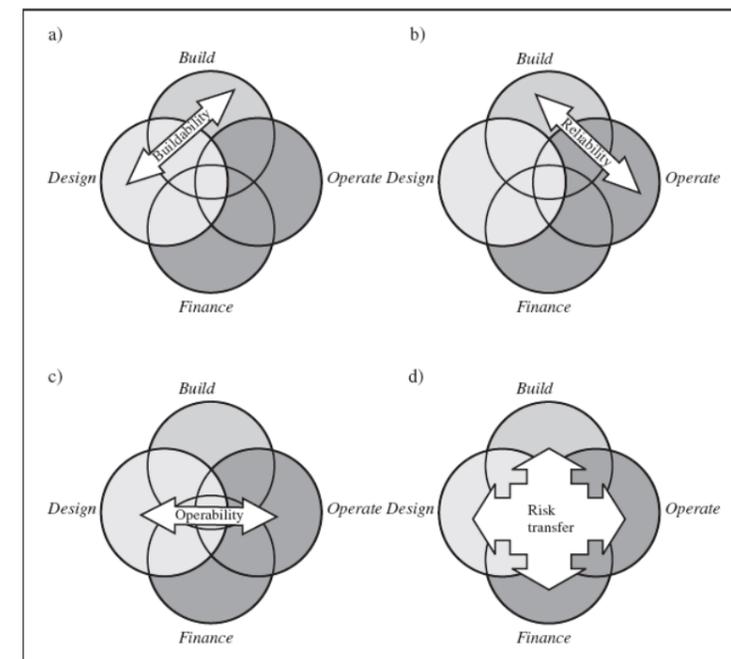
- Build-operate-transfer (BOT)
- Design-build-finance-operate (DBFO)

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)**



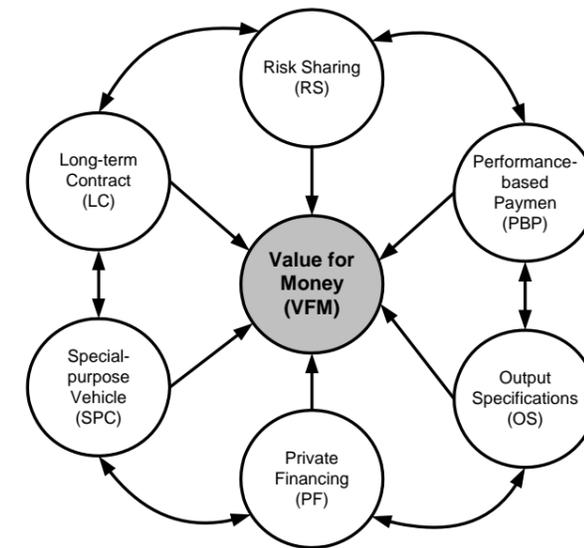
**Figure 2.1.3 Synergies in An Accommodation Project: (a)between Design and Construction;(b) between Building Process and Operations Phase; (c)between Design and Operation;(d)Finance and Full Risk Transfer (Dinesen & Thompson, 2003)**

## **2.2 The Mechanisms of PPP**

The current studies (Allan, 2001; Dinesen and Thompson, 2003; HM Treasury, 2003b; Infrastructure Australia, 2008a; United Nation, 2002) summarized a good PPP/PFI procurement embodies six key mechanisms to create Value for Money (VFM): Risk Sharing (RS), Long-term Contract (LC), Special Purpose Vehicle (SPV), Private Financing (PF), Output Specifications (OS), and Performance-based Payment (PBP). As shown in Figure 2.2.1, the PPP mechanisms RS, LC, SPV, PF, OS, and PBP bind tightly to create PPP core VFM. RS is the basic mechanism for PPP, and it is performed through LC. LC contracted with other subcontracts needs to be controlled and managed under SPV. SPV needs to get funding to ensure project performance to meet OS through PF. SPV needs to repay PF through good PBP according to the conditions set out in OS. It will create good VFM for PPP if RS, LC, SPC, PF, OS, and PBP can be incorporated to work smoothly.

### **2.2.1 Value for Money (VFM)**

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; it does not simply mean the lowest costs or cheapest price (HM Treasury, 2004c; United Nations, 2002). Researchers in current literature most commonly describe the VFM as a core objective of PPP. Allan stated that the PPP projects most 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 The Key Mechanisms of PPP**

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 comparison between PPP or traditional procurement (Grimsey & Lewis, 2005), particularly in the United Kingdom, the Netherlands, Canada, Australia, and New Zealand (Regan, 2005). In the Figure 2.2.2 (Skanska, 2004), the NPV has three cost components which consist of whole life costs, finance costs, and risk costs retained by public sector. The NPV difference between 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

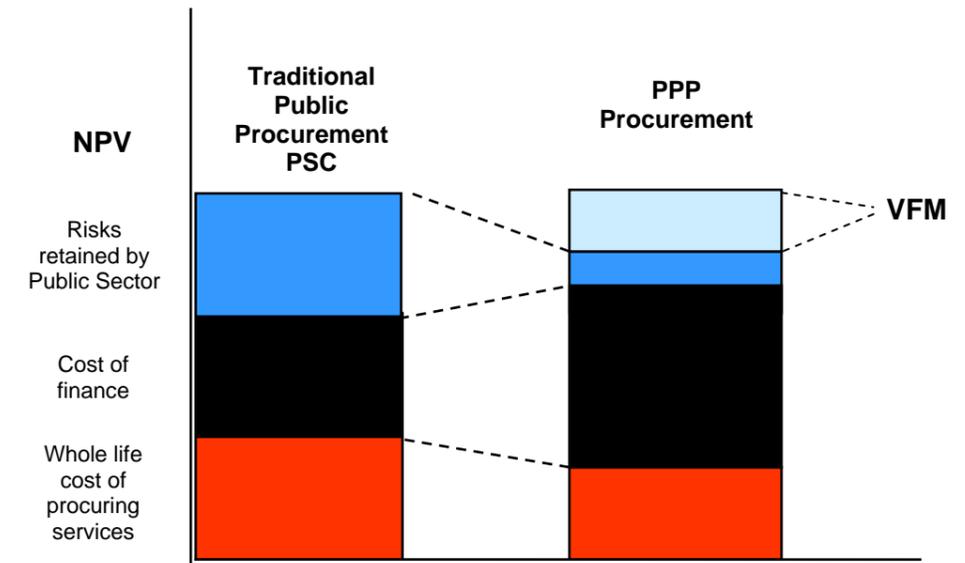
words, officials have indicated that the prerequisite for implementing PPP is evidence that whole life benefits of the project outweigh the risk costs of PPP procurement at a recognizable level. If PPP does not demonstrate superior VFM, then officials should use traditional procurement.

In some studies (Grimsey & Lewis; Shaoul, 2002, 2005), scholars evaluated whether the current methods and tools for VFM assessment were adequate for infrastructure investment decision-making. In practice, officials of in the UK and Australian governments have continued to reform investment appraisal by publishing the renewed guidance for VFM assessment. For example, the editors of the *Green Book, Appraisal and Evaluation in Central Government* (HM Treasury, 2003a) outlined the approach of officials of the UK government to investment appraisal which took effect in 2003. Reforms for PPP investment appraisal were included in the publications *PPP: Meeting the Investment Challenge* (HM Treasury, 2003b) and *PPP: Strengthening Long-term Partnerships* (HM Treasury/UK, 2006a). Officials established the guidance for appraising the VFM for investment proposals in *Value for Money Assessment Guidance* (HM Treasury, 2004c) and *Quantitative Assessment User Guide* (HM Treasury, 2004b). These approaches for VFM assessment will be further described and discussed in Section 2.2.3.

Researchers at the HM Treasury indicated that most of the PPP projects could deliver better VFM than traditional procurement because PPP projects are being delivered on time and on budget. The researchers demonstrated that completed PPP projects performed at 88% thereby producing returns in a timely manner and with no public financial burden. Other research has shown that 70% of non-PPP projects were delivered late, with budget breaches at 73% (HM Treasury, 2003b). Some scholars question the objectivity of this data (Pollock, Price & Player, 2005), however, updated HM Treasury research (HM Treasury/UK, 2006b; Partnerships UK, 2006) indicated 500 projects, including refurbished assets and transport assets have entered the operational phase. Based on this, researchers demonstrated that 79% of projects reported user satisfaction, 89% of projects reported that services closely followed contracts, and 96% of projects reported successful performance overall.

There are several sources which create supervisor VFM for private-public partnerships. These include the expertise of the officials of the private sector who are incentivized by risking private finance (Allan, 2001; HM Treasury/UK, 2006a), known as risk sharing/transfer and private financing. Additional

sources include output specifications and long-term contract, which specifies that output services are delivered through long-term contracts with the objective to encourage innovative solutions. Lastly, a special purpose vehicle integrates the partnership responsibility for the design, construction, operation, and maintenance of the relevant assets. All of these concepts will be discussed in the following subsections.



**Figure 2.2.2 Value for Money (VFM) Demonstration(Skanska, 2004)**

### 2.2.2 Risk Sharing (RS)

“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 than in 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).

### **2.2.3 Long-term Contract (LC)**

The long-term contract is designed by officials for risk sharing and allocation between the public and private sectors. A PPP infrastructure project is long-term with a specified concession period, usually 15 to 30 years or more, depending on the nature of the facilities and services to be delivered (Spoehr et al., 2002). The contract length typically extends the entire economic life of the asset including the operation stage. This ensures that the private sector partner evaluates asset development in a whole life-cycle context. The contractor (the private partner) will then manipulate the asset in innovative and cost-effective ways over its entire economic life; in this way the cost of the project is minimized and the VFM maximized (Ministry of Finance/Singapore, 2004). However, the more time spent in development, the higher the likelihood that the project will be affected by emergent events (Dey & Ogunlana, 2004; Flyvbjerg et al., 2002, Flyvbjerg et al., 2003a, Flyvbjerg et al., 2004b; Miller & Lessard, 2000) An experienced private partner is required for success in PPP risk management.

#### **2.2.4 Special Purpose Vehicle (SPV)**

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 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 BOT/PPP arrangement is obtaining private finance for ongoing operations.

#### **2.2.5 Private Financing (PF)**

A private-sector party generally raises project funds both in equity and debt finance for PPP. The concessionaire is usually owned by one or more equity investors. Some of these shareholders may be contractors in the consortium, carrying out construction, design or facilities management work on the project. An equity investor only benefits from a PPP project after successful completion as the public sector participants involved in the project start paying, or the private sector participants start to get revenue from the end-users when the asset becomes available. 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. When the lenders consider financing a project, they exercise extensive due diligence (Dey & Ogunlana, 2004; Ministry of Finance/Singapore, 2004), aided by independent advisors in technical, insurance, legal and financial aspects of the PPP deal. Debt finance is usually 70% of total financing (Esty, 2003). In the United Kingdom, this financing often totals an estimated 90% (HM Treasury, 2004b). There is always a high-gearing SPC for a PPP arrangement. For a BOT project, officials of the SPV are responsible for securing long-term sources of funding of up to 20 years with high-gearing financing risks to ensure ongoing development and operation. Both equity and debt finance concerns impact the overall success of the PPP projects, but high-gearing private finance must be evaluated by officials to prevent VFM erosion due to poor project performance.

### **2.2.6 Output Specifications (OS)**

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

Private sector innovation is especially critical for PPP deals in which the private provider is expected to generate better management than public sector in-house services (Davies & Eustice, 2005). The output specification is vital for the public sector officials to maintain VFM while creating better VFM for the PPP deals. Public service requirements are normally framed as an output specification with a broadly defined objective which allows the private sector officials to produce innovative and cost-effective solutions, as opposed to the technical and narrow specifications included in many traditional agreements (Allan, 2001; Davies & Eustice, 2005; UN/ECE, 2000). “Output specification define 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 not how it is to be achieved.

The specifications should clearly and comprehensively state what is required and the standards to be achieved so that it reduces the uncertainty faced by both the public sector and the private sector provide (4Ps, 2005). An important link between the output specification and payment mechanism for PPP sets out the performance requirements for services in the output specifications and how the public sector officials can make payments to the private sector parties based on whether the output specifications are met.

Therefore, it is vital that communication between the public and the private parties clarifies how performance against these outcome/output specifications is measured and monitored (UN/ECE, 2000; Aziz, 2007).

### 2.2.7 Performance Based Payment (PBP)

The essence of the PPP arrangement is the procurement of services. The robustness of PBP system is an important source of comfort to government that the private party is meeting its obligations to deliver services (Infrastructure Australia, 2008b). The PBP Mechanism is fundamental to the PPP Contract, as it puts into financial effect the allocation of risk and responsibility between the public and the private parties (4Ps, 2005). Payments vary depending on whether the services meet the performance outcome mandated in the output specifications. Substandard performance and services by the private parties ideally would result in reduced payment (HM Treasury, 2003). If the private provider consistently fails to meet the required performance requirements, several options for quality service restoration would be (Ministry of Finance/Singapore, 2004):

1. Deductions/Penalties: If the private party delivers a project behind schedule or the goods or services provided are substandard, deductions and penalties can be imposed by the public party. This is to ensure that private party pursues remedies in service delivery.
2. Stepping in to take over operations: The public party can gain control of operations and services delivery in certain circumstances such as circumstances of serious risk to public health, safety, or the environment, national security, or a national economic dilemma.
3. Terminating the contract due to private sector default: Where the private party consistently fails to deliver adequate services and has failed to remedy this deficiency, the PPP contract will default, giving the public party the right to terminate the contract and step in for assistance.

It is important that the PBP mechanism includes appropriate incentives for the private party to deliver superior goods and services. The PBP will increase the probability that public objectives for the project are being realized. Therefore, this method should be implemented alongside project goals in the output specification (4Ps, 2005; UN/ECE, 2000).

## 2.3 PPP Risk Management and Procurement

### 2.3.1 Project Risk Management (PRM)

Cooper, Grey, Raymond and Walker (2005) defined risk as “exposure to the consequences of uncertainty”. In a project context, it is the possibility of something happening that will have an impact upon project objectives. Such risks include the possibility of loss or gain, or variation from a desired or planned outcome, as a consequence of the uncertainty associated with following a particular course of action. Risk thus has two elements: the likelihood or probability of something happening, and the consequences or impacts if it does. Officials at the Project Management Body of Knowledge (PMBOK) published *Project Management Institute of USA* (PMI, 2004) acknowledging that “the objectives of Project Risk Management are to increase the probability and impact of positive events and decrease the probability and impact of negative events adverse to project objectives.”. Officials at the Association for Project Management of UK (APM, 2000) indicated that “Project Risk Analysis and Management is a process which enables the analysis and management of the risks associated with a project”. Cooper et al. wrote that project risk management processes are designed to assist project planners and managers in identifying significant risks, developing measures and controlling their consequences which leads to more effective and efficient decisions and greater certainty for project performance.

There are four guidelines for project risk management that are used extensively by professional organizations (Cooper et al., 2005) as listed below:

- *Project Management Body of Knowledge* (PMBOK) published by Project Management Institute (USA) (PMI, 2004).
- *Project Risk Analysis and Management* (PRAM) published by Association for Project Management (UK) (APM, 2000) .
- *Risk Management AS/NZS 4360 Standard*, published by Standards Australia/Standards New Zealand (Australia/New Zealand) (SA/SNZ, 2004).
- *Management of Risk* (MoR) published by UK Office of Government Commerce Management / HM Treasury (HM Treasury, 2004a).

The above resources for risk management guidance work relative to different versions of the project risk management process, but each has intrinsic value, and they do not conflict with each other (Cooper et al., 2005). There are four common features in the project risk management processes which last throughout the entirety of the whole life cycle of the project:

1. Risk identification: identifies all the risks relevant to the project.
2. Risk assessment: determines the likelihood of identified risks and the magnitude of their consequences.
3. Risk mitigation: identifies actions most likely to reduce consequences of the risk.
4. Monitoring and review: continuously monitors project to detect and prevent new risks.

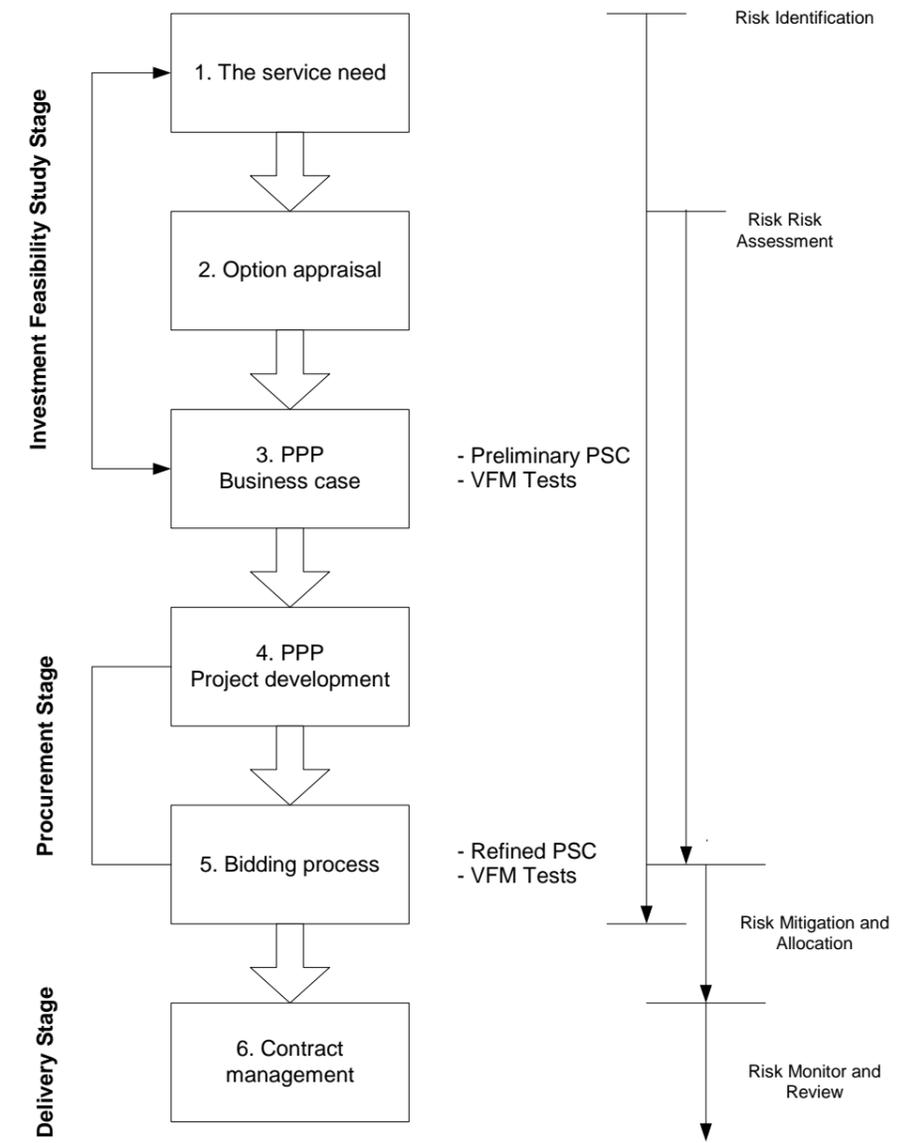
### **2.3.2 PRM and PPP Procurement**

The emergence and increased use of PPP arrangements has changed the traditional procurement environment. These new agreement structures require different varieties of contractual arrangements and new forms of control and accountability, which unfortunately create new kinds of risks (Cooper et al., 2005). The government officials monitor PPP projects and the quality of their VFM, which has a higher priority than those of government owned, financed and managed projects. The PPP procurement process requires risk allocation analysis by officials between public and private parties so the likelihood and severity of project shocks can be reduced. This monitoring also results in lower risk premiums and reduced project costs (Allan, 2001). Cooper et al. wrote that risk management is a critical element in strategic planning for PPP procurement. Government measures are sometimes needed to improve the quality of procurement activities.

The PPP process has been designed to apply risk management processes over the whole life cycle of the project. This includes establishing the context, identification, analysis, evaluation, management and monitoring of the risks of a project. The details of PPP process for various countries may be different, but the general framework is the same. Figure 2.2.1 (HDR, 2005; HM Treasury, 2003b; Partnerships Victoria, 2001a) shows the whole PPP process is generally categorized into three sequential stages: investment

feasibility, procurement, and delivery. The major steps and tasks for each stage are listed below (HM Treasury, 2003b; Partnerships Victoria, 2001a):

1. The Investment Feasibility Stage: The first step is to identify public service needs, and formulate output specifications, which had been outlined in Section 2.1.5. The output specifications should allow for innovation in creating value for money. The second step is to consider the PPP option versus the public procurement option by identifying project risks and evaluating financial impacts. The final step is to formulate a PPP business case with proper perspective on the identified risks and costs to develop a cost-benefit analysis to test the net benefit of the proposal. The preliminary PSC is developed to confirm that the PPP option demonstrates VFM. The business case should identify all significant risks, allocating some to a private party, and some to be retained by the government. The effected business case is used to obtain funding and project approval.
2. The Procurement Stage: The first step is project development. After funding approval is obtained, the project plan and commercial principles are developed, and the resources for project procurement are ranked by real formal market interest. In this step, a detailed and refined PSC is developed by officials for bids evaluation. The second step is the bidding process. This includes developing “Expression of Interest Invitation,” the proposed risk allocation of the project (risks that would be transferred to the private sectors), and the details of the services that the private sector parties are being invited to deliver, to allow potential bidders to form a view on whether they have the necessary capabilities. Secondly, a *Project Brief*, which includes output specification, conditions to bid, and bid evaluation criteria is developed. Third, the VFM test is implemented to choose the preferred bidder. This bidder is then invited for contract negotiation for optimal risk allocation. Finally, the parties involved reach financial close by awarding the contract.
3. The Delivery Stage: The major task is to monitor project delivery and manage project risks and variants by contract management.



**Figure 2.3.1 The Risk Management and PPP Process**

## 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), this 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 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).

The IRR is the interest rate that makes the NPV of a cash flow project equal to zero (Park & Sharp-Bette, 1990). The multiple values of IRR make it a poor substitute for NPV as a factor in bid comparison (Watson, 2005). In many cases, multiple values of IRR are especially likely, such as when the annual net cash flow of the project alternates between positive and negative figures because of project cyclical re-capitalization requirements or fluctuations in the prices of inputs and outputs (Park & Sharp-Bette). The multiple values of IRR are not easily calculated by computer. In some cases it may lead to incorrect decisions among bids if a single value for the IRR is applied (Watson).

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).

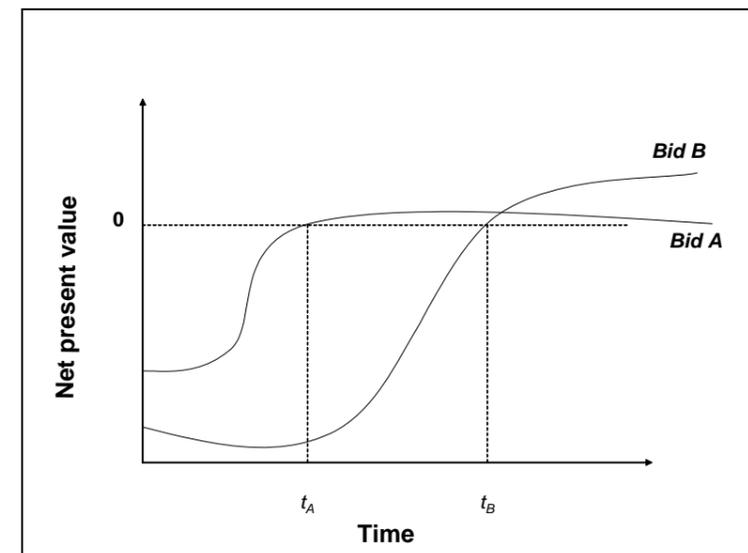
The payback period is defined as the time it takes for the cumulative present value of benefits to equal that of cumulative present value of costs. In general, shorter payback periods are better. This can, however, be misleading in that it ignores everything that happens after the payback point. It is 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.

**Example 2.4.1**

	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 BCA 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 risk matrix with expertise judgment and statistic techniques can help to quantify subjective and qualitative data and convert non-monetary terms to monetary terms in an objective and systematic manner. This is discussed in Chapter 3: Research Methodology.



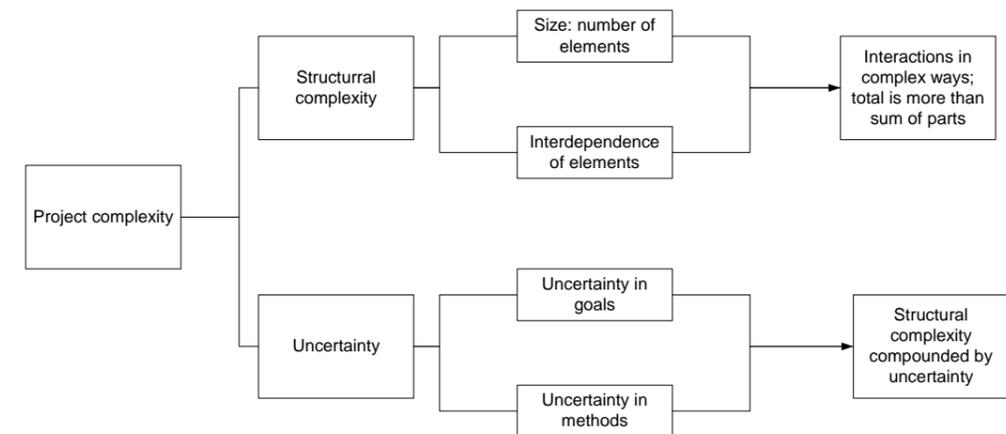
**Figure 2.4.1 Payback Period Compared for Two Bids (Watson, 2005)**

- ***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 behavior. 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 modeling 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 behavior, 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.



**Figure 2.4.2 Dimensions of Project Complexity(Williams, 2002)**

## 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?

- ***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 ensure 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, all of the PPP projects are unique with specific risks (HM Treasury, 2003a, 2004c; Partnerships Victoria, 2001b, 2003a). 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 the approaches such as risk matrix with expertise 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**

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:

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

Where  $\rho$ : is the consumption per capita

$\mu$ : is the elasticity of marginal utility of consumption

$g$ : is 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)

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

Where:

- $R_a$  is 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;
- $R_f$  is the risk-free rate;
- $\beta_a$  is 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:

- $\beta_a = \frac{\delta a m}{\delta m^2}$

where:

$\beta_a$  is the beta for asset ‘a’;

$\delta a m$  is the covariance of returns of asset ‘a’ compared to market returns;

$\delta m^2$  is the variance of market returns.

- $R_m - R_f$  is 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.

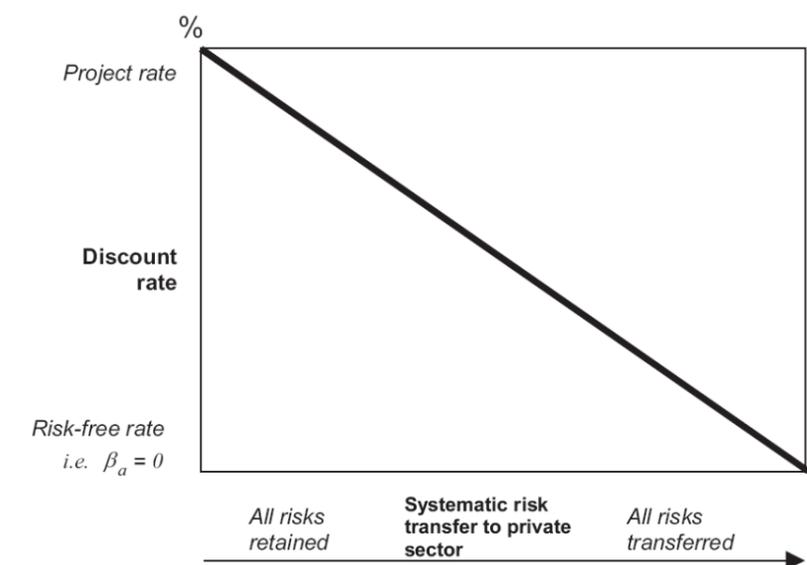
- Projects with net cash outflows: When calculating discount rates for net cash outflow projects, a more risky net cash outflow would be assigned a higher discount rate, resulting in a lower net present cost (*NPC*). This would make the higher risk project seem preferable to a lower risk project. Therefore, 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).

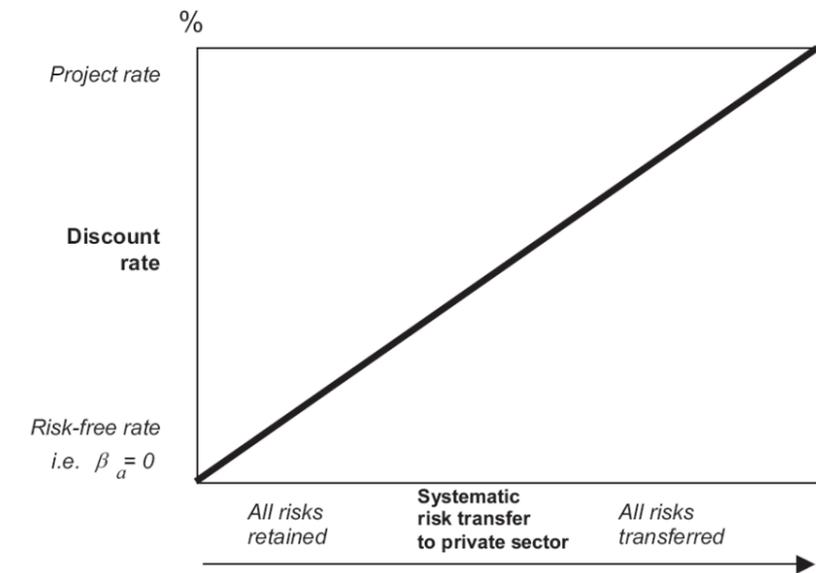
In practice, accuracy of the discount rate calculation will yield marginal benefits unless the cash flows can also be forecast to the same degree of accuracy. For most PPP projects, this will likely prove time-consuming, and for minimal gain (Heald, 2003). To minimize the bias on discounting cash flow 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	<b>Accommodation and related services</b> Aged care housing Public housing Hospital facilities Correctional facilities	0.3	1.8	5.0% (4.8% rounded to nearest whole number)
Low	<b>Water, transport and energy</b> Wastewater treatment plants Water infrastructure Hospital car parking Hospital energy plants Road projects (non-toll)	0.5	3.0	6.0%
Medium	<b>Telecommunications, media and technology</b> 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 States 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):

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

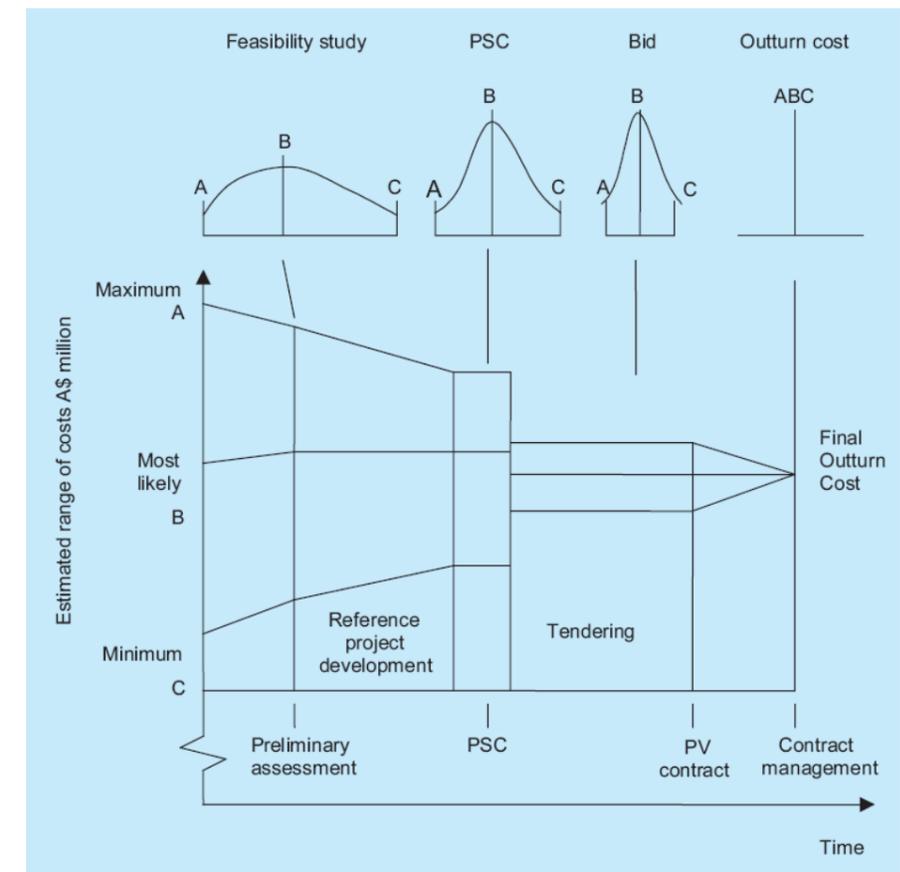
Mott MacDonald (2002) indicated that optimism bias is caused by a failure to identify and effectively manage project risks. Additionally, optimism bias for a project decreases through its project life-cycle. For early estimates, the typical average deviation (confidence range) is larger than in definite 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. 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. 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 Torpedo diagram, as shown in Figure 2.4.5 (Partnerships Victoria, 2003a), indicates these effects of uncertainty. This diagram shows how the development of the reference project (business case) generally results in a better understanding of the risks associated with the project and a corresponding reduction in the spread (confidence range) of potential outcomes. The step-down between the PSC and the PV contract (the PPP contract of Victoria/Australia government) represented VFM outcome 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.

“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 Flyvbjerg. 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 Flyvbjerg 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 (%) <sup>2</sup>			
	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%

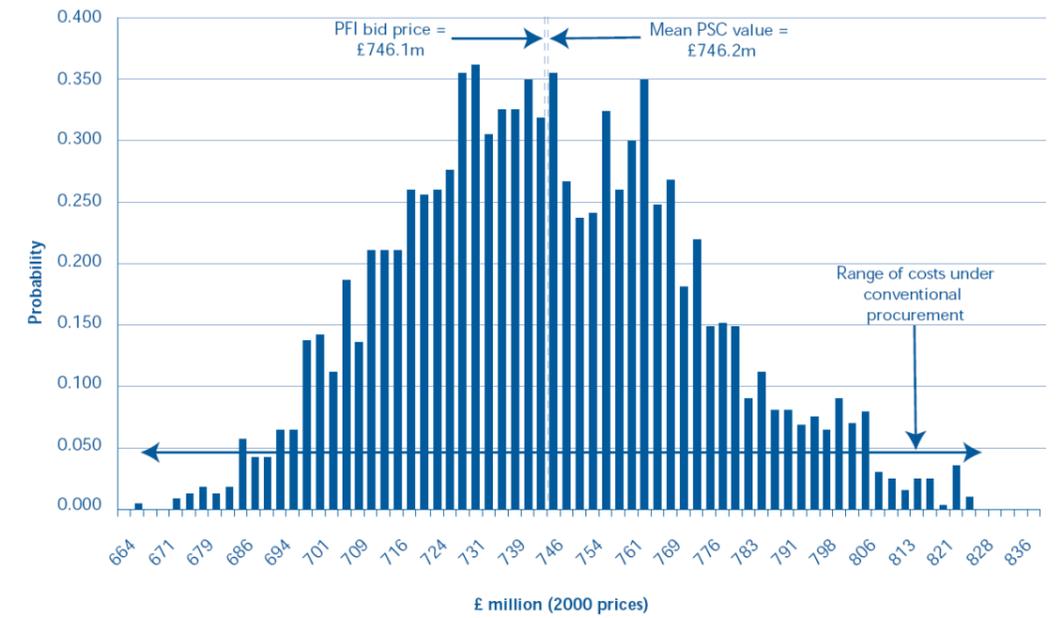
## 2.4.5 Critics on the Bids Comparison

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 2.5<sup>th</sup> percentile of PSC distribution) to £807m (the 97.5<sup>th</sup> 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;).

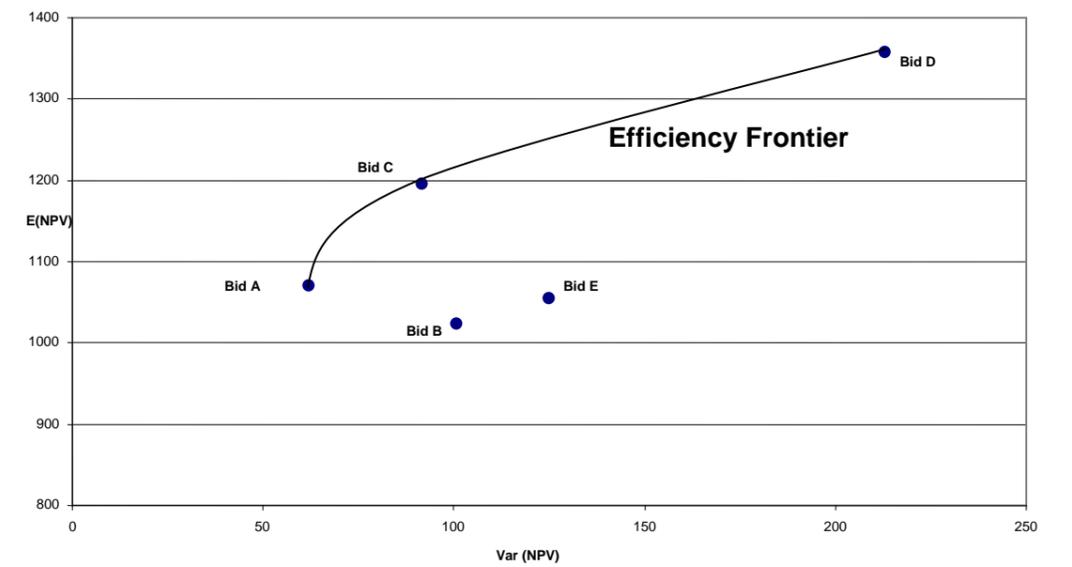
Full statistical analysis of outcomes using the Monte Carlo simulation, incorporating sensitivity analysis and worst/best case scenario analysis, gives more realistic risk analysis and representation in terms of range (confidence intervals) of possible outcomes, and provides the most detailed comparisons (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)**

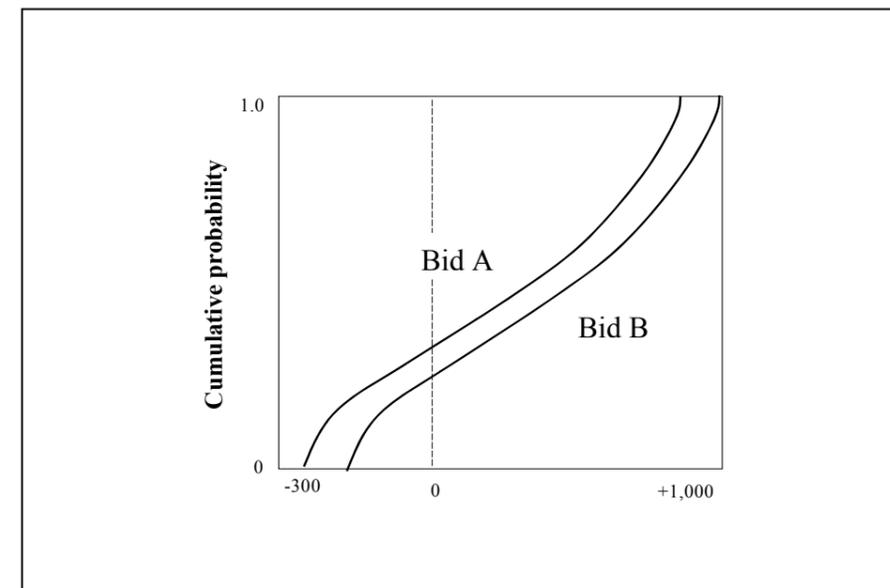


**Figure 2.4.7 Mean-variance Plot for Bid Comparisons (Park & Sharp-Bette, 1990)**

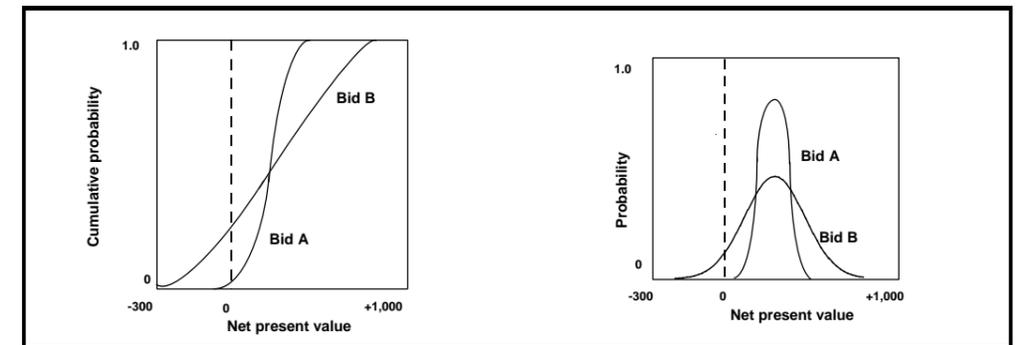
However, the mean-variance rule has shortcomings in that if the outcomes are not distributed normally, the model solutions may become unreliable. “Typical dispersion statistics used as risk measures may lead to some efficient solutions, stochastically dominated by other feasible solutions (Oryczak, 2000).”

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-averse* 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)**

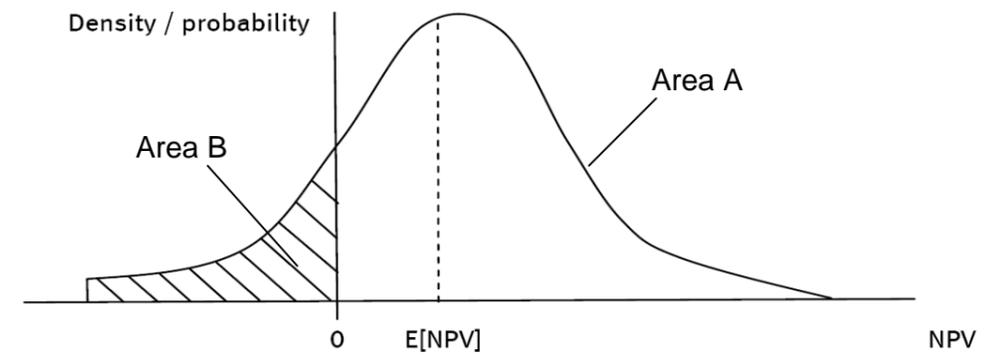
One measure that is particularly useful in summarizing of the overall level of risk in public investment is the expected-loss ratio (ELR), which refers to (Limbu et al., 2006; Stahr, 2006; Watson, 2005):

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

Where  $L$ : the expected loss;

$G$ : the expected gain;

As shown in Figure 2.4.10, the area B shows the expected value of all losses ( $L$ ) which is defined as the proportion 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.

## **2.5 Issues of Computer-aid Systems**

The increasing complexity in making decisions has resulted in the creation of many decision support systems or expert systems for the infrastructure-related projects. Mysiak, Giupponi and Rosato (2005) designed a decision support system (DSS) for water pollution management under the European research project MULINO. Their system uses a systematic approach based on DPSIR framework formulated by the European Environmental Agency (EEA) which involves driving force-pressure-state-impact-state-response to structure and exploring the different causes for the semi-structured or unstructured problems for environmental issues, predicting the future effects of response actions. Pollution density is the decision variable for study and the study is quantitative in nature. The multiple-criteria analysis is applied in rationing the preference uncertainty and aggregating the conflicting group preference. The authors, using

this system, allowed the end-users to be involved at earlier stage of the system development and engage in highly interactive feedback to change system. Perdomo (2004) introduced a DSS for supply chain management in the construction industry. Based on the operations process, this system consisted of six decision models, corresponding to six major tasks of material management that included (a) what material to buy, (b) how much to buy, (c) when to buy materials, (d) when to deliver materials, (e) where to deliver materials, and (f) where to store on sites. The parameters used to measure the performance for each decision model are classified and ranked by a system called SPARCS (supply-chain parameter classification system). Each decision model allows analysts to extract the parameter information needed from specific data sources. Perdomo stated that by using this system professionals can group data effectively and support data integrity for effective decision making. Unfortunately, there is no clear picture to describe the mechanism used in the decision models and SPARCS.

Deng (2004) proposed a case based reasoning DSS to predict cash flows and develop strategic project financing plans. Among the items in a case library, the previous solutions to those identified cases were similarly structured and adapted to current problems. Based on the characteristics of the project, analysts using this system search its database and select the most relevant project and present the adjusted cost-time profile with possible variations to the user. The generic algorithm then is used for project financing optimization. The use of this system closely reproduced the opinions of the domain experts, and system outputs were correct and consistent. Kazeli, Keravnou, & Christofides (2003) developed a DSS consisting of four modules: (a) data, (b) decision maker, (c) manager, and (d) display module for water resources allocation. The data module manages the data and information required by the overall system; the decision maker module simulates the different water allocation strategies under various assumptions; the manager module controls the overall system, and the display module stores and displays all the resulting information. This system applied multiple regression and time series to analyze the uncertainty in water supply and demand which were the major control variables. System dynamic modeling and priority matrices allow decision-makers to use what-if reasoning and heuristic judgment of the conflicting resources allocation priorities. This system could address the real, heterogeneous and highly complex problems so as to effectively manage water resources.

Matzoros (2002) introduced a DSS for public transport service management. This system consists of a data warehousing subsystem for the integrated management of a wide variety of data sources and online analytical processing tools for what-if scenario testing. To achieve optimal service quality and performance with minimum development time and risk, this system uses ready-made software packages that allow rich functionality and open architecture to facilitate expandability and adaptability to future changing needs. The major objectives of this system were to optimize management's decisions and operational planning, to minimize management's reaction time, and to optimize the use of available resources. Several categorized parameters regarding data warehousing objectives were discussed, but there was no description of analytical tools or approaches for the online analytical processing. Molenaar and Songer (2001) proposed a Web based DSS for design/build project selection. This system consisted of 3-tiered architecture: input level, processing level, and output level. In the input level, a project characteristic questionnaire and a success criteria questionnaire are used to collect data on project variables and outcomes, thus forming the basis prediction models in the next level. The process level is a mathematical mechanism. Multiple regressions are used in the process level to model the score and weight of each linear predictive equation, and pair-wise matrix comparison for project success criteria. The output level provides a graphic display for the overall project rating and individual variable analysis, plus a series of text formed advisory information to give insight interpretation of the analysis results. The benefits of this Web based DSS are accessibility, efficient distribution, effective administration and cross-platform flexibility. Mezher, Abdul-Malak, and Dayya (1999) proposed a DSS to help in the management of the infrastructure of telecommunication projects. The major objective was to evaluate and control the performance for prime contactors, subcontractors, and sub-subcontractors. There are three standard components in the Mezher et al. system: data base, model base, and user interface. To promote accessibility for the intended users, top managers, project managers, engineers, data assessment and control managers and computer operators, this system was installed on different local area networks. The user interface has critical features including a user-friendly interface module, modular structure, build-in queries and several types of reports. The creators also believed their system is effective in providing managers with timely, accurate, concise, relevant and complete information. Unfortunately, the Mezher et al. did not introduce the backend

analytical decision-making tools. For example, how this system can verify the resources availability and help in projecting what additional resources are required is unknown.

Russell (1992) presented a framework of a hybrid computerized DSS for the evaluation of construction contractors' suitability to perform infrastructure projects, integrating the existing software packages and decision modeling techniques. This system integrates several facets to assist in evaluation of suitability. These facets include (a) a financial model to determine the maximum financial capacities of a contractor, (b) a linear model with multiple ratings to combine subjectively rated criteria for decision and corresponding probabilities to account for the imprecision, (c) a fuzzy set model for qualitative criteria; a statistical model to quantitatively evaluate criteria, (d) a multi-attribute utility model to combine multiple qualitative and quantitative decision criteria and objectives, (e) a methodology model to combine qualitative and quantitative criteria for decision making, and (f) a hybrid model to integrate decision models. It was supposed that this system would enhance the ability to arrive at solutions and use available data to its full potential.

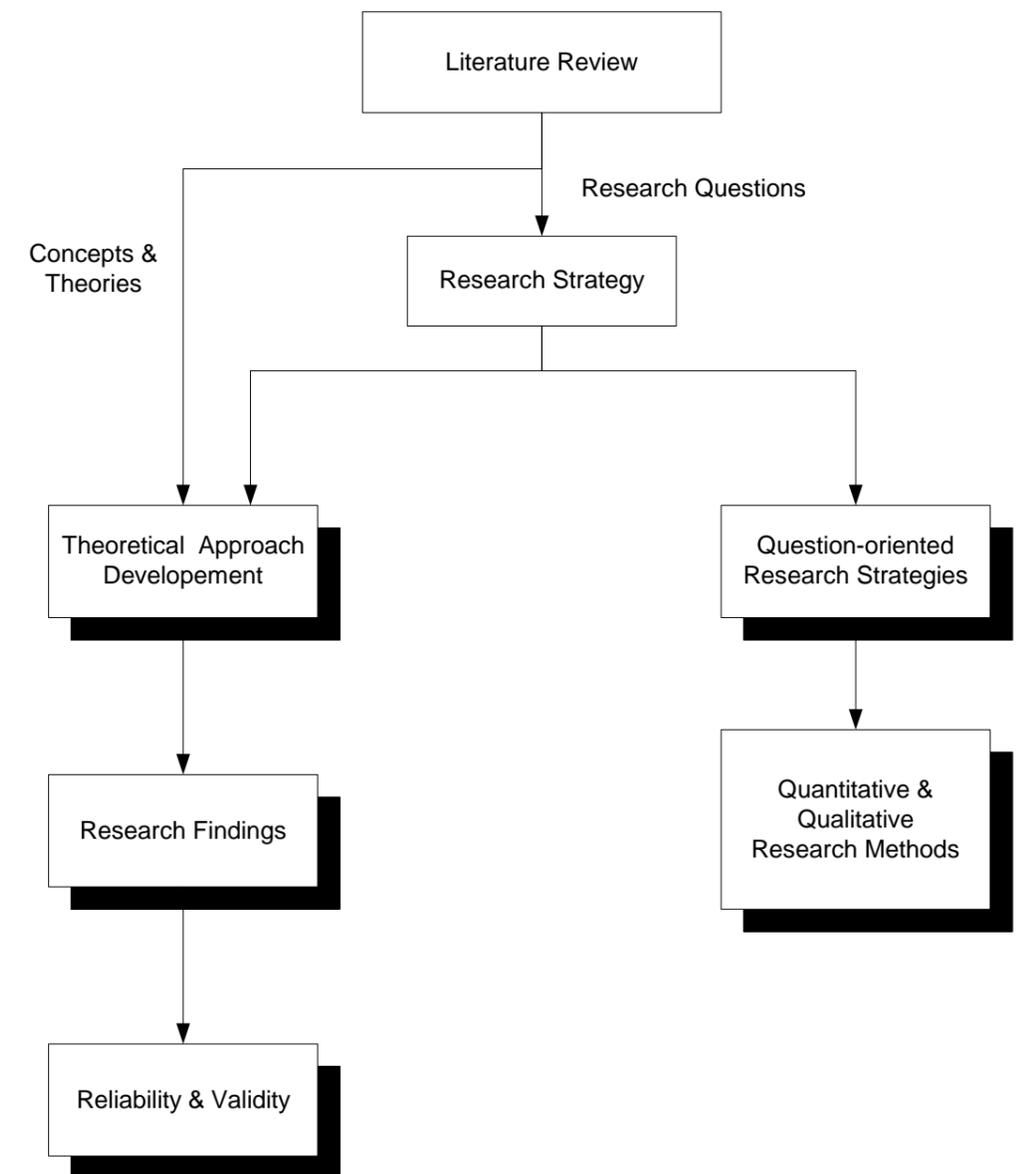
There are many knowledge-based risk management systems currently implemented as prototypes. Tah and Carr (2001) developed a rule-base system that utilizes fuzzy logic in risk quantification. Zoysa and Russell (2003) explored a knowledge-based DSS for risk identification in infrastructure projects. Baloi and Price (2003) developed a fuzzy decision framework for contractors to handle global risk factors affecting construction cost performance at a project level. Deng(2004) developed a decision support system and expert system for PPP project funding and cash flow management.

This researcher has introduced various characteristics of the current computer-aided systems for infrastructure projects. Most of these systems are still in the stages of conceptual framework or prototype systems and have not actually been implemented. Therefore, it was difficult for this researcher to collect sufficient information to judge whether these systems are, in fact, successful in their respective domains. Each computer-aided system has its own advantages and disadvantages. The authors of these systems had described the system features and declared the benefits in their studies. However, the common limitations of the current computer-aided systems identified by researchers (Butler & Fitzgerald, 1999; Finlay & Forghani, 1998; Labadie, 2004; Matzoros, 2002; Mysiak et al., 2005; Nord & Nord, 1995; Palva &

Chervany, 1995; Poon & Wagner, 2001; Reidsema & Szczerbicki, 2002; Salmeron & Herrero, 2005; Turban & Aronson, 2001) are summarized in the following points:

1. Inability to deal with unstructured problems: The risk problems for a large-scale infrastructure concern the aspects of technology, economy, environment, and politics which are heterogeneous, structured, as well as unstructured in nature. For example, some systems for environmental infrastructure projects only focus on physical pollution problems and exempt social, political, and regulatory problems. The physical problems are often more structured in nature. These systems are therefore incapable of dealing with the unstructured problems.
2. Inability to track problems throughout the life cycle of the project: The risk problems in terms of cost, schedule, quality, and the like dynamically reflect over the whole project life cycle. Some of the current systems lack the global view on project life cycle. For example, most of the systems for infrastructure projects focus on the construction stage only, and ignore the other stages. Therefore, it is difficult for evaluators to thoroughly mitigate the risks raised from the design and operation stages.
3. Inability to support the overall risk management: “The effective risk management involved three distinct stages, namely risk identification, risk quantification and risk response and control (Akintoye et al., 2001)” Most systems for infrastructure projects do not account for all stages of risk management simultaneously. Moreover, some systems adopt only a single decision technique which is incapable of accounting for the decision-making processes relative to multi-domain risk problems in an infrastructure (Russell, 1992).
4. Inability to reach a consistent decision making conclusion and adapt to flexible change: Most of the current systems do not begin with both internal and external searches from various database groups. In addition, they lack a feedback mechanism. This leads to inconsistent decision-making among various groups and inflexible system changes in the future. For example, risk variables not consistently identified and defined through various managerial levels may cause different structures for decision variables. It cannot support a consistent decision-making and flexible change without a feedback design.

## Chapter 3 Research Methodology



**Figure 3.1 Research Framework**

Figure 3.1 shows the whole research framework for this research. Drawing from the literature review described in Chapter 2 for the relative issues of PPP project contractor-selection methods, this researcher developed the research questions, concepts and theories in terms of PPP project contractor selection. The corresponding strategies, including qualitative and quantitative research methods are developed to address each research question. By combining these concepts, theories, and research strategies, a theoretical approach is developed to build a decision model for PPP project bid-evaluation. The relative methods were applied to test research findings to ensure the developed theoretical approach is reliable and valid.

### 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 physical 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 physical 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
<p>1. Are risks physically independent? How can the relationship of risks be identified if they are not physically independent?</p>	<p>As the literature review discussed in Chapter 2, the risks may not be physically independent in reality.</p>	<p>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.</p>	<p>1 What are the generic risk events inherent in the PPP transport projects over project life? 2 How can we model the risk interrelationships of the PPP transport projects?</p>
<p>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?</p>	<p>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 &amp; 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 &amp; Lewis, 2005). Furthermore, there is the widely belief that</p>	<p>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.</p>	<p>3 How can we quantify the qualitative risk effects, while using CBA for cash flow analysis? 4 How can we quantify physical risk interrelationships?</p>

	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.		
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 this research. This 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	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	None.	None.

<p>cash flow analysis is performed to estimate NPV for comparing the PSC with bidding proposals?</p>	<p>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.</p>		
<p>6. Should a single number or a range of NPV values be examined to choose the preferred bidding proposal with the best VFM?</p>	<p>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 &amp; Brown, 2004; Stahr, 2006).</p>	<p>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.</p>	<p>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?</p>

## **3.2 Research Strategy**

As shown in Figure 3.1, this 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, this 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 natural 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: *facilitation* 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 this research was to develop a bid-selection method for the PPP transport projects which should effectively predict the trends of project net present value and compare and choose a preferred bidding proposal with the best value for money. It investigates different aspects of a phenomenon for this 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 behavioral 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 Behavioral 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 behavior 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 behavior 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 behavior 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, this 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	<p>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 this research question.</p> <p>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.</p>

Research question 2	How can the physical 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 modeling and statistic analysis.
Rationales	<p>This is a How question to explain the phenomena about the cause-effect for risks and their physical 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 modeling and statistic analysis are applicable to this research question.</p> <p>A PPP transport project was chosen as an example to model and explain the physical risk interrelationships over the whole project life cycle. 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 transport 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 modeling. After all, a statistic analysis was performed to formulate the physical risk interrelationships.</p>

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	<p>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.</p>

	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.
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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 modeling 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 modeling 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

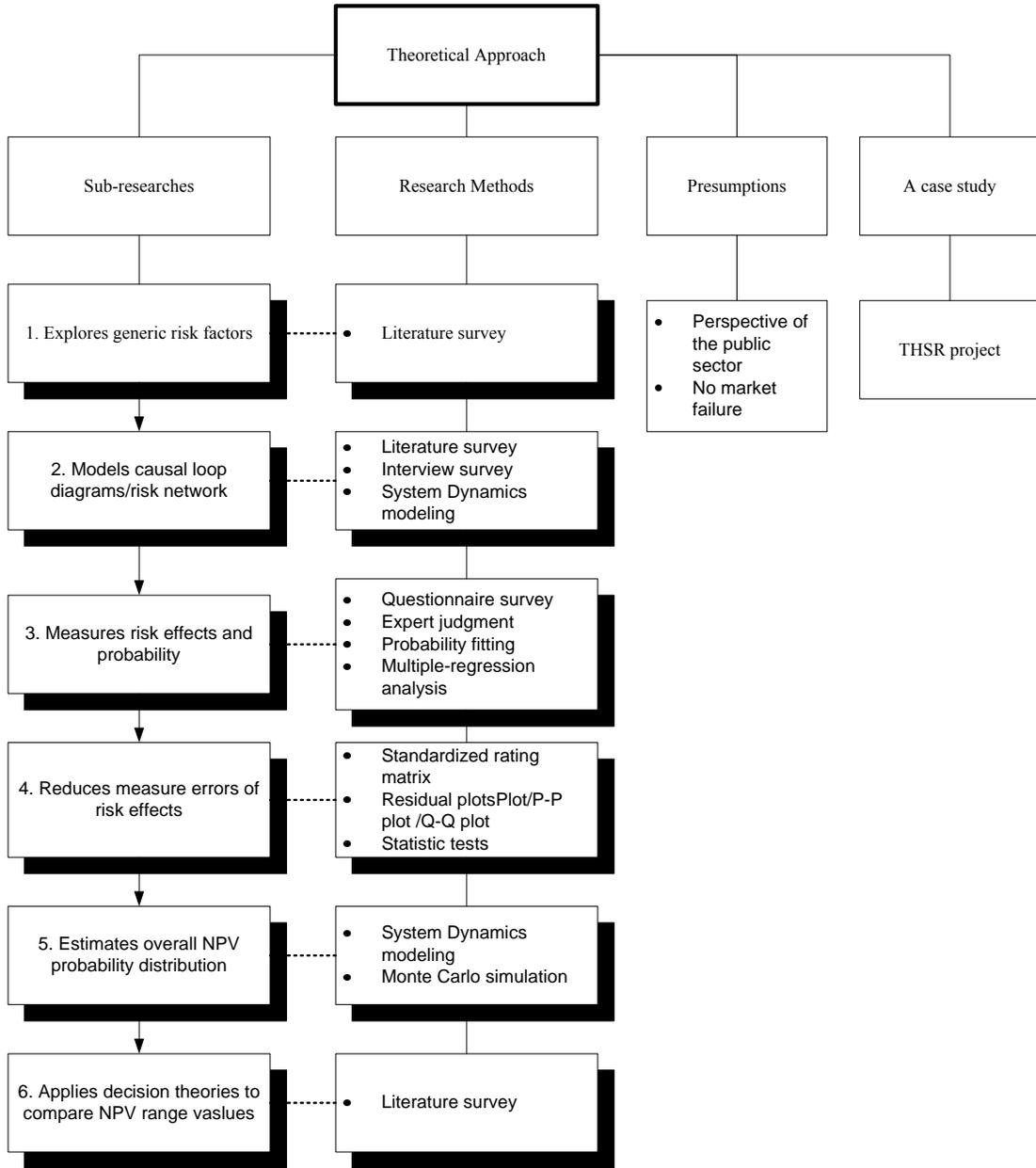
The objective of this research was to develop a theoretical approach in building a decision model for the PPP project bidding-proposal selection. The researcher investigated different aspects of issues and phenomena to determine what needed to be addressed and how to evaluate these seven research questions. This researcher expects this research to help the public sector officials better select a concessionaire who is most capable of managing project risks in a cost effective manner and also provide better value for the money paid. The Taiwan high speed rail project is an application case that was employed by this researcher to demonstrate the theoretical approach development.

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

1. Investigated the generic risk factors. Explored using literature survey, the generic risk factors that have created downside effects on PPP project performance during concession periods.
2. Modeled causal loop diagrams. Modeled and interpreted the physical risk interdependencies and interactions by literature survey, interview survey, and System Dynamics modeling technique.
3. Measured risk effects and probability. Measured and quantified qualitative risk effects using questionnaire surveys with a risk rating matrix. Inferred risk effect probability distribution by probability fitting; estimated and quantified risk interrelationship by multiple-regression analysis.
4. Reduced measured errors of risk effects. Reduced measure errors and ensured data reliability through a standardized rating matrix with clear definitions for rating risk effects; performed the probability plot/P-P plot /Q-Q plot with Anderson-Darling statistic and chi-square statistical tests to ensure the theoretical probability distribution fit exogenous risk variables well; conducted residual plots with R-square and  $p$  value statistical tests to ensure that multiple-regression models adequately explained risk effect interrelationships.
5. Estimated the overall NPV probability distribution. Modeled 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 modeling technique; estimated the probability distribution for project NPV time-profile by running Monte Carlo simulation.
6. Applied decision theories to compare NPV range values. Using the literature survey, investigated and applied appropriate decision methods to compare NPV probability distribution among the bidding proposals.

It was assumed by this researcher that the proposed research approach would improve the current methods for bid-selection process for the PPP transport projects, and it was assumed that this research would apply to other PPP projects in a beneficial manner. This was all based on the following presumptions by this researcher:

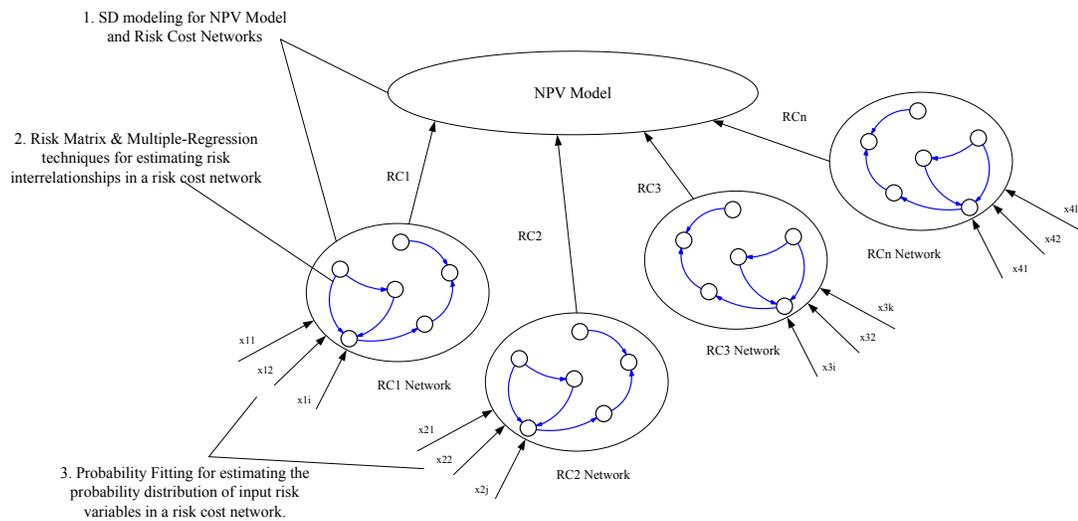
1. The bids selection method is developed from the perspective of public sectors.
2. The bids selection method is developed for all transport projects that can satisfy the preliminary conditions described in previous chapters that they are suitable for a PPP procurement approach, which include:
  - 1) The transport infrastructure projects have undergone investment feasibility analysis so that officials can provide better *value for money* by using PPP approaches instead of traditional public procurement approaches. This researcher assumed that PPI delivery approaches are better than traditional approaches for infrastructure project procurement.
  - 2) The public sector officials have sufficient capability and skills to adopt the PPI approach that formulates the service specifications to determine which bid ensures the best value for the money and to conduct and manage a long-term contract relationship with the private sector officials.
  - 3) 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 Bid-Selection**

### 3.4 The State-of-the-Art

The major risk analysis techniques used in this research were System Dynamics modeling, risk rating matrix, multiple-regression analysis, and probability fitting. As shown in Figure 3.4.1, this 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.



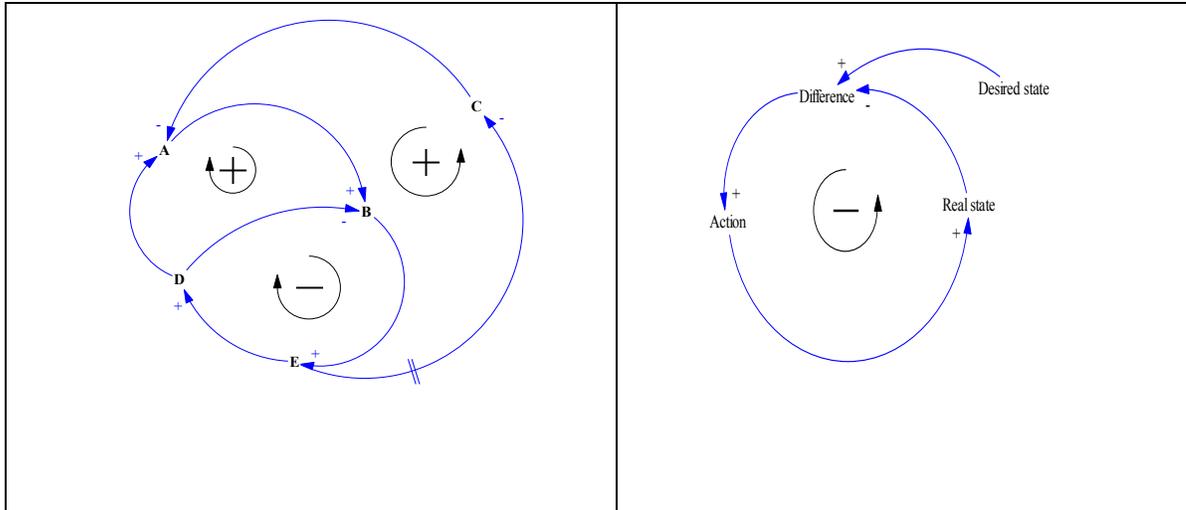
**Figure 3.4.1 The Major Risk Analysis Techniques**

### 3.4.1 System Dynamics

In a large-scale project, applying a causal-effect modeling 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 modeling the inter-relationships such as non-linear behavior, 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 behavior 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.



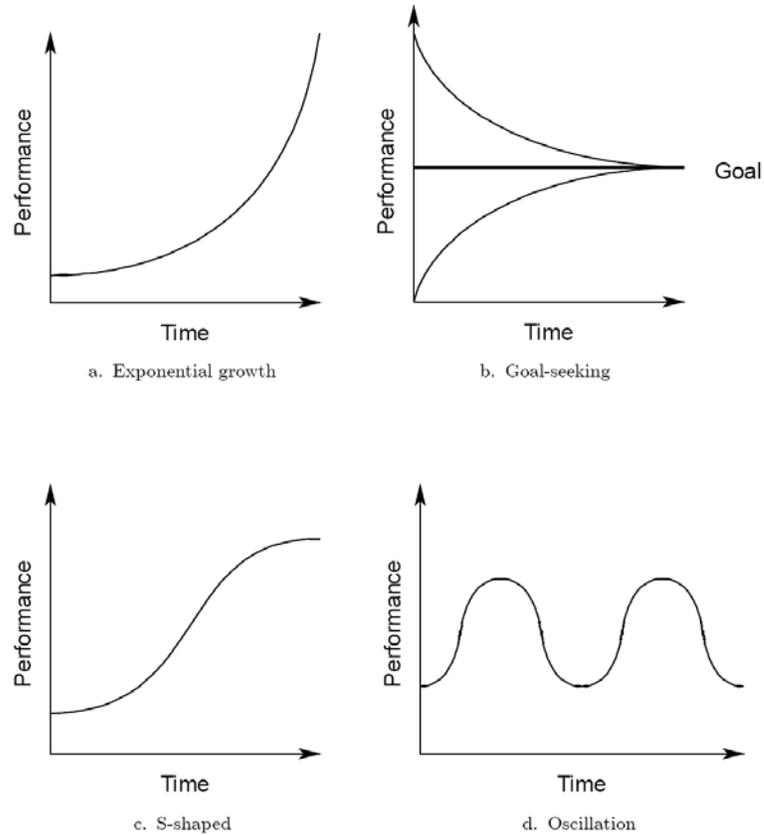
**Figure 3.4.2 System Dynamics Feedback Loops (Left) and Go-seeking Feedback Loop (Right) (Sterman, 2000)**

Kirkwood (1998) wrote that a system compounds specific events which will often cause four basic problematic patterns of behavior over time. As shown in Figure 3.4.3 (Kirkwood), these patterns of behavior 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 modeling requirements, especially for large-scale construction models”

System Dynamics modeling 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 behavior 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, this researcher found that SD is a sustainability tool for modeling 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 modeling 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 modeling challenging (Coyle, 2000; Luis & Deborah, 2003). Concerning the modeling 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 modeling may be necessary (Williams). This research combines various techniques and tools to infer the risk consequence and likelihood for risk variables.



**Figure 3.4.3 Patterns of System Behavior (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 degree scale numbering from 1 to 25. The degree rating in a risk matrix indicates the severity and effects of each risk alongside the project performance outcomes. A higher rating indicates a greater degree of impact of the risk. This researcher designed a questionnaire survey based on the 1 to 25 scale of the risk matrix shown in Table 3.4.1. This researcher sent this questionnaire survey to participants asking them to rate the risk degree 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, this 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 this research, this researcher incorporated clearly-defined risk rating matrix 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 based on the risk rating matrix 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**

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

### 3.4.2.3 Multiple Regress Analysis

The regression modeling 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 modeling 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. This researcher will apply the quadratic multiple regression model including interaction terms and quadratic terms to quantify the functional relationships for a risk variable and its independent variables in a risk cost network, which is expressed as:

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

, where  $Y_i$  = the value of the dependent variable in risk network  $i$ ;  $\beta_0$  to  $\beta_j$  = constant or regression coefficients;  $X_{i1}$  to  $X_{ij}$  = the value of the independent variables in risk network  $i$ ;  $i$  = the  $i$ th risk cost network;  $j$  = number of relatively independent variables;  $\varepsilon_i$  = the *RANDOM NORMAL*(0,  $\sigma$ ) for the error term of  $Y_i$  that is a normal distribution with mean of 0 and standard deviation  $\sigma$ , where  $\sigma$  = 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, this 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 this research.

- *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.
- *Construct validity*: Yin (2003) defined this 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). Especially Yin recalled a case study investigator who was often criticized for failing to develop a sufficiently operational set of measures and subjective judgments to collect the data.

To ensure construct validity, this 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 quantitative 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” This 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 a case study report was reviewed by key participants who are experienced or expert in the field related to the PPP projects

**Table 3.5 Criteria and Actions to Ensure Research Quality**

<b>Criteria</b>	<b>Actions</b>	<b>Phase of research process to take actions</b>
Reliability	<ul style="list-style-type: none"> <li>• The research procedure will be described in detail (Mitchell &amp; Jolley, 2006).</li> <li>• Well documented data (Yin, 2003; Tellis, 1997).</li> <li>• Makes citations for data sources (Yin, 2003; Tellis, 1997).</li> <li>• Establishes a database (Yin, 2003; Tellis, 1997).</li> <li>• Makes a chain of evidence (Yin, 2003; Tellis, 1997).</li> </ul>	<ul style="list-style-type: none"> <li>• Data collection</li> </ul>
Construct validity	<ul style="list-style-type: none"> <li>• Collects multiple sources of evidence (Yin, 2003; Tellis, 1997).</li> <li>• Conducts data triangulation (Yin, 2003; Tellis, 1997).</li> <li>• Makes a chain of evidence (Yin, 2003; Tellis, 1997).</li> <li>• Let key informants review the draft for the case study report (Yin, 2003; Tellis, 1997).</li> </ul>	<ul style="list-style-type: none"> <li>• Data collection</li> <li>• Composition</li> </ul>
Internal validity	<ul style="list-style-type: none"> <li>• Applies cause-effect modeling (Yin, 2003)</li> <li>• Does pattern-matching with analytic analyses such as descriptive statistics, probability distribution analysis. scenario &amp; sensitivity analysis and discrepancy comparison (Kazell &amp; Keravnou, 2003; Mitchell &amp; Jolley, 2006; Yin, 2003).</li> </ul>	<ul style="list-style-type: none"> <li>• Data analysis</li> </ul>
External validity	<ul style="list-style-type: none"> <li>• Formulate theory and prepositions (Yin, 2003).</li> <li>• Use falsification to test generalization (Flyvbjerg, 2006).</li> </ul>	<ul style="list-style-type: none"> <li>• Research design</li> </ul>

- *Internal validity*: Mitchell and Jolley (2006) defined this 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. This researcher focused on building a cause-effect model to predict project NPV trend for PPP project bid-selection, which involves the above two definitions.

As for the first definition, this researcher has designed this 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 this 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, this 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. This researcher applied cause-effect modeling 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).

- *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. Flyvbjerg further asserted that a single case is ideal for generalizing by using falsification, which is “the most rigorous tests to which a scientific proposition... If just one observation doesn’t fit with the theory proposition, it is considered not valid generally and must therefore be either revised or rejected”. This researcher designed this research to develop a bid-selection theoretical method for the PPP transport projects underlying a single-case study, incorporated with quantitative and qualitative strategies. This 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 bid-selection. By applying falsification, the developed selection theoretical method is expected to be applicable and informative to other same types of project in the same industry.

## Chapter 4 Risk Factors and Causal Loop Diagrams

The purpose of this 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, this researcher investigated and identified the generic risks which would impact PPP project performance in the first instance. The physical 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

This 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**

<b>Authors</b>	<b>Research methods</b>	<b>Types of Project</b>	<b>Risk Focuses</b>
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**

<b>Authors</b>	<b>Research Methods</b>	<b>Types of Project</b>	<b>Risk Focuses</b>
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 this researcher cannot demonstrate research reliability described previously in Chapter 3 in which outcomes are predictable and coherent. Therefore, to achieve research reliability, this 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: Some 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. For example, it resulted in unnecessary difficulties when *neutral-meaning* or *positive-meaning* terminologies were used instead of *negative meaning* terminologies to represent the risk factors. All of these issues incorrectly and inconsistently describe and measure risks. As a result, this research could not meet the requirements for internal validity described previously in Chapter 3. Therefore, to achieve internal validity, this researcher defined and described the generic risk factors by using negative-meaning terminology.
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, this 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 this research cannot meet the requirements for construct validity and external validity described in Chapter 3. To achieve both construct and external validity, this 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 for Case Study**

Risk Factors	Internal/ External to Project	Project Phases	Evidence
<b>Availability risks</b>			
(1) Land unavailable	Internal	Construction	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the Melbourne City Link (Hodge, 2004), the Yangtze Three Gorges Project (Lu, 2004), the Bangkok Second Stage Expressway (The Work Bank, 1999).</li> </ul>
(2) Resources unavailable	Internal	Construction/ operation	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>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).</li> </ul>
(3) Performance unavailability	Internal	Construction/ operation	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the London Underground (EC, 2002; PAC, 2005a), the Melbourne City Link (Hodge, 2004).</li> </ul>
<b>Design risks</b>			
(4) Scope changes	Internal	Construction/ope	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table</li> </ul>

		ration	4.1.2 <ul style="list-style-type: none"> <li>Case: the Channel Tunnel Rail Link(PAC, 2006a), the Thailand Underground Rail Project (Ghosh &amp; Jintanapakanont, 2004)</li> </ul>
(5) Defective design	Internal	Construction	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the Melbourne City Link (Hodge, 2004).</li> </ul>
(6) Design changes	Internal	Construction/operation	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the BBC's White City 2 Development (PAC, 2006b), the Melbourne City Link (Hodge, 2004), the Thailand Underground Rail Project (Ghosh &amp; Jintanapakanont, 2004).</li> </ul>
<b>Construction risks</b>			
(7) Construction cost overrun	Internal	Construction	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>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).</li> </ul>
(8) Construction delay	Internal	Construction	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the Melbourne City Link (Hodge, 2004), the Thailand Underground Rail Project (Ghosh &amp; Jintanapakanont, 2004).</li> </ul>
(9) Defective construction	Internal	Construction	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the Melbourne City Link (Hodge, 2004).</li> </ul>
(10) Construction changes	Internal	Construction/operation	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the Melbourne City Link (Hodge, 2004).</li> </ul>
(11) Complex system interface/integration	Internal	Construction/operation	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: Airwave(PAC, 2002a), London Underground(PAC, 2005a).</li> </ul>
(12) Failed commissioning tests	Internal	Construction	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the Melbourne City Link (Hodge, 2004).</li> </ul>
<b>Operation risks</b>			
(13) Low operating productivity	Internal	Operation	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the Karvina Sewerage (EC, 2004b), the Thailand Underground Rail Project (Ghosh &amp;</li> </ul>

			Jintanapakanont, 2004).
(14) Mis-pricing	Internal	Operation	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the ASA and Rethmann and the RWE Entsorgung (EC, 2004b).</li> </ul>
(15) Revenue loss	Internal	Operation	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the Channel Tunnel Rail Link (PAC, 2006a), the Melbourne City Link (Hodge, 2004), the ASA and Rethmann (EC, 2004b).</li> </ul>
(16) System breakdown	Internal	Operation	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the Melbourne City Link (Hodge, 2004), the Thailand Underground Rail Project (Ghosh &amp; Jintanapakanont, 2004).</li> </ul>
(17) High maintenance frequency	Internal	Operation	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the Thailand Underground Rail Project (Ghosh &amp; Jintanapakanont, 2004).</li> </ul>
(18) Accidents and safety issues	Internal	Construction/ operation	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the London Underground (EC, 2002; NAO, 2004a), the Thailand Underground Rail Project (Ghosh &amp; Jintanapakanont, 2004).</li> </ul>
<b>Cost risks</b>			
(19) Price escalation	Internal	Construction/ operation	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the London Underground (EC, 2002), China case (Lu, 2004).</li> </ul>
<b>Technology risks</b>			
(20) Complex/non-innovation technology	Internal	Construction/ operation	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the London Underground (PAC, 2002a; PAC, 2005a), National Physical Laboratory (NAO, 2006).</li> </ul>
<b>Organization risks</b>			
(21) Poor cooperation/ coordination	Internal	Construction/ Operation	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the London Underground (EC, 2002), the Yangtz River Three Gorges (Lu, 2004).</li> </ul>
<b>Finance risks</b>			
(22) Finance unavailable	Internal	Construction/ operation	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the Channel Tunnel Rail Link(PAC, 2006a), the National Air Traffic Services(PAC, 2003c).</li> </ul>
(23) Refinancing	Internal	Construction/	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table</li> </ul>

liabilities		operation	4.1.2 <ul style="list-style-type: none"> <li>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).</li> </ul>
(24) Insolvency of contractor	Internal	Construction/ operation	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the Thailand Underground Rail Project (Ghosh &amp; Jintanapakanont, 2004), the Royal Armouries Museums in Leeds (PAC, 2001).</li> </ul>
(25) Ownership change	Internal	Construction/ operation	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the Channel Tunnel Rail Link (PAC, 2006a)</li> </ul>
(26) Tax increases	External	Construction/ operation	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the Xiaolangdi Project on Yellow River (Lu, 2004).</li> </ul>
(27) Insurance increases	Internal/ External	Construction/ operation	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the Laibin B Power Plant (Lu, 2004).</li> </ul>
<b>Contract risks</b>			
(28) Contractual disputes	Internal	Construction/ operation	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the Melbourne City Link (Hodge, 2004), the Thailand Underground Rail Project (Ghosh &amp; Jintanapakanont, 2004).</li> </ul>
(29) Inflexible contract arrangements	Internal	Construction/ operation	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>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).</li> </ul>
(30) Delay in contract change negotiation	Internal	Construction/ operation	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the London Underground (NAO, 2004a), National Airport Traffic Services (PAC, 2003c), the Thailand Underground Rail Project (Ghosh &amp; Jintanapakanont, 2004)</li> </ul>
(31) Contract breach	Internal	Construction/ operation	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the North-South Expressway (NSE) and the Kuala Lumpur-Karak</li> </ul>

			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	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the London Underground (EC, 2002), the Melbourne City Link (Hodge, 2004), the Thailand Underground Rail Project (Ghosh &amp; Jintanapakanont, 2004).</li> </ul>
<b>Third party risks</b>			
(33) Default of subcontractor	Internal	Construction/operation	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the London Underground (EC, 2002), the Melbourne City Link (Hodge, 2004), the National Physical Laboratory (NAO, 2006), the Thailand Underground Rail Project (Ghosh &amp; Jintanapakanont, 2004).</li> </ul>
(34) Inspection and testing delay	Internal	Construction/operation	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the Thailand Underground Rail Project (Ghosh &amp; Jintanapakanont, 2004).</li> </ul>
<b>Asset ownership risks</b>			
(35) Latent defect	Internal	Construction/operation	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the London Underground (EC, 2002).</li> </ul>
(36) Shorter asset life	Internal	Construction/operation	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the London Underground (EC, 2002; NAO, 2004a).</li> </ul>
(37) Less residual values	Internal	Construction/operation	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the London Underground (EC, 2002; NAO, 2004a).</li> </ul>
(38) Termination liabilities	Internal	Construction/operation	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the North-South Expressway (NSE) and the Kuala Lumpur-Karak Highway (The Work Bank, 1999), the National Physical Laboratory (NAO, 2006)</li> </ul>
<b>Economy risks</b>			
(39) Higher level of inflation rate	External	Construction/operation	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the Channel Tunnel Rail Link (PAC, 2006a), the Thailand Underground Rail Project (Ghosh &amp; Jintanapakanont, 2004)</li> </ul>

(40) Volatility of exchange rate	External	Construction/ operation	<ul style="list-style-type: none"> <li>• Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>• 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 &amp; Jintanapakanont, 2004).</li> </ul>
(41) Higher level of interest rate	External	Construction/ operation	<ul style="list-style-type: none"> <li>• Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>• Case: the North-South Expressway (NSE) and the Kuala Lumpur-Karak Highway(The Work Bank, 1999), the Harnaschpolder Wastewater Treatment Project (Smith, 2006).</li> </ul>
<b>Market risks</b>			
(42) Less demand	Internal/ external	Operation	<ul style="list-style-type: none"> <li>• Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>• Case: the Channel Tunnel Rail Link (PAC, 2006a), the National Air Traffic Services (PAC, 2003c).</li> </ul>
(43) Higher competition	External	Operation	<ul style="list-style-type: none"> <li>• Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>• Case: Channel Tunnel Rail Link (PAC, 2002b), the Melbourne City Link (Hodge, 2004), the Zhuhai International Airport(Lu, 2004).</li> </ul>
(44) Downside economic events	External	Construction/ operation	<ul style="list-style-type: none"> <li>• Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>• Case: the Asia Toll Road Projects (The Work Bank, 1999), the Thailand Underground Rail Project (Ghosh &amp; Jintanapakanont, 2004).</li> </ul>
<b>Politics risks</b>			
(45) Political interference	External	Construction/ operation	<ul style="list-style-type: none"> <li>• Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>• 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).</li> </ul>
<b>Regulatory risks</b>			
(46) Unsuitable regulatory policy	Internal/ external	Construction/ operation	<ul style="list-style-type: none"> <li>• Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>• Case: National Air Traffic Services (NAO, 2004b; PAC, 2003c), the Melbourne City Link (Hodge, 2004), the Liaoning Wastewater Treatment Plant (Lu, 2004).</li> </ul>
(47) Approval delays	Internal/ external	Construction/ operation	<ul style="list-style-type: none"> <li>• Data sources: Table 4.1.1 &amp; Table 4.1.2</li> </ul>

			<ul style="list-style-type: none"> <li>Case: National Air Traffic Services (NAO, 2004b; PAC, 2003c), the Water and Wastewater Infrastructure in Southern China (Lu, 2004).</li> </ul>
(48) Law/policy changes	External	Construction/operation	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the London Underground (EC, 2002), the Melbourne City Link (Hodge, 2004).</li> </ul>
<b>Environment risks</b>			
(49) Unforeseen site conditions	Internal	Construction	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the Thailand Underground Rail Project (Ghosh &amp; Jintanapanont, 2004).</li> </ul>
(50) Environmental pollutions	Internal	Construction/operation	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the Great Belt and Oresund Links/Demark (Flyvbjerg et al., 2003).</li> </ul>
<b>Industrial relation risks</b>			
(51) Industrial disputes	External	Construction/operation	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>Case: the Vasco da Gama Bridge (EC, 2003), the Thailand Underground Rail Project (Ghosh &amp; Jintanapanont, 2004).</li> </ul>
<b>Force Majeure risks</b>			
(52) Force Majeure	External	Construction/operation	<ul style="list-style-type: none"> <li>Data sources: Table 4.1.1 &amp; Table 4.1.2</li> <li>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 &amp; Jintanapanont, 2004).</li> </ul>

## 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, this 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 this 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. This 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. This 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, modeling such soft risks as human factors would be beyond the scope of this 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.

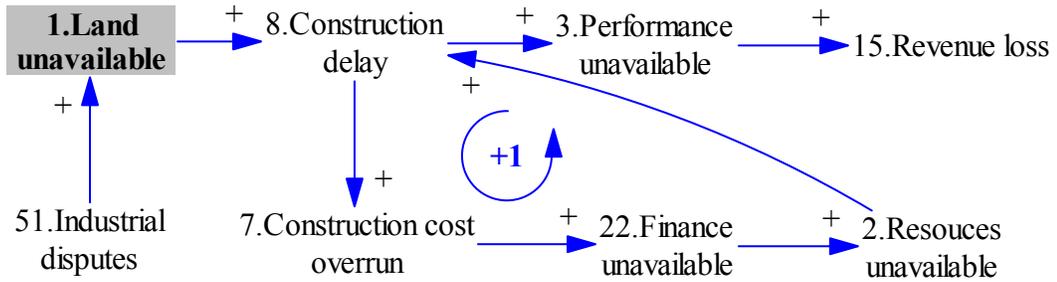
Therefore, the risk causal loop diagrams were modeled based on the major risk variables that can be allocated through commercial contract terms and conditions.

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 World 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).

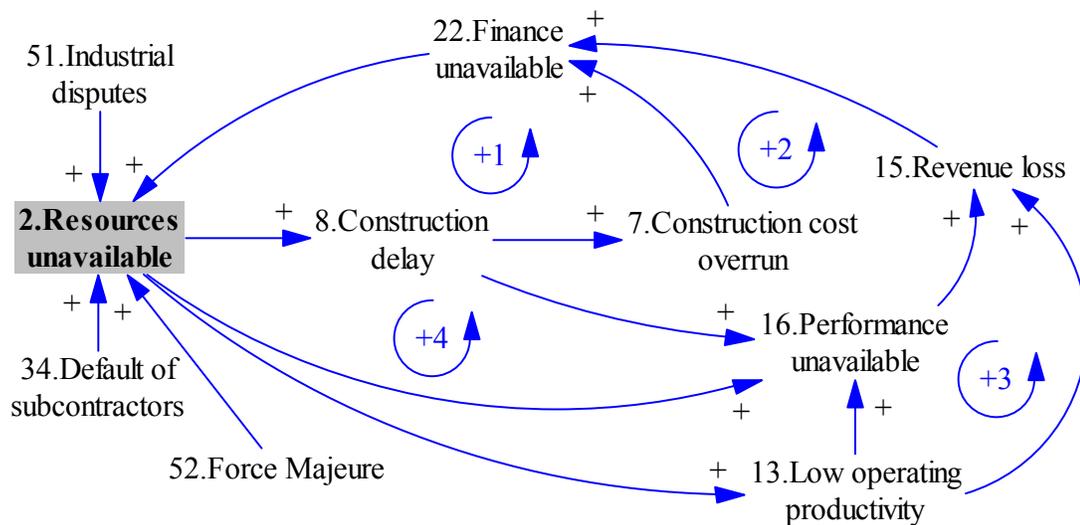


**Figure 4.2 (1) Causal Loop Diagram for ‘Land Unavailable’ Risk Event**

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.

## 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).

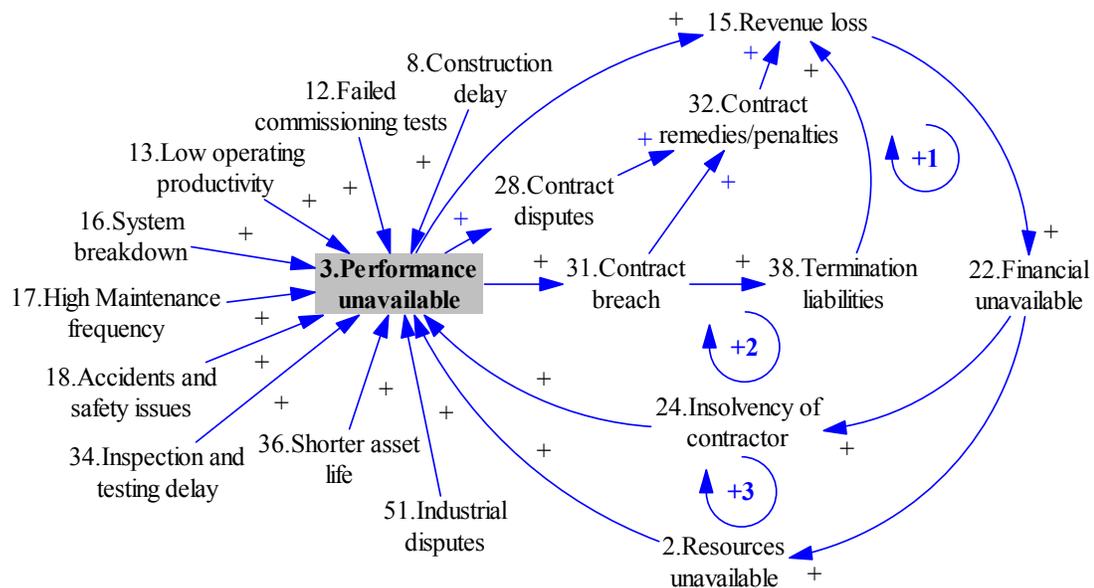
This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for the cases, the UK National Audio Office's report (NAO, 2004a) on the London Underground indicated that they are unclear for both of the PPP project operation contractor, LUL, and infrastructure construction

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.)



**Figure 4.2 (3) Cause Loop Diagram for ‘Performance Unavailable’ Risk Event**

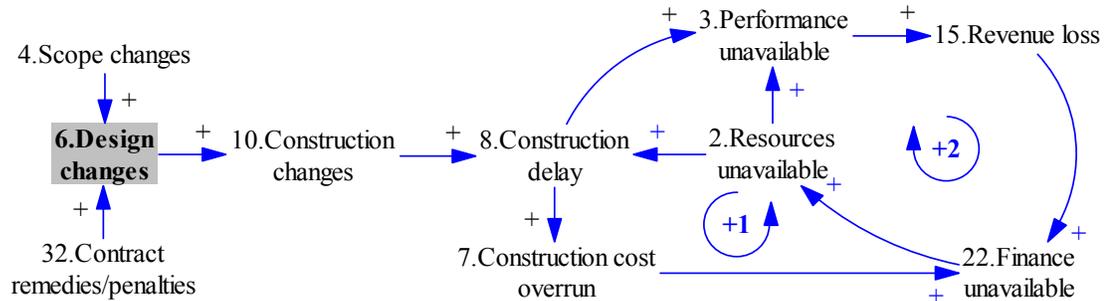
Furthermore, the performance unavailable event would cause a contract breach risk event when the operating parties could not provide services to meet the contract requirements. This event would lead to termination liability for which the operating parties pay according to the contract terms and conditions (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.

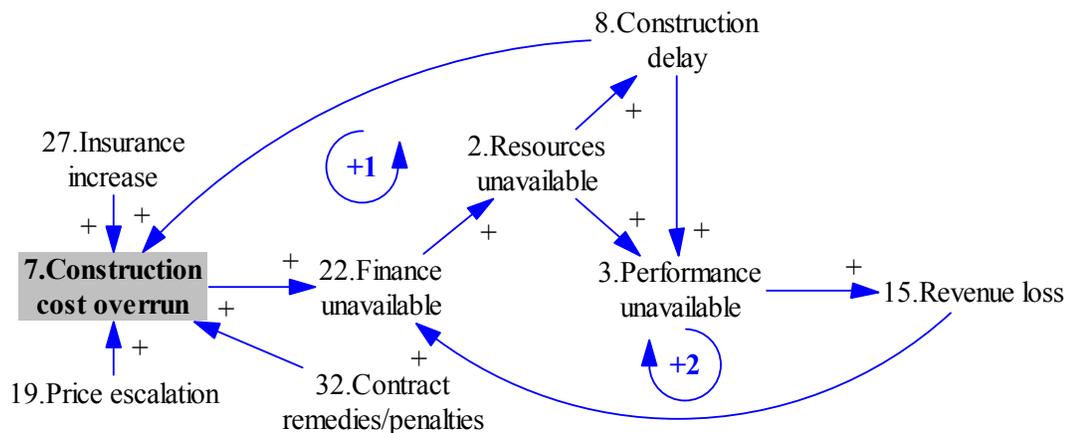
The design changes risk event would possibly be triggered by the risk events such as: (a) scope changes (PAC, 2006a) which result when design or construction parameters need to be changed to meet the new scope requirements; and (b) contract remedies/penalties (Hodge, 2004; PAC, 2006b) because the remedies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

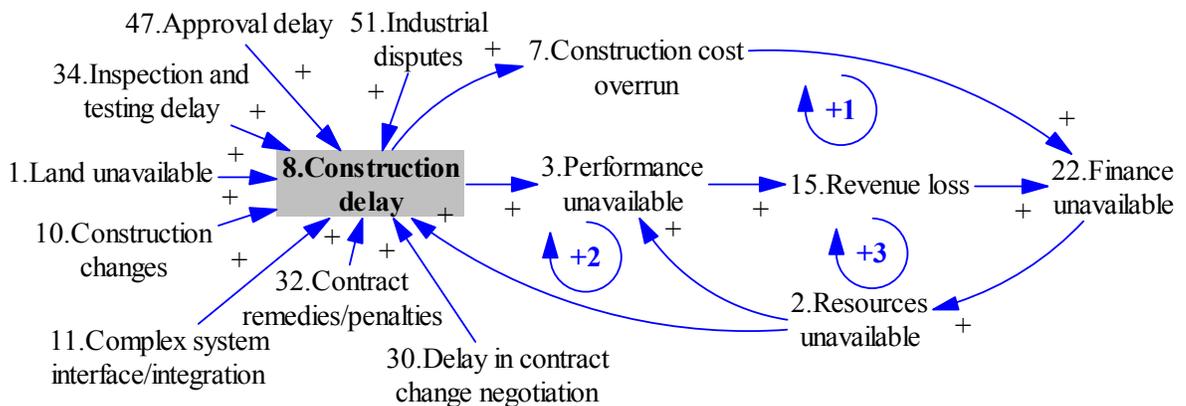
The construction cost overrun event is often triggered by risk events such as: (a) construction delays resulting in extra costs incurred during the construction time delay; and (b) price escalation which is the unexpected increase in the labor costs, materials and equipments used for infrastructure construction (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



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; (e) 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.

# Chapter 5 Taiwan High Speed Rail Project Risks

## 5.1 The Background of THSR

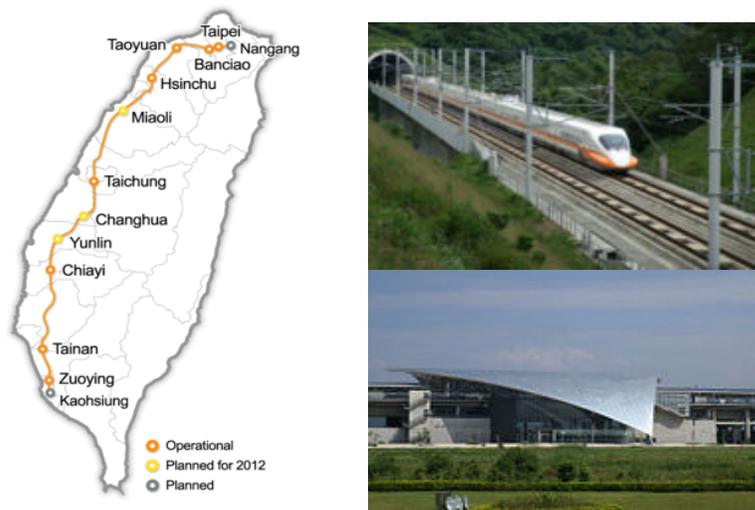
The network for Taiwan high speed rail (THSR) is shown in Figure 5.1.1. The THSR consists of a 345km (220 miles) route from northern Taiwan to southern Taiwan. The THSR is designed for express trains capable of traveling at up to 350 km/h. The THSR allows travelers to make the trip in roughly 90 minutes 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 VI and the CLD illustrated in Figure VI, 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.***”

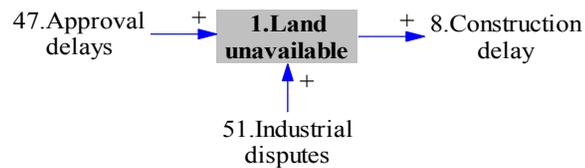
“All of land acquisition requires a negotiation with the land owners, a setup of property rights of superficies and an approval request from the related government authority for lands. However, you know there are 1,607 houses, 225 factories, 1,095 graves, and 70 stables on the lands. Thus negotiation 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 Bauaktiengesellschaft 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, this 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.***”

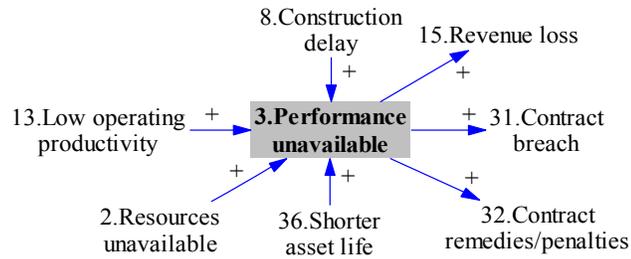
“For example, if the Turn Out system that is used to guide the trains on the right track is ***out of order***, then the regular trains would be canceled or delayed for services, which would cause that ***the whole system broke down*** or even lead to the ***rail crash***. The unreliable integration 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, this 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

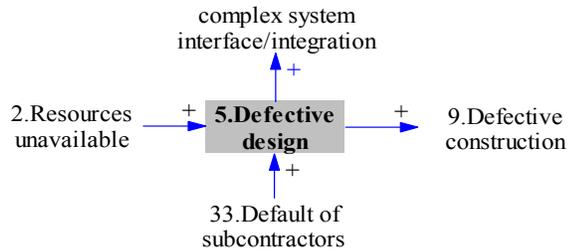
As discussed in the Section V5 and the CLD shown in Figure V5, the defective design would lead to a defective system that would potentially cause defective construction and performance unavailable events, possibly catalyzed by defaults of subcontractors and resources unavailable events. Relative to the 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’**

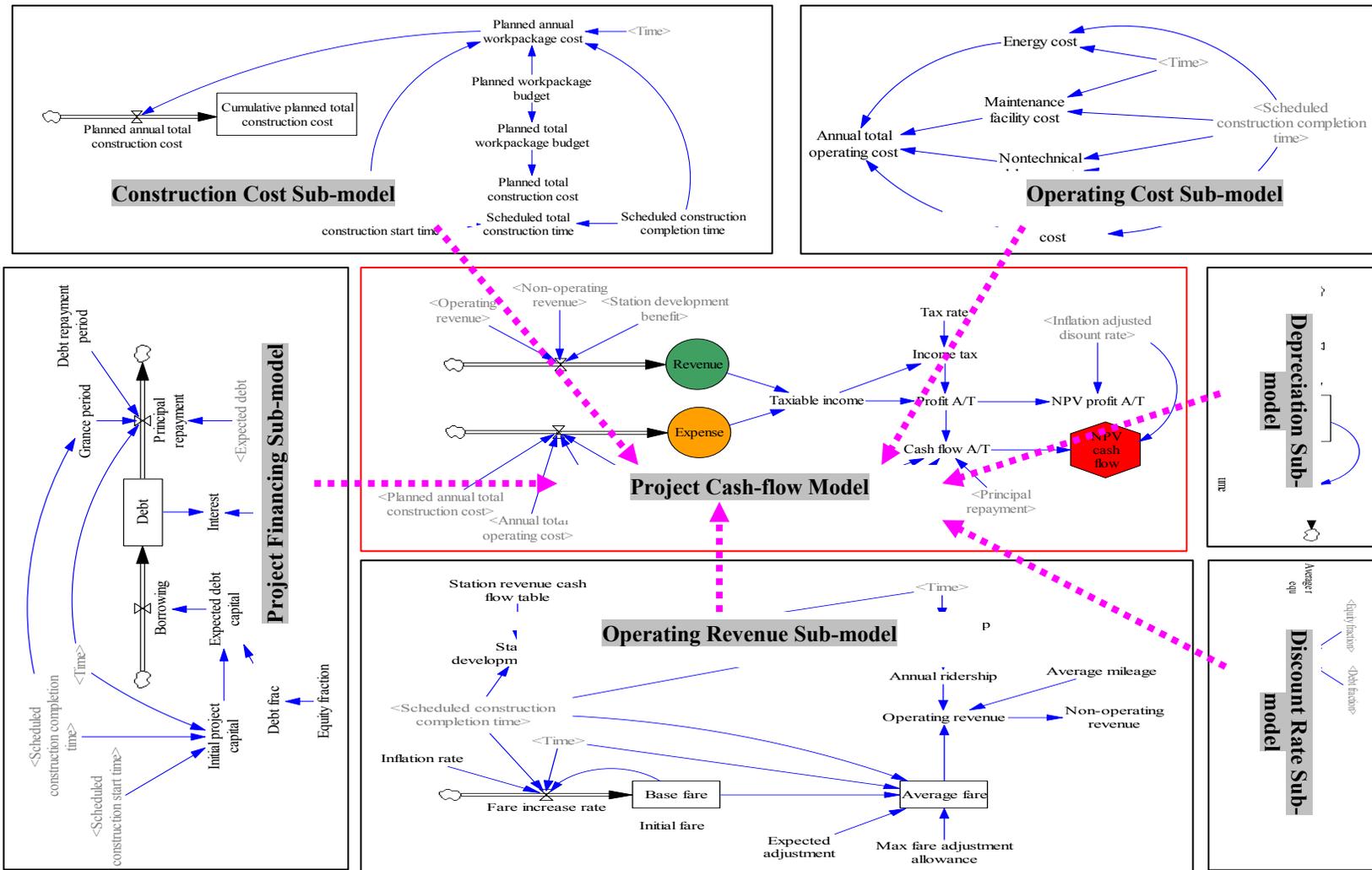
## Chapter 6 Risk Network Modeling and Simulation

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, this 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 Modeling

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 modeling are linked to Figure 6.1 to form risk estimated project cash flow model (project NPV cash flow: the estimated) that was proposed in this 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 modeling. These two cost profiles were compared with each other to determine whether the approach proposed by this 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<sub>i</sub>: 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 (Bureau of High Speed Rail, 2007; Hsu, 2000). Therefore, the scheduled start time for construction was the earliest start time for all work packages:

$$SCST = \text{Min} (SST_i)$$

where

*SCST*: scheduled construction start time;

*SST<sub>i</sub>* = 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:

$$SCCT = \text{Max} (SCT_i)$$

Where

*SCCT*: scheduled construction completion time;

*SCT<sub>i</sub>* = scheduled completion time of work package;

*i*: Work package index

Thus, the scheduled total construction duration was:

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

Where

*STCD*: scheduled total construction duration;

*SCCT*: scheduled construction completion time;

*SCST*: scheduled construction start time;

*SCT<sub>i</sub>* = scheduled completion time for work package;

*SST<sub>i</sub>* = 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

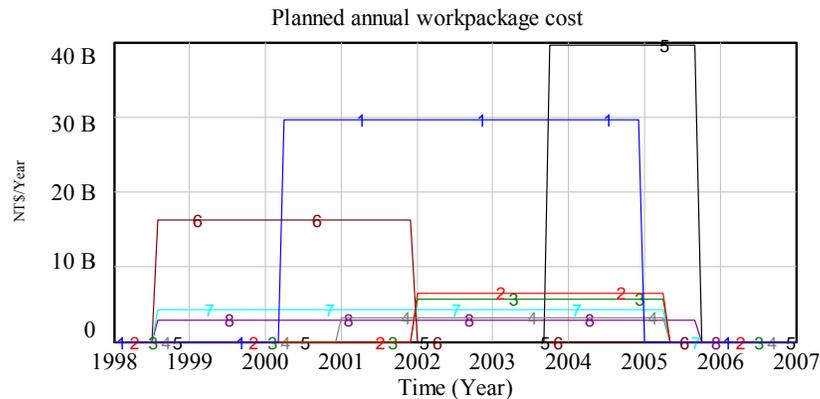
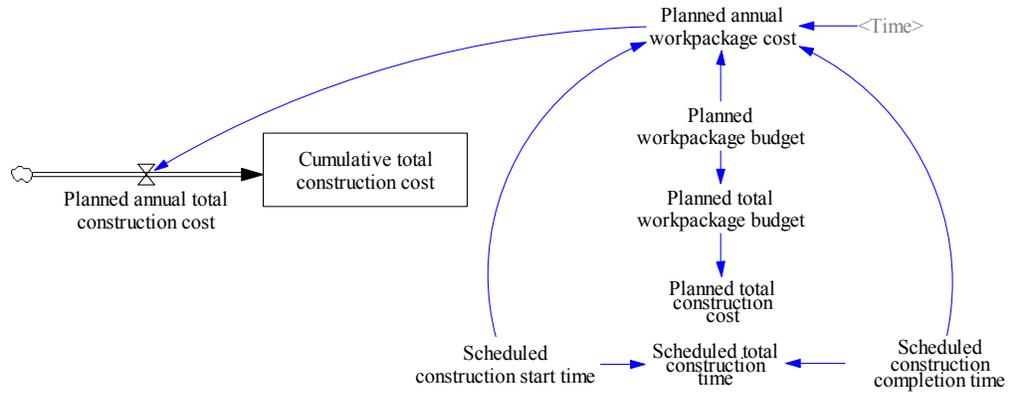
*PAWC*: planned annual work package cost;

*PWB<sub>i</sub>*: planned work package budget;

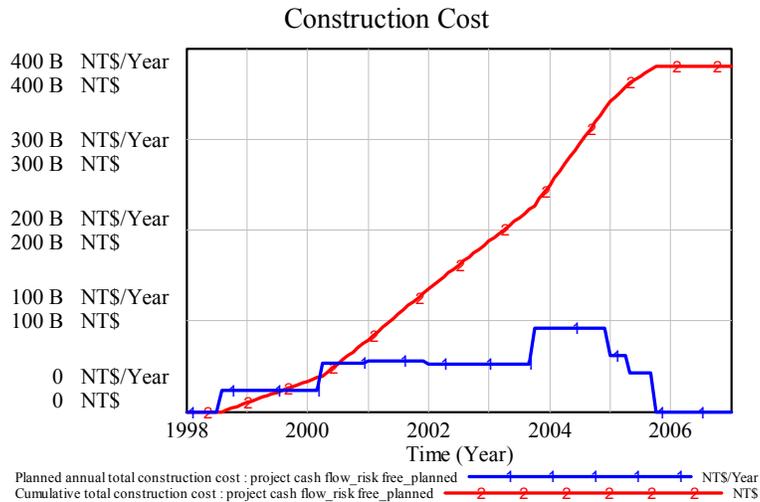
*SCT<sub>i</sub>* = scheduled completion time for work package;

*SST<sub>i</sub>* = scheduled start time for work package;

*i*: Work package index



Planned annual workpackage cost[civic work]: project cash flow\_risk free\_planned — 1 — 1  
 Planned annual workpackage cost[track work]: project cash flow\_risk free\_planned — 2 — 2  
 Planned annual workpackage cost[station construction]: project cash flow\_risk free\_planned — 3 — 3  
 Planned annual workpackage cost[depot construction]: project cash flow\_risk free\_planned — 4 — 4  
 Planned annual workpackage cost[core system]: project cash flow\_risk free\_planned — 5 — 5  
 Planned annual workpackage cost[land acquisition]: project cash flow\_risk free\_planned — 6 — 6  
 Planned annual workpackage cost[Taipei underground]: project cash flow\_risk free\_planned — 7 — 7  
 Planned annual workpackage cost[design and supervision]: project cash flow\_risk free\_planned — 8 — 8



Planned annual total construction cost: project cash flow\_risk free\_planned — 1 — 1 NT\$/Year  
 Cumulative total construction cost: project cash flow\_risk free\_planned — 2 — 2 NTS

**Figure 6.1.1 The SD Model for Total Construction Cost and Its Outputs**

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<sub>i</sub> = scheduled completion time for work package;*  
*SST<sub>i</sub> = scheduled start time for work package;*  
*i: Work package index*

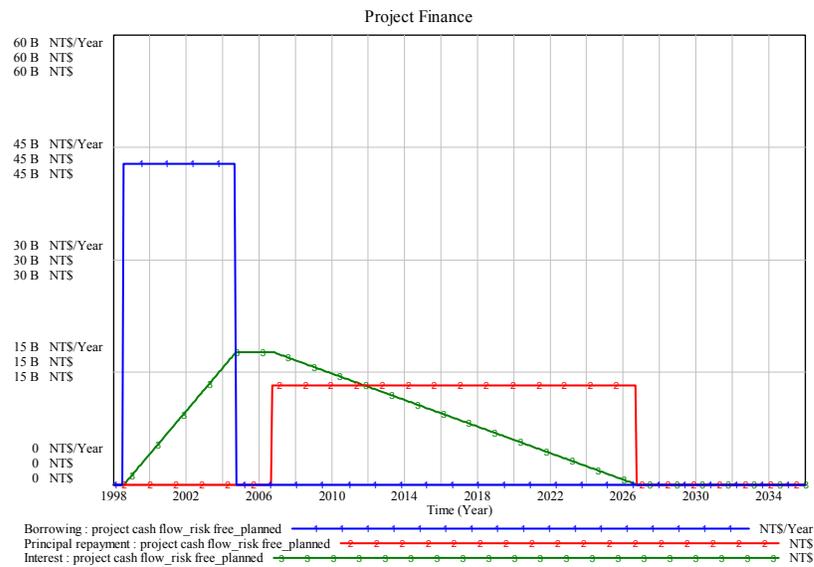
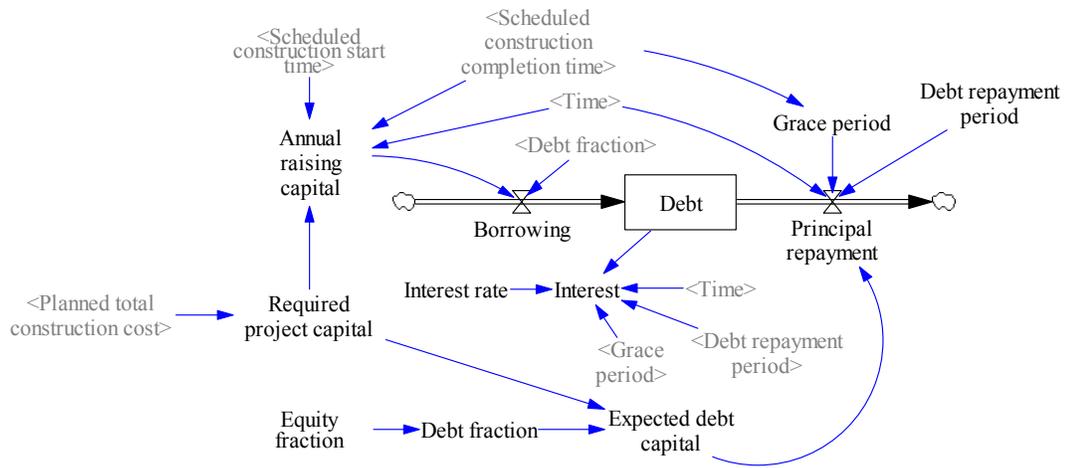
The basic fiscal requirement of the public sector for project capital structure was 30% of total capital investment for equity, and the rest was for debt, including the government long-term fund and bank loan. Therefore, the equity/debt ratio = 3 to 7 which meant that the equity fraction is 30% and debt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

$$B = APC * W_d$$

Where

*APC*: annual project capital;

*W<sub>d</sub>*: 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:

$$P = DC/DRP = PTCC \cdot d / DRP$$

Where

*DC*: debt capital

*PTCC*: planned total construction cost;

*W<sub>d</sub>*: 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 (Bureau of High Speed Rail, 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 (Bureau of High Speed Rail, 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  $n$ th year after starting operation.

Therefore, the average fare approved by BHSR was:

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

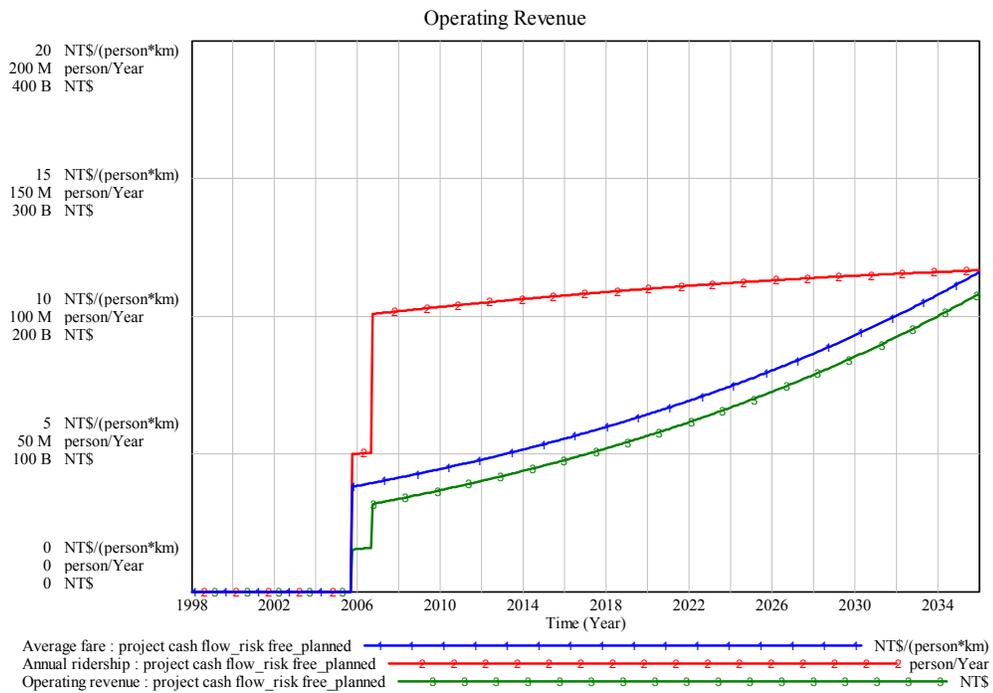
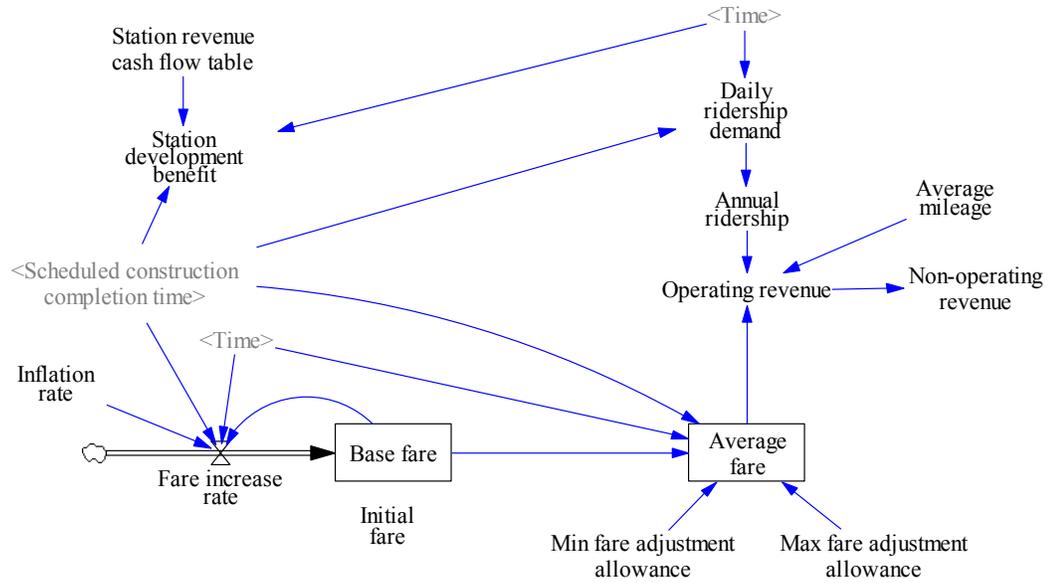
Where

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

$F_b$ : base fare;

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

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



**Figure 6.1.3 The SD Model for Operating Revenue and Its Outputs**

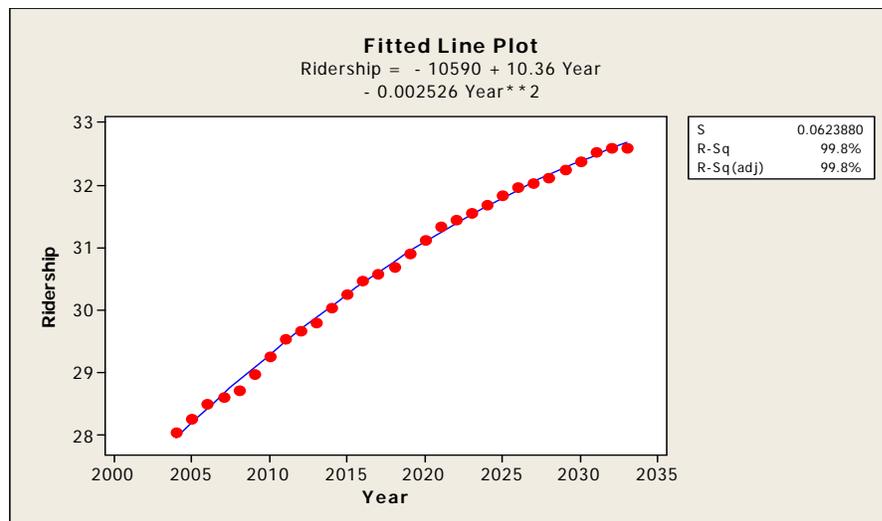
According to the research report for ridership forecast conducted by Hsu (2000), the data is plotted for the estimated average daily ridership (person/day) as shown in Figure 7.1.3.1. This figure showed that the daily ridership forecast can fit a quadratic regression model over time with a very low square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

$$AR = DRD * 365, \text{ where AR: the annual ridership}$$

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 this researcher input data as lookup variables in the SD model.

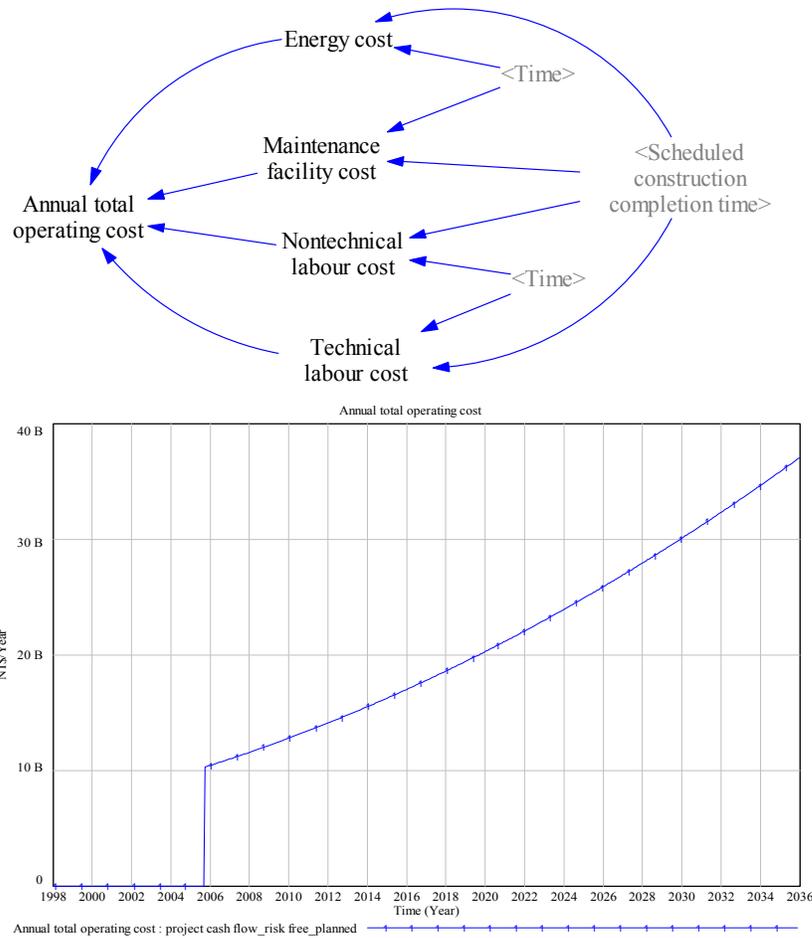
$$TOC = \sum OC_i$$

Where

*TOC*: annual total operating cost;

*OC<sub>i</sub>*: operating cost elements;

*i*: operation cost element index

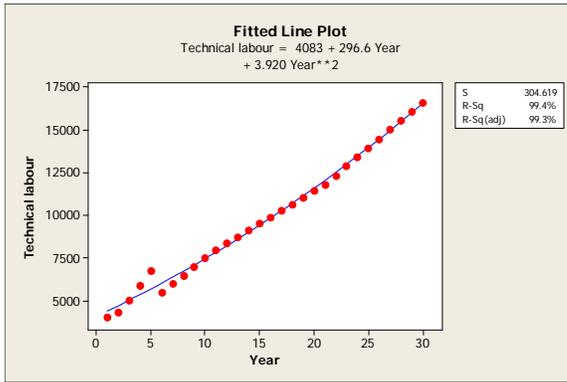


**Figure 6.1.4 The SD Model for Operating Cost and Its Outputs**

### 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, 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.

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

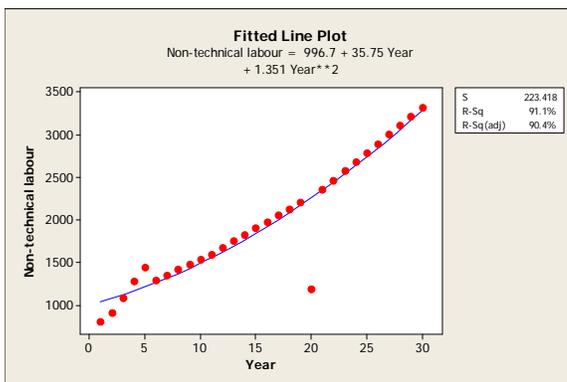


The regression equation is  
 Technical labour = 4083 + 296.6 Year + 3.920 Year\*\*2

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			

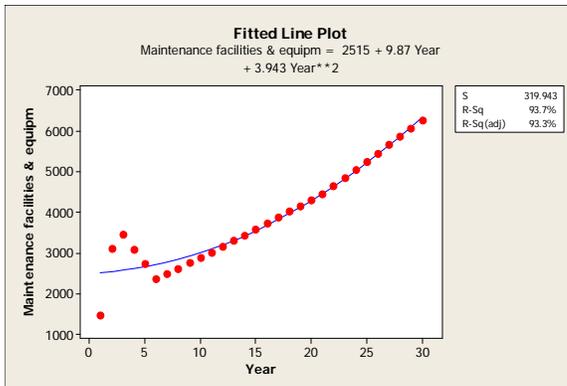


The regression equation is  
 Non-technical labour = 773.3 + 77.65 Year

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			

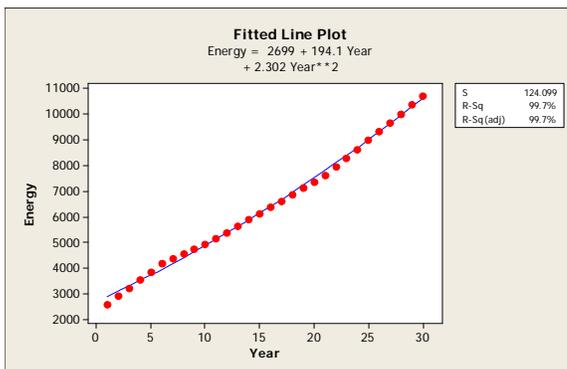


The regression equation is  
 Maintenance facilities & equipm = 2515 + 9.87 Year + 3.943 Year\*\*2

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			

## 6.1.5 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):

$$\alpha = \lambda(100\%/L)$$
$$D_n = \alpha BB_{n-1} = \alpha C_{asset} (1 - \alpha)^{n-1}$$
$$BB_n = C_{asset} (1 - \alpha)^n, n=1, \dots, L$$

Where

$\alpha$ : the fraction of the book balance;

$\lambda$ : multiplier = 1.5

$D_n$ : the depreciation value at nth year;

$C_{asset}$ : the estimated cost of asset;

$BB_n$ : 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;

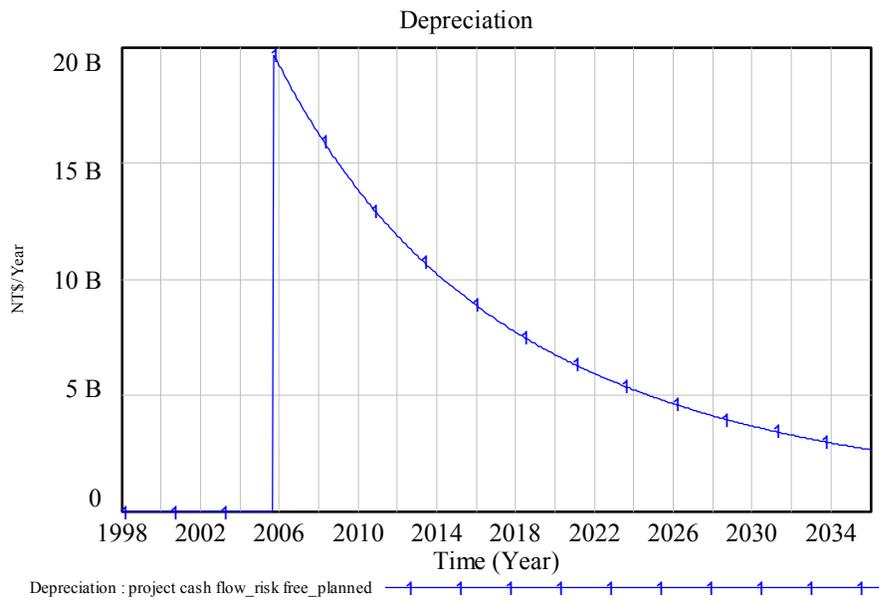
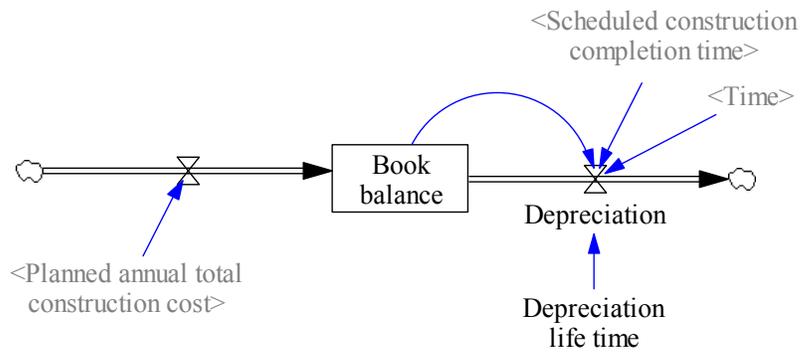
$w_e$ : equity fraction;

$r_e$ : return on equity;

$w_d$ : debt fraction;

$r_d$ : debt interest;

$t_m$ : tax rate



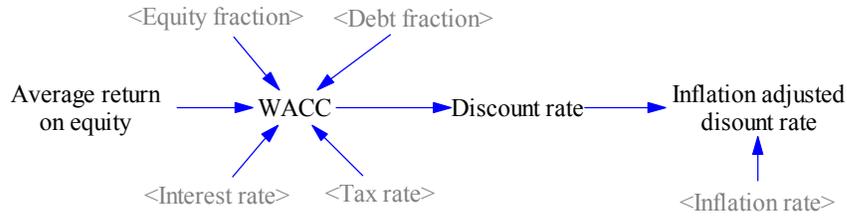
**Figure 6.1.5 The SD Model for Depreciation and Its Outputs**

It is adjusted by inflation effect as:

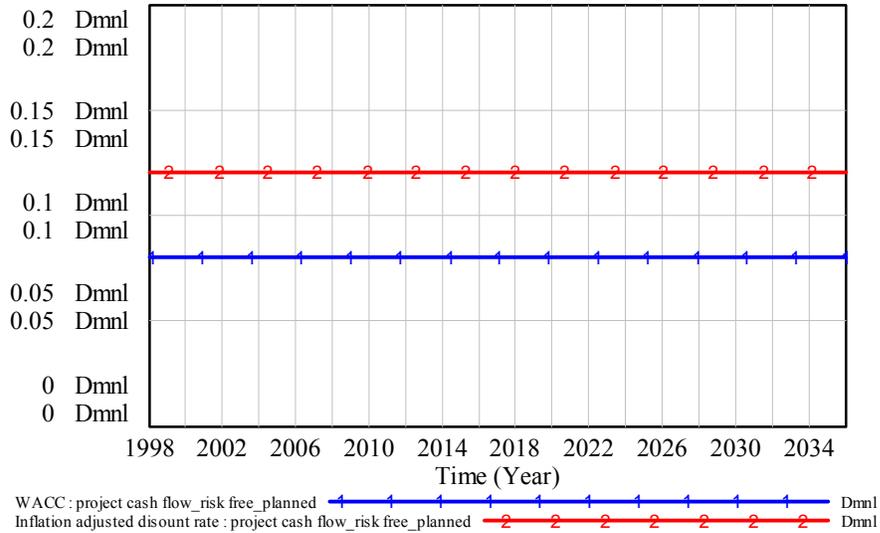
$$r'_{wacc} = r_{wacc} + r_{inf} + r_{wacc} r_{inf}$$

Where

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



### Discount Rates



**Figure 6.1.6 The Discount Rate SD Model and Outputs**

### 6.1.7 Project NPV Cash Flow Model

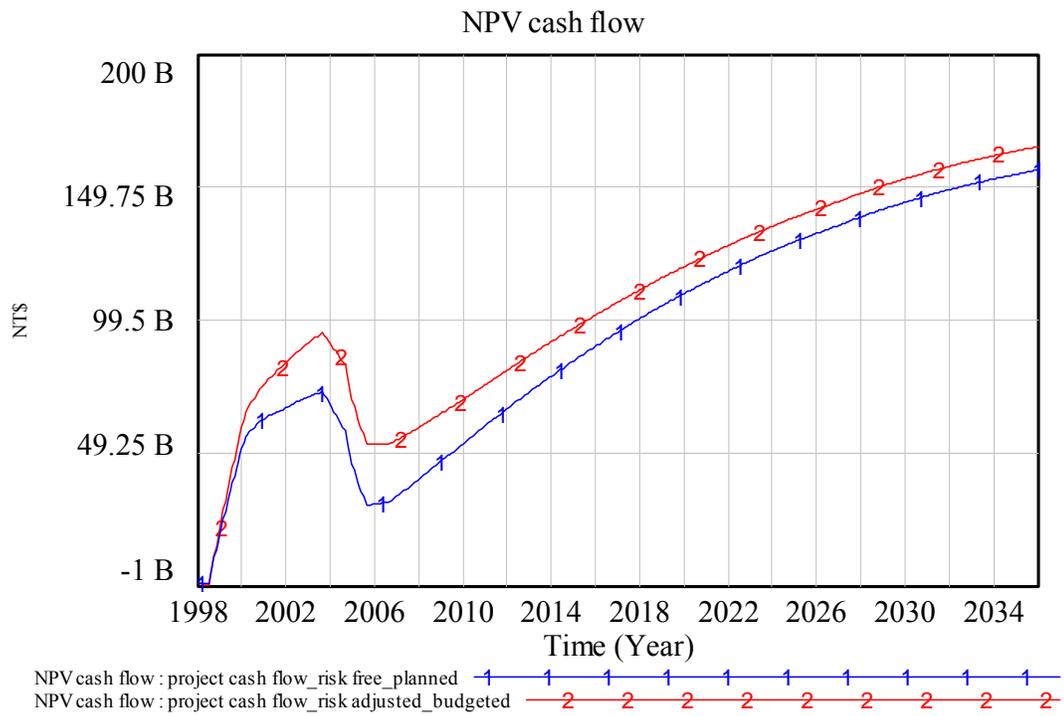
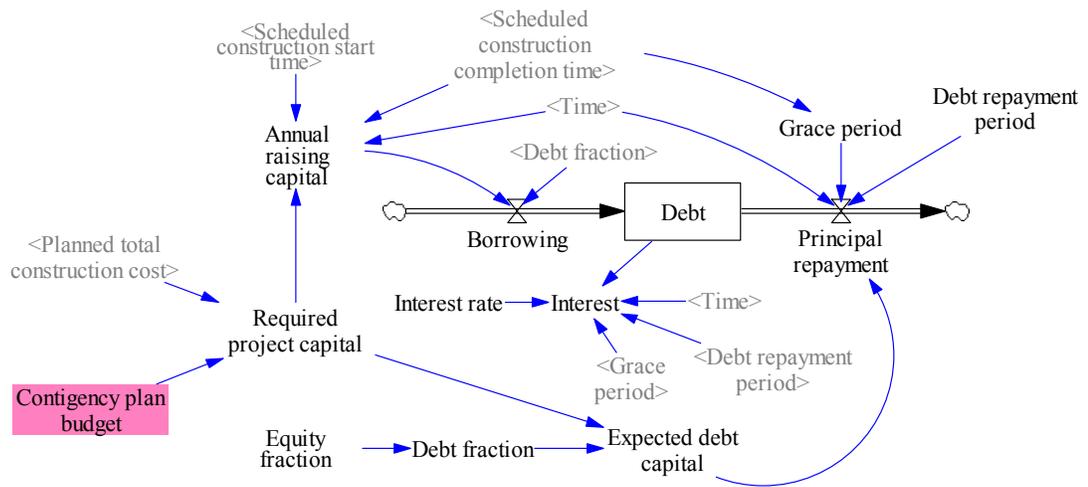
As shown in Figure 6.1.7, the project net cash flow = profit A/T (after tax) + annual raising capital - annual principal repayment + depreciation = (ΣRevenue[i] - ΣExpense[j])\*(1-tax rate) + annual raising capital - annual principal repayment + depreciation. The project NPV is (Park & Sharp-Bette, 1990):

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

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.





**Figure 6.1.8 The Project Cash Flow Model Including Risk Budget**

## 6.2 System Dynamics for Risk Network Modeling

This researcher used a 1 to 25 scale to represent the risk degree (expected effect) for a risk event. As described in Chapter 3 and Appendix IV, the questionnaire survey was conducted to investigate and measure the qualitative risk effects through expert judgment. Then, the probability distribution for the expected risk effects and their relationships 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 VII and the Figure VII, 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<sub>k</sub>*: random variable for the expected risk effect;

*k*: time period, *c* (construction stage); *o* (operation stage);

*lu*: risk event for ‘land unavailable’;

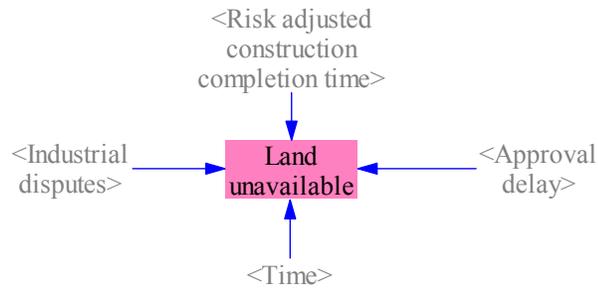
*id*: risk event for ‘industrial disputes’;

*ad*: risk event for ‘approval delay’;

*β<sub>0k</sub>*: the constant term for the multiple regression model;

*β<sub>1k</sub>, β<sub>2k</sub>*: the relational coefficients for the independent risk variables;

*ε<sub>k</sub>*: the random error for the multiple regression model;



**Figure 6.2.1 The SD Model for ‘Land Unavailable’ Risk Effect**

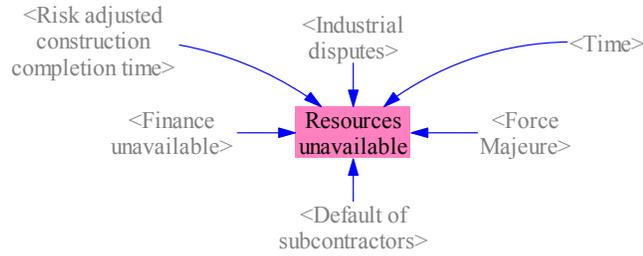
## 6.2.2 RCN for ‘Resource Unavailable’ on THSR

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’;
- $\beta_{0k}$ : the constant term for the multiple regression model;
- $\beta_{1k}, \beta_{2k}, \beta_{3k}, \beta_{4k}$ : the relational coefficients for the independent risk variables;
- $\varepsilon_k$ : 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’;
- $\beta_{0k}$ : the constant term for the multiple regression model;
- $\beta_{1k}$ : the relational coefficients for the independent risk variables;
- $\varepsilon_k$ : 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, this 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<sub>max</sub>*: 25;  
*RD<sub>min</sub>*: 1;  
*DeT<sub>max</sub>*: 45 trains;  
*DeT<sub>min</sub>*: 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;

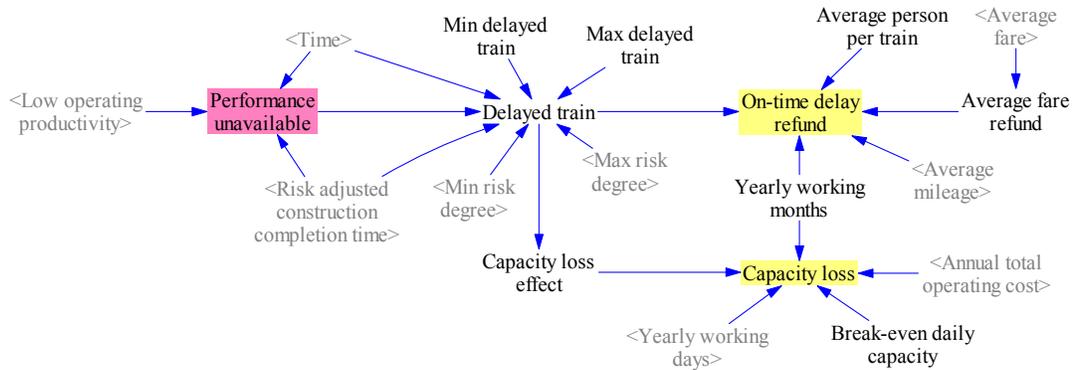
According to the interview statement in Appendix VI3, another consequence for capacity loss arising from less capacity than break-even daily capacity was:

$$CLE = Int(DeT * 0.2)$$

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

Where

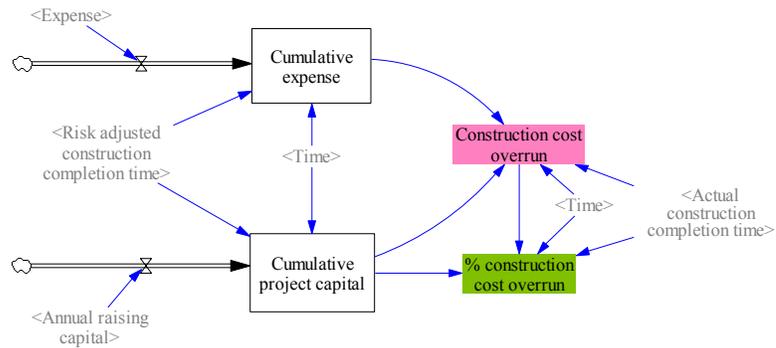
*CLE*: capacity loss effect;  
*Int[x]*: Integer function;  
*DeT*: the number of trains that would likely delay on-time service;  
*CL*: capacity loss;  
*BEDC*: break-even daily capacity for a single way = 60;  
*TOC*: annual total operating cost



**Figure 6.2.3 The SD Model for 'Performance Unavailable' Risk Effect**

### 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**

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

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

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

$$CCO = CE - CPC$$

where

*E*: the annual expense;

*C<sub>radj</sub>*: the risk adjusted annual construction cost;

*C<sub>ins</sub>*: the annual insurance cost;

*C<sub>int</sub>*: 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<sub>ij</sub>*: time delay effect for a risk event on a work package (in percentage);

*RD<sub>i</sub>*: random variable for the expected risk effect;

*TCMAX<sub>ij</sub>*: maximum time delay effect for a risk event in a work package (in percentage);

*TCMIN<sub>ij</sub>*: minimum time delay effect for a risk event in a work package (in percentage);

*RD<sub>max</sub>*: 25;

*RD<sub>min</sub>*: 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

$\Delta TD_{ik}$ : 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:

$$CD = \text{Max}(RCCT_j) - \text{Max}(SCT_j)$$

where

$CD$ : construction time delay;  
 $\text{Max}(x_j)$ : the maximum value of the elements in an array  $x_j$ ;  
 $RCCT_j$ : 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:

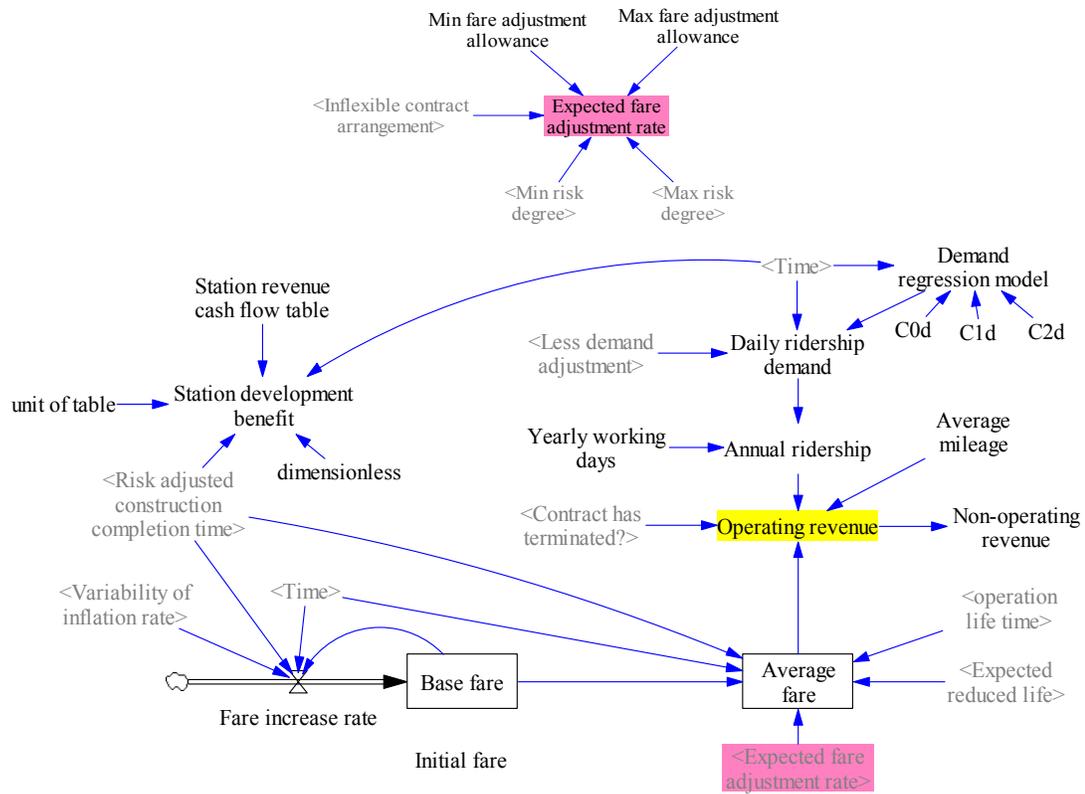
$$CDC = CD * ACDC$$

where

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



$RD$ : random variable for the expected risk effect;  
 $Ica$ : risk event 'inflexible contract arrangement';  
 $RD_{max}$ : 25;  
 $RD_{min}$ : 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:

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

where

*RD<sub>k</sub>*: 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'  
 $\beta_{0k}$ : the constant term for the multiple regression model;  
 $\beta_{1k}, \beta_{2k}, \beta_{3k}, \beta_{4k}$ : the relational coefficients for the independent risk variables;  
 $\epsilon_k$ : the random error for the multiple regression model;

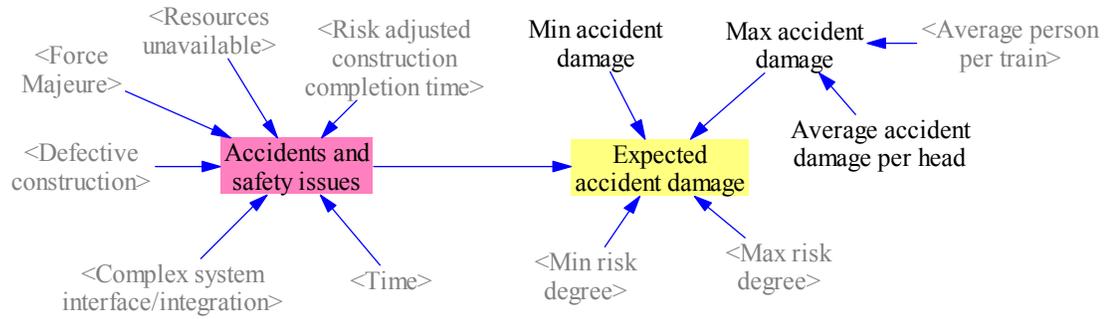
As for the direct consequence of contract remedies/penalties, according to the interview statements, the maximum accident and safety loss for death penalty and system damage due to human factor and national disaster is NT\$0.174 billion. This researcher assumes the expected accident and safety loss is 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<sub>max</sub>*: 25;  
*RD<sub>min</sub>*: 1;  
*ASD<sub>max</sub>*: maximum accident damage, NT\$1.3 millions;  
*ASD<sub>min</sub>*: 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;

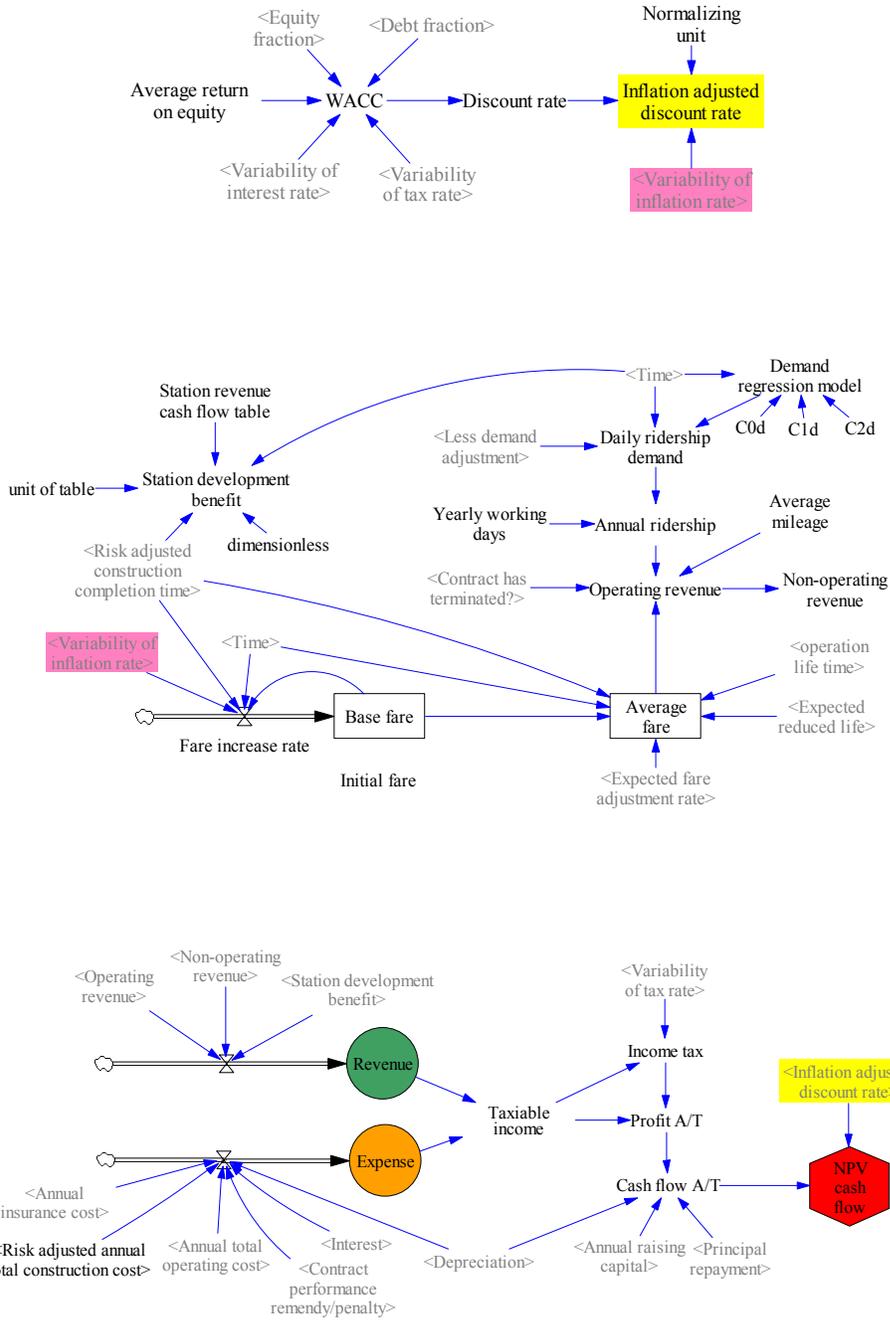
$CDC$ : construction delay cost

$r'_{ex}$ : risk adjusted exchange rate =  $MAX(r_{rex}, r_{ex})$

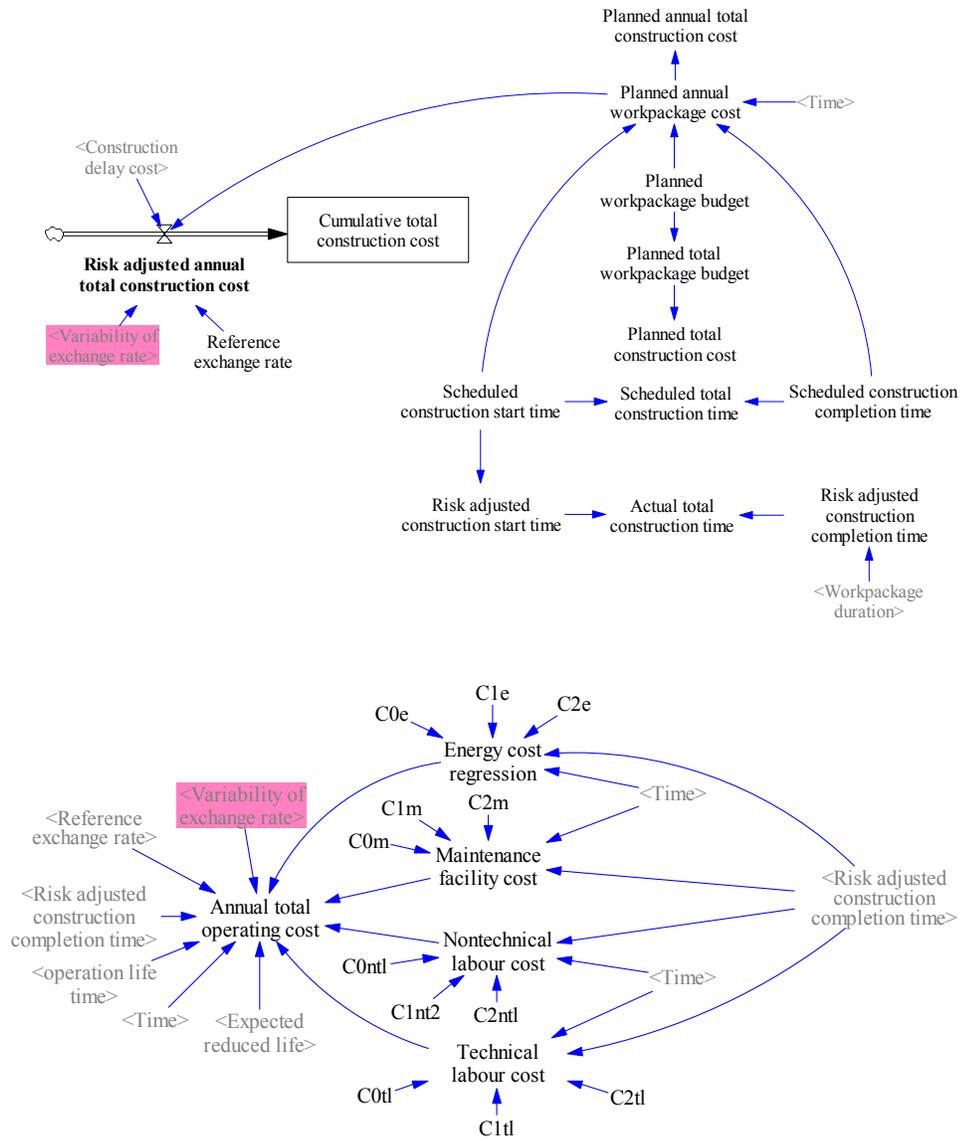
$r_{rex}$ : reference exchange rate = 33;

$MAX(A,B)$ : maximum function of two alternatives A, B;

$r_{ex}$  = 'variability of exchange rat' addressed in Appendix VII40



**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**



**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:

$$RD_k(fu) = \bar{\pi} + \varepsilon_k, k=c;$$

$$= \bar{D}_{sc} + \varepsilon_k, k=o;$$

Where

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

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

$$\pi = (EXP-APC)/APC*100\%$$

$$\bar{\pi} = \int_{t_{sc}}^t \frac{\pi - \bar{\pi}}{t - t_{cs}}$$

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  $\bar{\pi}$  when  $-100\% < \bar{\pi} < 0\%$ :

$$RD_k(fu) = 1 + \varepsilon_k, \bar{\pi} \leq -100\%;$$

$$= (\bar{\pi} + 1)(RD_{max} - RD_{min}) + 1 + \varepsilon_k, -100\% < \bar{\pi} < 0\%;$$

$$= 25 + \varepsilon_k, \bar{\pi} \geq 0\%$$

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:

$$D_{sc} = Eb / (I + (Pr / (1 - Tm)))$$

$$\bar{D}_{sc} = \int_{t_{os}}^t \frac{D_{sc} - \bar{D}_{sc}}{t - t_{os}}$$

where

$E_b$ : Earnings before Interest, Tax and Depreciation  
 $I$ : Interest  
 $Pr$ : Principal Repayment  
 $Tm$ : Tax Rate

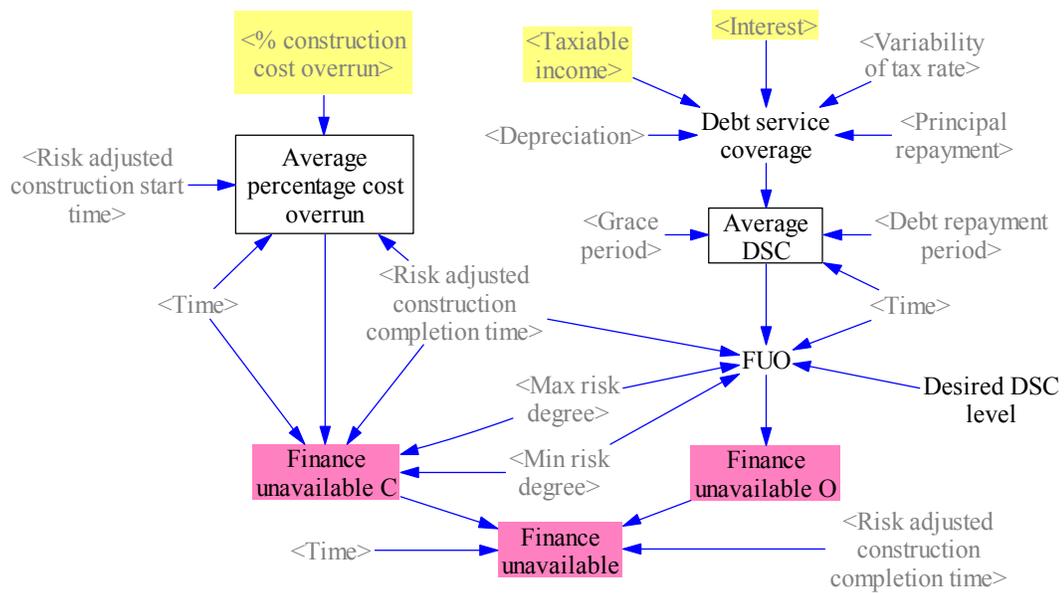
According to the interview statement, the  $RD_k(fu)$  during operation stage was assumed to be a linear relationship with  $\bar{D}_{sc}$  when  $0 < \bar{D}_{sc} < D_{sc}^*$  (desired DSC level) :

$$RD_k(fu) = 1 + \varepsilon_k \bar{D}_{sc} \geq D_{sc}^*$$

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

Where

$D_{sc}^*$ : 1.2;  
 $RD_{max}$ : 25;  
 $RD_{min}$ : 1;  
 $k$ : time period  $o$  (operation stage)



**Figure 6.2.9 The SD Model for 'Finance Unavailable' Risk Effect**

### 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). This 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

#### 1. The procedure of 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 ( $p\text{-values} > \alpha = 0.05$ ) 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  $\alpha = 0.05$ , 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*	0.0516	0.0226	2.285	0.032
default of subcontractor				
resource unavailable*	0.3413	0.1003	3.403	0.003
resource unavailable				
poor cooperation/coordination*	-0.0538	0.3977	-0.135	0.894
poor cooperation/coordination				
defective design*	-1.0349	0.4341	-2.384	0.026
default of subcontractor				
defective design*	-3.1535	0.8740	-3.608	0.002
resource unavailable				
defective design*	0.6733	1.0637	0.633	0.533
poor cooperation/coordination				
default of subcontractor*	0.2703	0.0799	3.384	0.003
resource unavailable				
default of subcontractor*	-0.0494	0.1063	-0.465	0.646
poor cooperation/coordination				
resource unavailable*	-0.4911	0.2475	-1.984	0.060
poor cooperation/coordination				

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 <  $\alpha$  = 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*	0.0458	0.0211	2.167	0.040	
default of subcontractor					
resource unavailable*	0.2456	0.0916	2.681	0.013	
resource unavailable					
defective design*	-0.9408	0.4051	-2.323	0.028	
default of subcontractor					
defective design*	-2.5400	0.8107	-3.133	0.004	
resource unavailable					
default of subcontractor*	0.2290	0.0753	3.041	0.005	
resource unavailable					

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
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 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*	0.0564	0.0203	2.780	0.010	
default of subcontractor					
resource unavailable*	0.3389	0.0953	3.555	0.002	
resource unavailable					
defective design*	-1.1472	0.3893	-2.947	0.007	
default of subcontractor					
defective design*	-3.2554	0.8227	-3.957	0.001	
resource unavailable					
default of subcontractor*	0.2817	0.0742	3.798	0.001	
resource unavailable					
resource unavailable*	-0.3307	0.1497	-2.209	0.037	
poor cooperation/coordination					

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’+Random Normal~( $\mu$ ,  $\sigma$ ), where  $\mu=0$ ;  $\sigma=0.1$ ’ 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				

2. The model test: With the same data set, removing insignificant terms should not result in model coefficients that are substantially changed and the remaining terms should still be significant. To remove a significant linear term while keeping the corresponding squared term to see what happened.

1) From the following full quadratic model, the linear term “resource unavailable” and its corresponding squared term are significant.

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
<b>resource unavailable</b>	<b>13.1980</b>	<b>3.6789</b>	<b>3.587</b>	<b>0.002</b>
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*	0.0516	0.0226	2.285	0.032
default of subcontractor				
<b>resource unavailable*</b>	<b>0.3413</b>	<b>0.1003</b>	<b>3.403</b>	<b>0.003</b>
<b>resource unavailable</b>				
poor cooperation/coordination*	-0.0538	0.3977	-0.135	0.894
poor cooperation/coordination				
defective design*	-1.0349	0.4341	-2.384	0.026
default of subcontractor				
defective design*	-3.1535	0.8740	-3.608	0.002
resource unavailable				
defective design*	0.6733	1.0637	0.633	0.533
poor cooperation/coordination				
default of subcontractor*	0.2703	0.0799	3.384	0.003
resource unavailable				
default of subcontractor*	-0.0494	0.1063	-0.465	0.646
poor cooperation/coordination				
resource unavailable*	-0.4911	0.2475	-1.984	0.060
poor cooperation/coordination				

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

Analysis of Variance for defective construction

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	14	9.9411	9.941099	0.710079	92.09	0.000
Linear	4	9.7797	0.138079	0.034520	4.48	0.008
Square	4	0.0297	0.098964	0.024741	3.21	0.032
Interaction	6	0.1318	0.131768	0.021961	2.85	0.033
Residual Error	22	0.1696	0.169638	0.007711		
Total	36	10.1107				

2) We remove the significant linear term “resource unavailable” while keeping its corresponding squared term. The following result indicates that its corresponding squared term becomes insignificant. It is looking somewhat reasonable.

Estimated Regression Coefficients for defective construction				
Term	Coef	SE Coef	T	P
Constant	-125.777	83.5360	-1.506	0.146
defective design	25.831	14.5821	1.771	0.090
default of subcontractor	-2.445	1.5223	-1.606	0.122

poor cooperation/coordination	11.201	10.8795	1.030	0.314
<b>resource unavailable*</b>	0.091	0.0886	1.024	<b>0.316</b>
<b>resource unavailable</b>				
defective design*	-0.523	0.5858	-0.893	0.381
resource unavailable				
default of subcontractor*	0.025	0.0509	0.493	0.627
resource unavailable				
resource unavailable*	0.074	0.2351	0.315	0.755
poor cooperation/coordination				
defective design*defective design	-0.744	1.5881	-0.468	0.644
default of subcontractor*	-0.012	0.0174	-0.668	0.511
default of subcontractor				
poor cooperation/coordination*	-0.425	0.4729	-0.898	0.378
poor cooperation/coordination				
defective design*	0.202	0.3249	0.621	0.541
default of subcontractor				
defective design*	-0.775	1.2117	-0.640	0.529
poor cooperation/coordination				
default of subcontractor*	0.090	0.1218	0.740	0.467
poor cooperation/coordination				

S = 0.108122 PRESS = 0.814429  
R-Sq = 97.34% R-Sq(pred) = 91.94% R-Sq(adj) = 95.84%

Analysis of Variance for defective construction						
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	13	9.8419	9.841860	0.757066	64.76	0.000
Linear	7	9.8186	0.097643	0.013949	1.19	0.345
Square	3	0.0056	0.013338	0.004446	0.38	0.768
Interaction	3	0.0176	0.017634	0.005878	0.50	0.684
Residual Error	23	0.2689	0.268877	0.011690		
Total	36	10.1107				

**3. The further model tests for more than two variables where we can remove one of them that is insignificant. With this make an additional run where we remove the interaction terms with that variable as well. Also, make another run with where we remove the interaction and squared terms involving the removed variable.**

I. Two variables:

1. A different full quadratic model with two variables is as below. It has a linear term ‘scope change’ that is not significant.

Estimated Regression Coefficients for design changes				
Term	Coef	SE Coef	T	P
Constant	-7.90704	8.75742	-0.903	0.374
scope change	0.80490	0.86833	0.927	0.361
contractual disputes	0.85342	0.31034	2.750	0.010
scope change*scope change	-0.00083	0.02243	-0.037	0.971
contractual disputes*	-0.00773	0.00873	-0.885	0.383
contractual disputes				
scope change*contractual disputes	-0.01729	0.01688	-1.024	0.314

S = 0.119632 PRESS = 0.772635  
R-Sq = 96.80% R-Sq(pred) = 94.42% R-Sq(adj) = 96.28%

2. The linear term ‘scope change’ that is not significant is removed.

Estimated Regression Coefficients for design changes

Term	Coef	SE Coef	T	P
Constant	-0.127678	2.49622	-0.051	0.960
contractual disputes	0.836919	0.30915	2.707	0.011
scope change*scope change	0.018906	0.00704	2.687	0.011
contractual disputes*				
contractual disputes	-0.009141	0.00858	-1.065	0.295
scope change*				
contractual disputes	-0.013993	0.01647	-0.850	0.402

S = 0.119368 PRESS = 0.659015  
R-Sq = 96.71% R-Sq(pred) = 95.24% R-Sq(adj) = 96.30%

**3. The linear term ‘scope change’ that is not significant and its interaction and squared terms are removed as well.**

Estimated Regression Coefficients for design changes

Term	Coef	SE Coef	T	P
Constant	1.10360	7.47109	0.148	0.883
contractual disputes	1.26511	0.92747	1.364	0.182
contractual disputes *				
contractual disputes	-0.03016	0.02864	-1.053	0.300

S = 0.451251 PRESS = 8.25348  
R-Sq = 50.00% R-Sq(pred) = 40.39% R-Sq(adj) = 47.06%

III. More than two variables (four variables):

**1. A different full quadratic model with four variables is as below. It has a linear term ‘resource unavailable’ that is not significant.**

Estimated Regression Coefficients for accidents and safety issues

Term	Coef	SE Coef	T	P
Constant	5.91767	2.89661	2.043	0.053
resource unavailable	-0.14516	0.17785	-0.816	0.423
defective construction	0.38855	0.23969	1.621	0.119
complex system interface/integr	0.21009	0.37376	0.562	0.580
Force Majeure	0.22314	0.02553	8.739	0.000
resource unavailable*	-0.00686	0.00586	-1.171	0.254
resource unavailable				
defective construction*	-0.00009	0.00428	-0.021	0.983
defective construction				
complex system interface/integr*	-0.00603	0.01249	-0.483	0.634
complex system interface/integr				
Force Majeure*Force Majeure	-0.00018	0.00017	-1.046	0.307
resource unavailable*	0.00755	0.00926	0.815	0.424
defective construction				
resource unavailable*	0.01929	0.00901	2.141	0.044
complex system interface/integr				
resource unavailable*Force Majeure	0.00188	0.00154	1.216	0.237
defective construction*	-0.01366	0.01175	-1.163	0.257
complex system interface/integr				
defective construction*Force Majeure	-0.00111	0.00132	-0.843	0.408
complex system interface/integr*	-0.00192	0.00128	-1.504	0.147
Force Majeure				

S = 0.0108765 PRESS = 0.00844488  
R-Sq = 99.99% R-Sq(pred) = 99.98% R-Sq(adj) = 99.99%

**2. The linear term ‘resource unavailable’ that is not significant is removed.**

Estimated Regression Coefficients for accidents and safety issues

Term	Coef	SE Coef	T	P
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Constant	4.64763	2.42533	1.916	0.068
defective construction	0.22901	0.13769	1.663	0.110
complex system interface/integr	0.35437	0.32691	1.084	0.290
Force Majeure	0.20867	0.01824	11.442	0.000
resource unavailable*	-0.00816	0.00560	-1.458	0.158
resource unavailable				
resource unavailable*	0.00859	0.00911	0.943	0.355
defective construction				
defective construction *	0.01265	0.00384	3.295	0.003
complex system interface/integr				
resource unavailable*	0.00194	0.00153	1.268	0.217
Force Majeure				
defective construction*	-0.00008	0.00424	-0.020	0.985
defective construction				
complex system interface/integr*	-0.01026	0.01127	-0.910	0.372
complex system interface/integr				
Force Majeure*Force Majeure	-0.00017	0.00017	-0.984	0.336
defective construction*	-0.00584	0.00675	-0.866	0.396
complex system interface/integr				
defective construction*Force Majeure	-0.00088	0.00128	-0.690	0.497
complex system interface/integr*	-0.00137	0.00107	-1.272	0.216
Force Majeure				

S = 0.0107973 PRESS = 0.00765356  
R-Sq = 99.99% R-Sq(pred) = 99.98% R-Sq(adj) = 99.99%

### 3. The linear term 'resource unavailable' that is not significant and its interaction terms are removed as well.

Estimated Regression Coefficients for accidents and safety issues				
Term	Coef	SE Coef	T	P
Constant	5.79023	2.67381	2.166	0.040
defective construction	0.29946	0.15548	1.926	0.065
complex system interface/integr	0.16145	0.35807	0.451	0.656
Force Majeure	0.21413	0.02077	10.310	0.000
resource unavailable*	0.00288	0.00011	25.134	0.000
resource unavailable				
defective construction*	-0.00029	0.00190	-0.151	0.881
defective construction				
complex system interface/integr*	-0.00095	0.01221	-0.078	0.939
complex system interface/integr				
Force Majeure*Force Majeure	-0.00010	0.00007	-1.419	0.168
defective construction*	-0.00151	0.00754	-0.200	0.843
complex system interface/integr				
defective construction*Force Majeure	-0.00067	0.00060	-1.122	0.272
complex system interface/integr*	-0.00009	0.00111	-0.080	0.937
Force Majeure				

S = 0.0124361 PRESS = 0.00901968  
R-Sq = 99.99% R-Sq(pred) = 99.98% R-Sq(adj) = 99.99%

The above tests indicates that With the same data set, removing insignificant terms should not result in model coefficients that are substantially changed and the remaining terms should still be significant. The models are reasonable.

### **4. Were the unreasonable outputs in the SD simulation a result of the choice of a linear scale? Is the selection of a non-linear scale a possibility?**

After ‘boundary adequacy tests’, ‘structure assessment tests’, ‘dimensional consistency tests’, ‘parameter assessment tests’, ‘extreme condition analysis’, ‘integration error tests’, ‘behavior reproduction tests’, and ‘sensitivity analysis’ for SD model validation stated in 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 ( $p\text{-value} < \alpha = 0.05$ ). These six models are shown in Table 6.3.1:

**Table 6.3.1 The Nonlinear Regression Models**

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

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

We apply “extreme condition analysis” as stated in point 2.5 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.

**5. Does the selection of a linear regression model have some negative implications for the analysis? (The SD analysis should produce some significant non-linear behavior.) This should be mentioned as a limitation to the current analysis.**

The SD model structure consists of many physical interactions of feedback loops. It will produce compounding effects, which are nonlinear and dynamic over time. As shown in Figure 3.4.3, the nonlinear behavior of SD outputs can be the combination of the following four nonlinear patterns: 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). A regression model is only used to specify the parameter values of a risk variable. Since the physical SD model structure is predominant in the SD output behavior, it won't change the SD model's nonlinear output behavior, regardless of linear or nonlinear regression model.

The model validation tests in Chapter 8 have proved that all of the outputs of SD are nonlinear and plausible as a result of the choice of a linear regression. Therefore, the selection of a linear regression model has no negative implications for the SD analysis. In this research, we measured THSR project performance based on net present value (NPV). Figure 8.8.1 indicates that the SD model outputs for the base case, best case and worst case of THSR project NPV are nonlinear when a linear regression model is used. These outputs are plausible. Their behavior can be reasonably interpreted in the section 8.8.

**6. The error term in the regression equation is additive. Is this reasonable? What assumptions are implied? Are there alternatives?**

The regression model is considered as a sum of the true value and the additive error. The error term is independently and normally distributed with zero mean and a mean of zero and a constant variance. This implies that the error term does not depend on the true value itself and the amount of residual error variability is the same at any value of an independent variable. A set of residual plots have shown that these assumptions of using additive error are met. Thus, the error term in the regression equation is additive that is reasonable.

In the section 8.4, a set of residual plots are performed to assess whether the assumptions underlying multiple regression hold. For example, Figure 8.4.1 shows a plot of the residuals versus any independent variable separately, which is used to identify whether there is any specific pattern where an independent variable is related to the residuals. Figure 8.4.1 shows, except for 2 or 3 outliers for each independent variable, the residuals falling randomly, with relatively equal dispersion about zero and no strong tendency to either greater or less than zero. Likewise, no pattern is found for large versus small values of the independent variable.

In addition, 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 form a straight line. The plot for residuals versus fits shows 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. In Figure 8.4.2, the plot for residuals versus order also shows that there is not any specific clustering of residuals with positive correlation or negative correlation.

All of the residual plots for multiple regression models that are used to express the functional relations of risk variables indicate that the error term has a zero population mean,  $E(\mu) = 0$ ; the independent variables are uncorrelated with the error,  $E(\mu | X) = 0$ ; the error term is independently distributed that observations of the error term are uncorrelated with each other,  $E(\mu_i \mu_j) = 0$  for all  $i \neq j$ ; the error term has a

constant variance,  $Var(\mu|X) = \sigma^2$  and  $Var(Y|X) = \sigma^2$ ; the error term is normally distributed,  $E \sim N(0, \sigma^2)$ . As a result, we can conclude the additive error in the regression model for this research is reasonable.

Since the error variability is constant at the values of all independent variables, that the error term is additive is basically adequate for the regression model. Particularly, there is not any specific pattern of residuals for large versus small values of the independent variable and the residuals don't depend on the true value as well. Thus, there is no requirement for the other forms of error term such as multiplicative error that is proportional to the true value and the mixed error that is the combination of additive error and multiplicative error in this research.

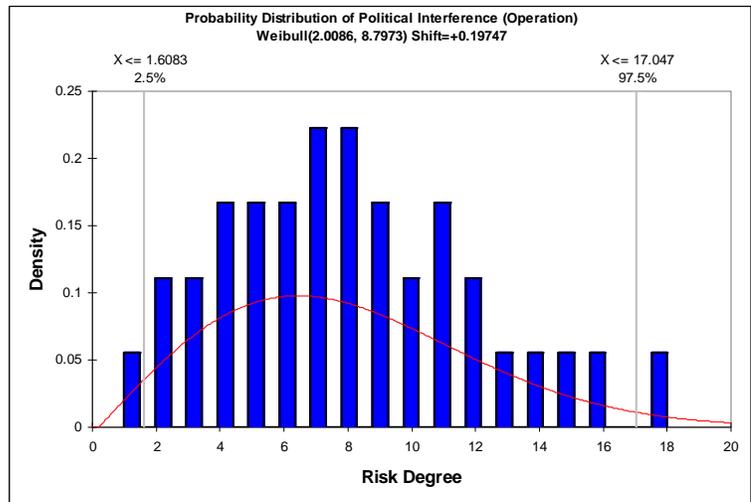
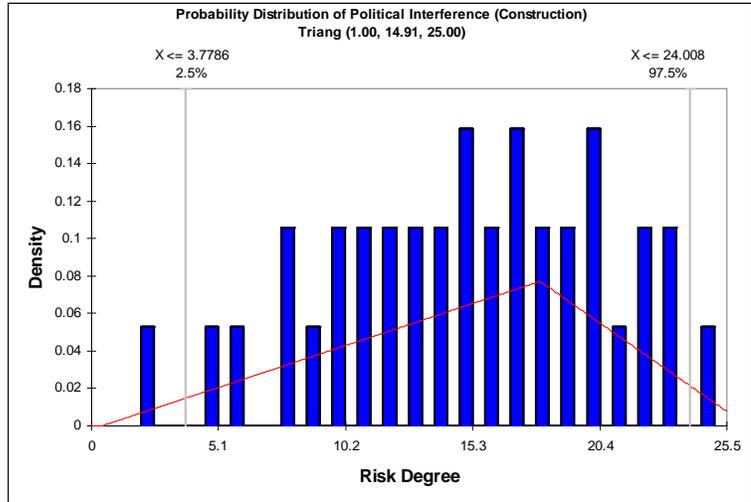
All of the multiple-regression models are included in Appendix VIII.

### **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 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.

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 outlined in Appendix II.

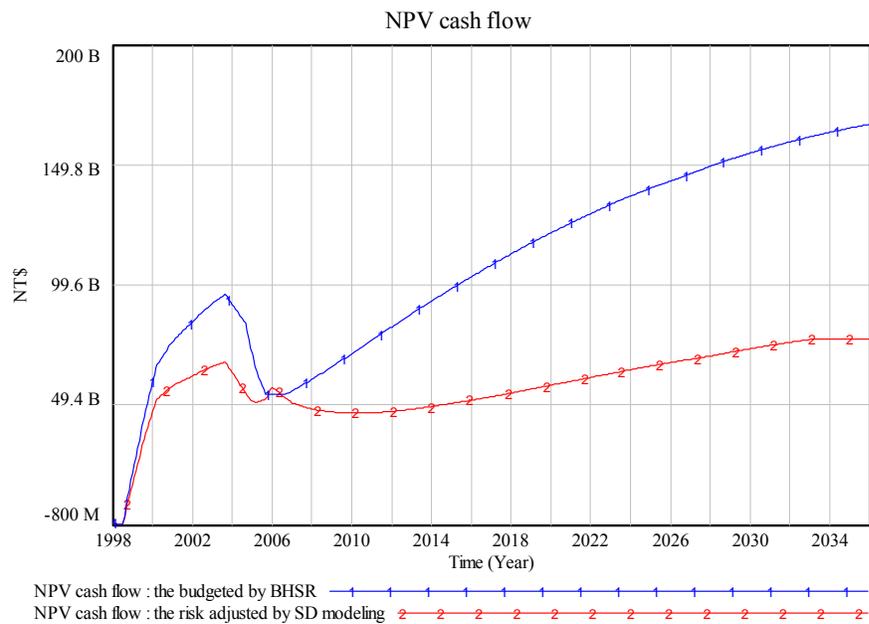


**Figure 6.3.1 The Fitted Probability Distribution for the Expected Risk Effect of ‘Political Interference’ At Construction and Operation Phases**

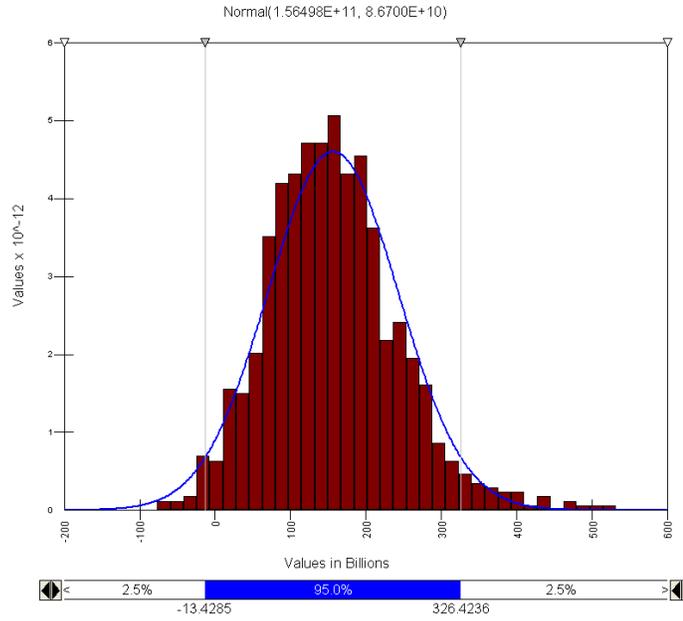
### 6.4 Monte Carol Simulation for Risk Compounding Effects

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.

In Figure 6.4.1 this researcher compares two NPV cash flows: the budgeted, estimated by BHSR (the public sector), and the risk adjusted, estimated by SD modeling. The figure indicates that the expected NPV estimated by the SD modeling (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 6.4.1 The Comparison of Project NPV**



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

# Chapter 7 Bidding Proposal Modeling and Simulation

## 7.1 System Dynamics for Bidding Proposal Modeling

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. This research developed a system dynamic model for risk cost network modeling 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 modeling 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

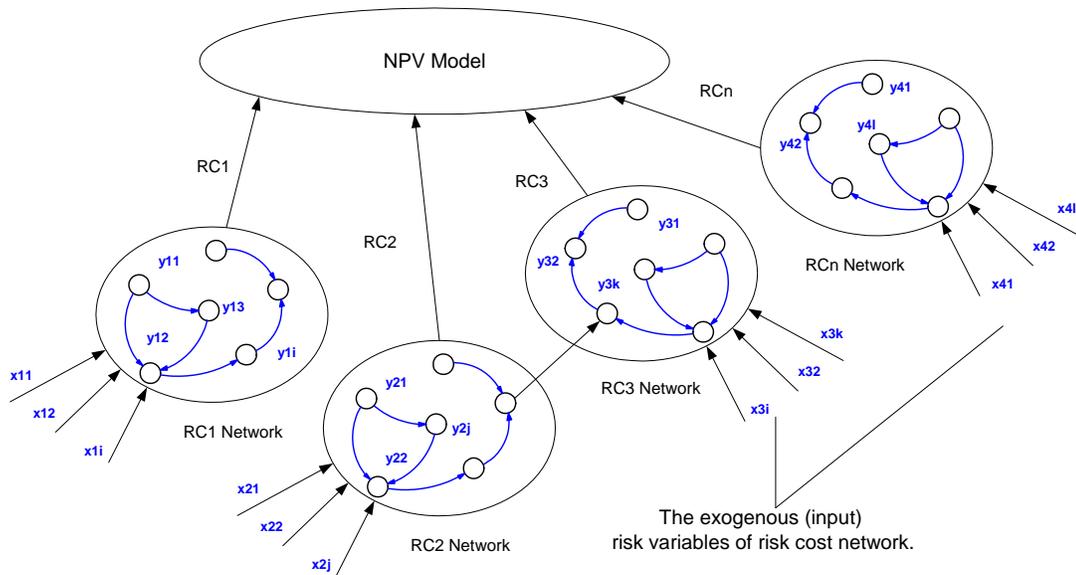
Similar to the current practice for PPP bid selection, this research proposed that the bidding proposals submitted to the public sector for bid competition should include cost components illustrated in Table 7.1, which would be modeled to estimate the overall NPV range values for bid benchmarking. They 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 low bidding costs intended for bid competition, 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**

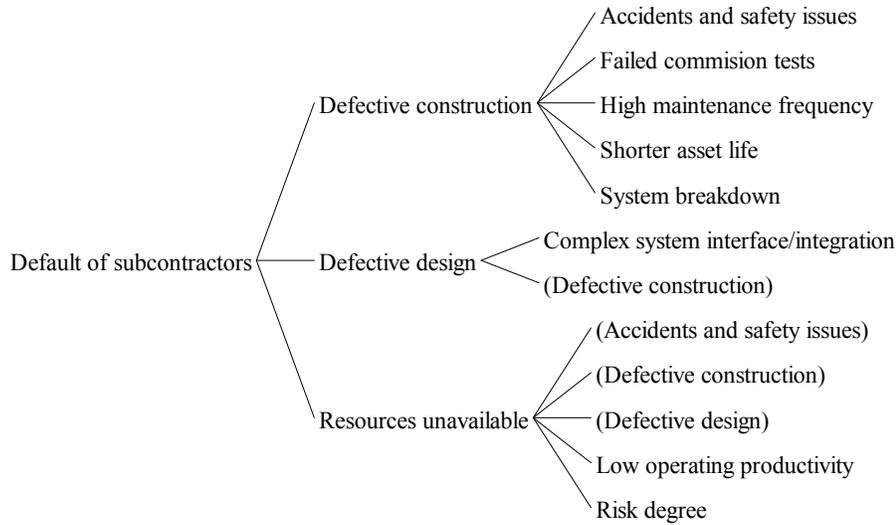
(2) Transferred risk: In addition to the plan and scheme for raw cost components, the concessionaire candidates (the private sectors/the bidders) are requested to demonstrate their capability of managing and controlling the allocated risks in their bidding proposals. On the other hand, the public sector 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
- $i$ :  $i$ th risk network;
- $j$ :  $j$ th exogenous risk variable of a risk network;
- $k$ :  $k$ th 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, this 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 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.

**Table 7.1.1 The ‘Default of Subcontractors (DOS)’ Control Scheme**

The ‘Default of Subcontractors (DOS)’ 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 Modeling**

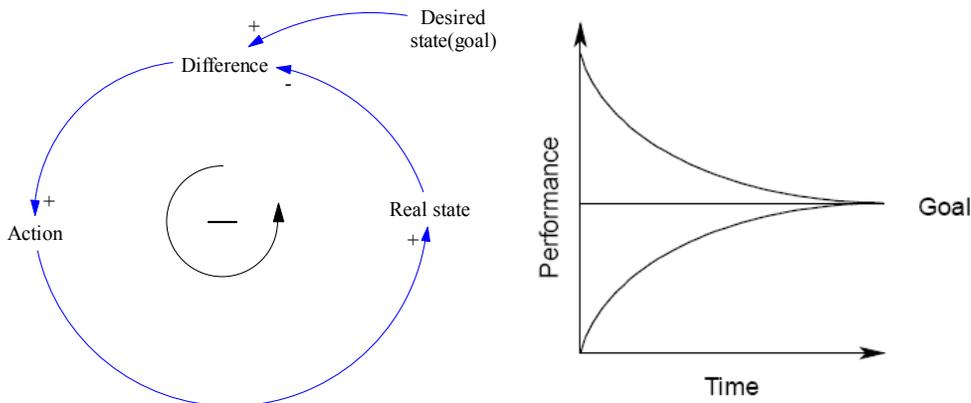
As discussed in chapters 4 through 6, there are always positive feedback loops (reinforce feedback loops) to generate, amplify and reinforce risk effects in a risk causal loop diagram. The negative feedback loops (the balance feedback loops) would reduce risk effects to seek status balance and equilibrium. Figure

7.1.3 shows a system dynamics causal loop diagram (left hand side) and a behavior 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 behavior to approach the goal (the desired risk degree 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;  
 $\Delta RD$ : the reduction of risk degree;  
 $\Delta T$ : risk control time;  
 $\Delta C$ : annual invested cost for a risk control scheme.



**Figure 7.1.3 The ‘Goal Seeking’ Structure and Behavior(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 degree = 5 (Appendix IV) under the expected time.

Figure 7.1.5 shows a case in which the SD modeling 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 degree = 5 is achieved using the DOS risk effect reduction rate as below:

$$\dot{Rd}_{ij} = \frac{Rd_{ij} - \hat{Rd}}{\hat{T}_{ij}} \text{ for } Rd_{ij} \geq \hat{Rd} \quad (7.1.2)$$

$$= 0, \text{ otherwise}$$

Where

$\dot{Rd}_{ij}$  : the DOS risk effect reduction rate;

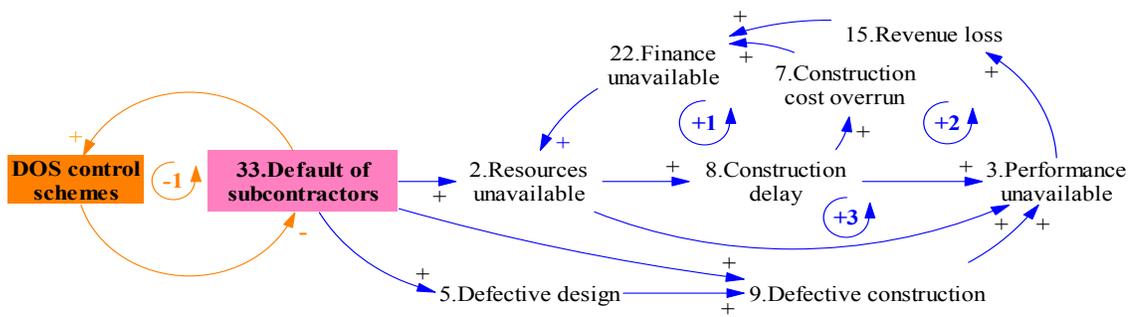
$Rd_{ij}$ : the random variable for the risk degree of a risk event;

$\hat{Rd}$  : the desired risk degree;

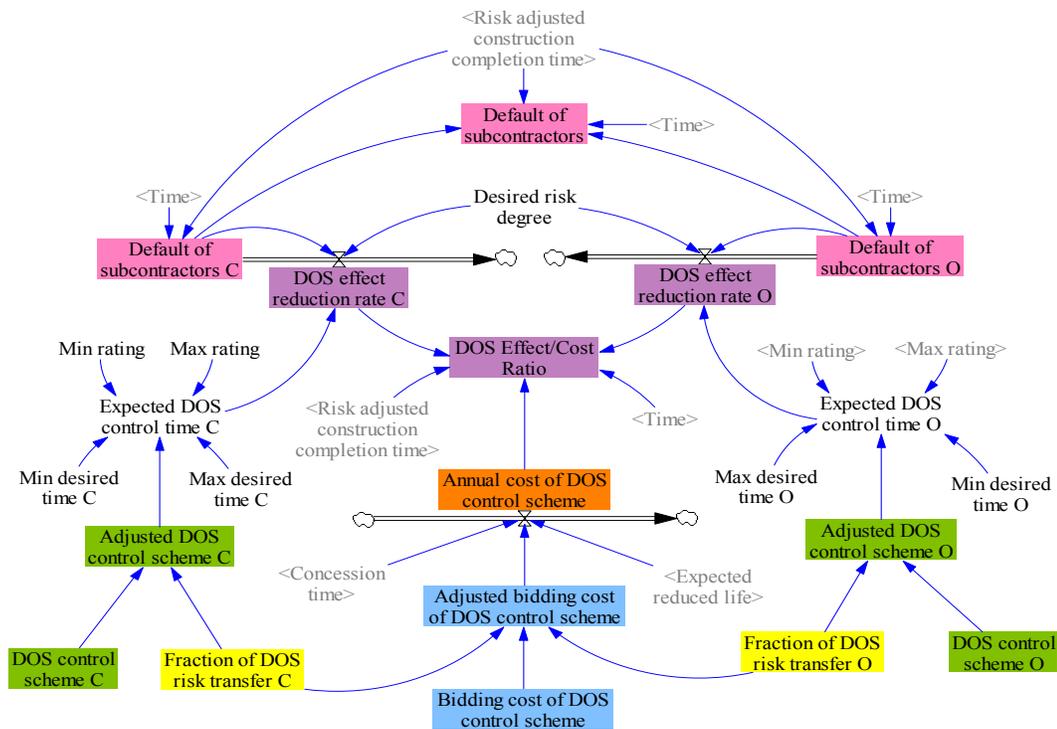
$\hat{T}_{ij}$  : the expected time (mean time) to reduce the risk degree until the desired level;

$i$ : 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 Modeling 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.

**Table 7.1.2 The Rating for 'DOS Risk Control Schemes' Effects**

<b>Rating for the expected effect of 'DOS Risk Control Schemes':</b>									
Base case:	(O 1)-	(O 2)-	(O 3)-	(O 4)-	(⊙ 5)-	(O 6)-	(O 7)-	(O 8)-	(O 9)
Bid A:	(O 1)-	(O 2)-	(O 3)-	(O 4)-	(O 5)-	(O 6)-	(O 7)-	(⊙ 8)-	(O 9)
Bid B:	(O 1)-	(⊙ 2)-	(O 3)-	(O 4)-	(O 5)-	(O 6)-	(O 7)-	(O 8)-	(O 9)
Bid C:	(O 1)-	(O 2)-	(O 3)-	(O 4)-	(O 5)-	(⊙ 6)-	(O 7)-	(O 8)-	(O 9)
Bid D:	(O 1)-	(O 2)-	(O 3)-	(O 4)-	(⊙ 5)-	(O 6)-	(O 7)-	(O 8)-	(O 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 degree 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 degree 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 degree 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 behavior 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.

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

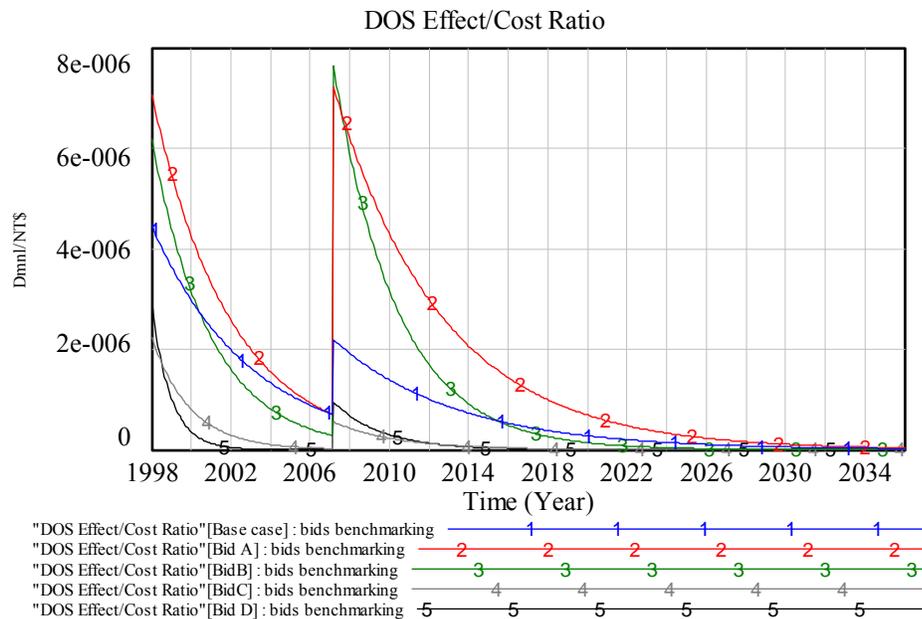
Where

- $Rcs'_{ij}$ : 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;
- $\theta_{ij}$ : the fraction of risk-transferred to the private sector

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

Where

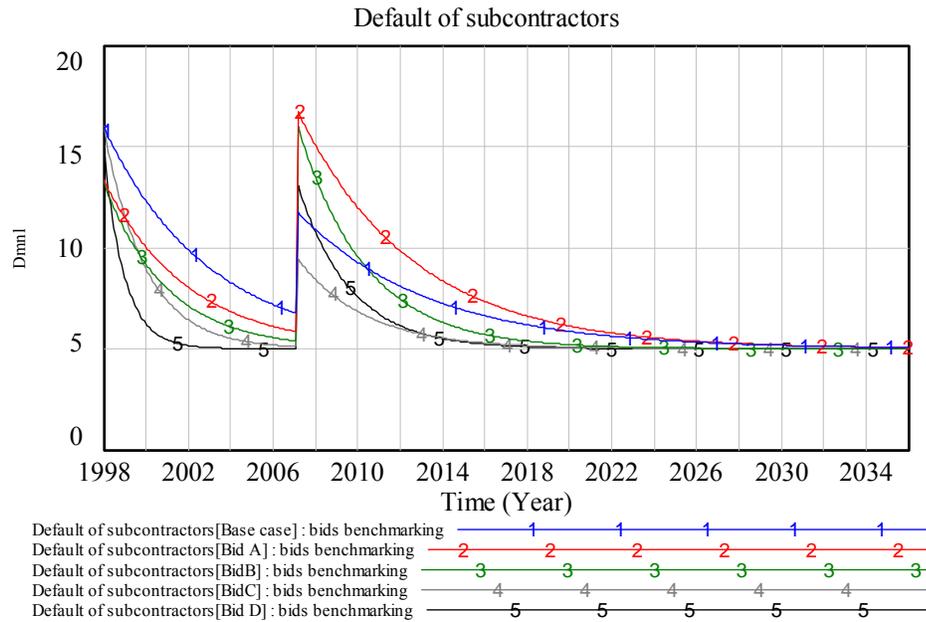
- $Crcs'_{ij}$ : the adjustment for a risk control scheme cost;
- $Crcs_i(bc)$ : the cost for a risk control scheme stated in the Base Case (the cost for all risks reserved);
- $Crcs_i(bids)$ : the cost for a risk control scheme proposed in the bidding proposals (the cost for transferred risks only);
- $\theta_{ij}$ : the fraction of a risk event transferred to the private sector



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

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 this 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 degree of DOS is 15) is gradually reduced until reaching the desired risk degree (assume ending risk degree of 5). This shows an exponential decay for goal-seeking behavior 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**



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;  
 $\beta_e$ : 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;  
 $\theta_{ij}$ : 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;  
 $\beta_e$ : 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.

**Table 7.1.4 An Example: the Percentage of Risk Premium Transferred to the Private Sector for Bid A2**

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			<b>0.901</b>

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;

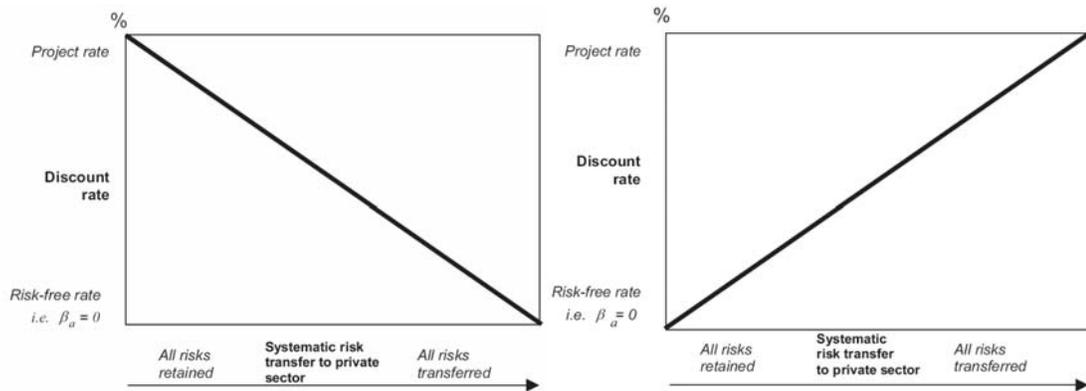
$w_e$ : equity fraction;

$r'_e$ : 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**

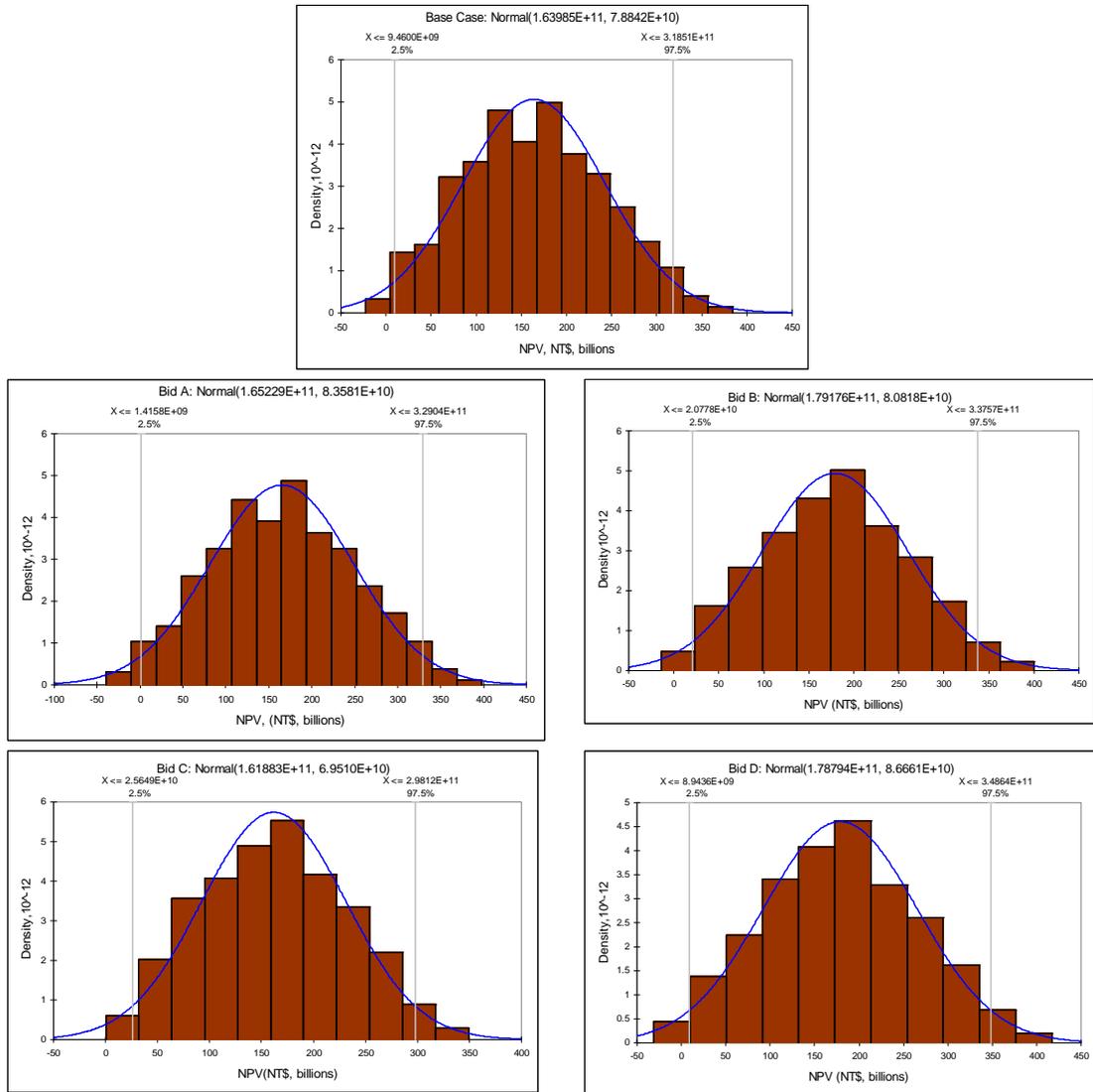
## 7.2 Monte Carlo Simulation for Bidding Proposals

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.

**Table 7.2.1 The Price of Bidding Proposals**

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

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.

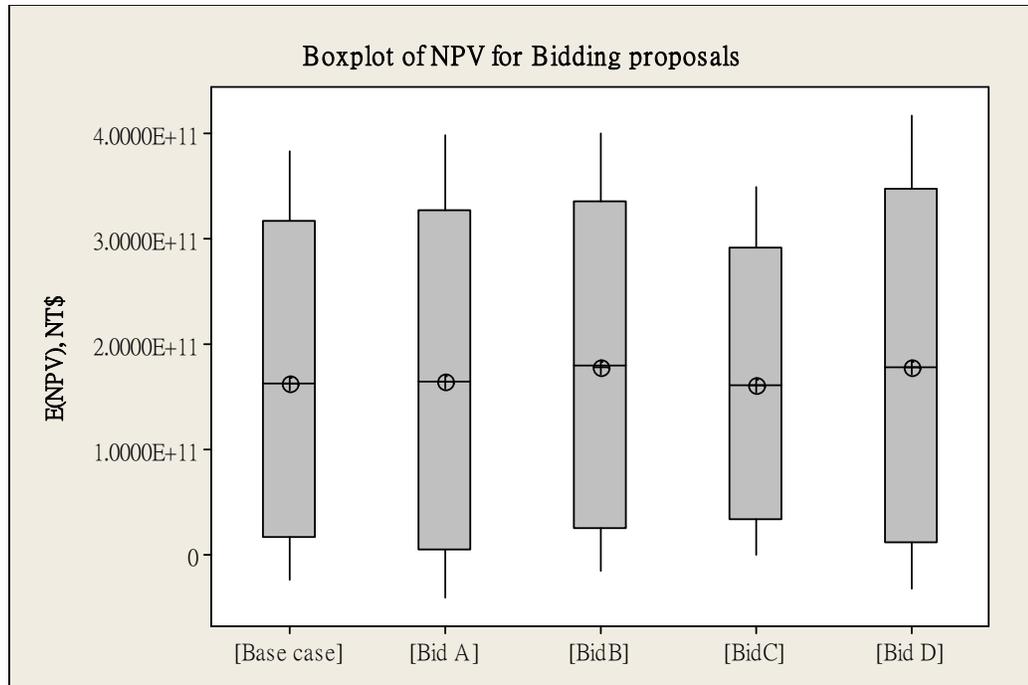


**Figure 7.2.1 The NPV Probability Distribution of Base Case and Bidding Proposals**

### 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 bounds 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. This researcher introduced some methods that are appropriate and easy to use in comparing bidding proposals and in choosing a bidding proposal.



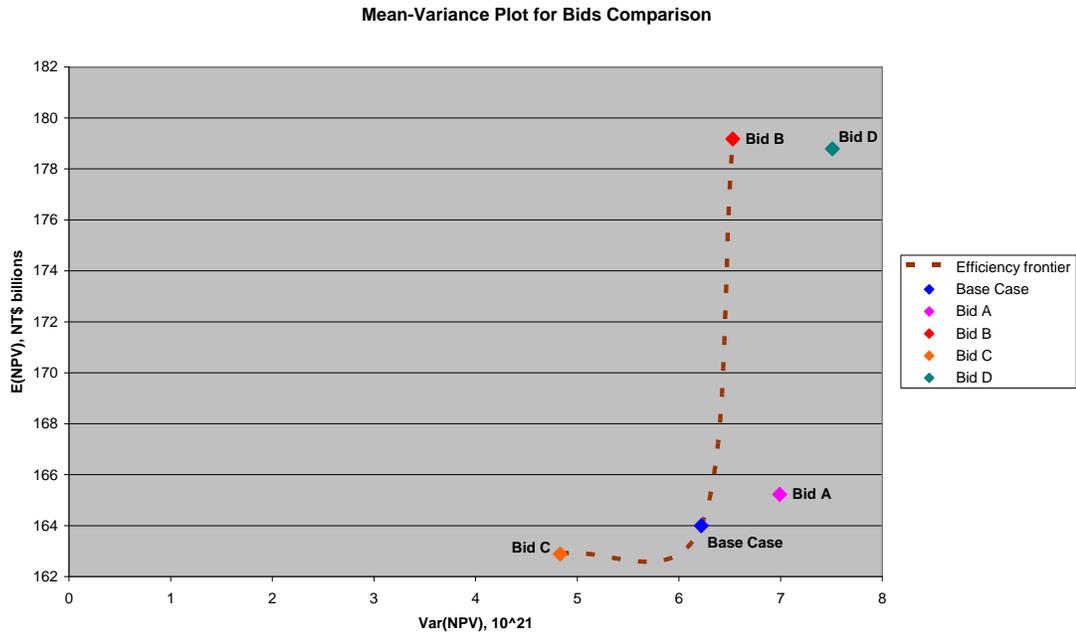
**Figure 7.2.2 The Boxplot with Mean and 95% Confidence Interval for the Expected NPV of Base Case and Bidding Proposals**

### 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**

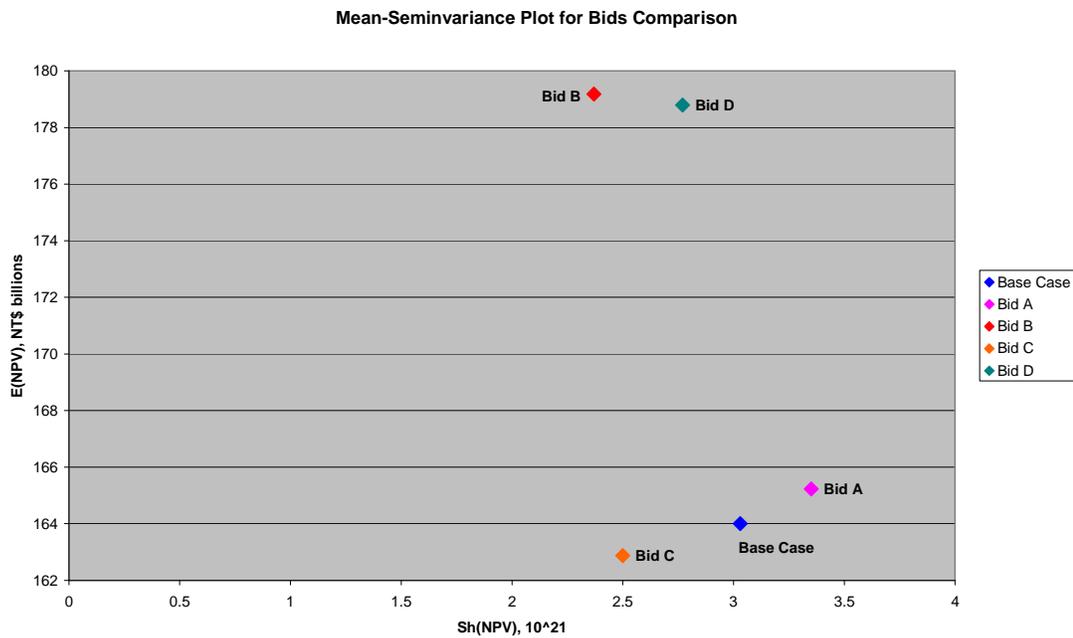
To differentiate the bidding proposals from the base case, the mean-semi variance ( $E-S_h$ ) criterion is a good option. However, it is suggested that only NPV variability is below the acceptable level is desirable; the variability within the acceptable region was not. Thus, the mean-semi variance rule 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  $x \leq h$ ;  
 $= 0$  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  $E-S_h$  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:*

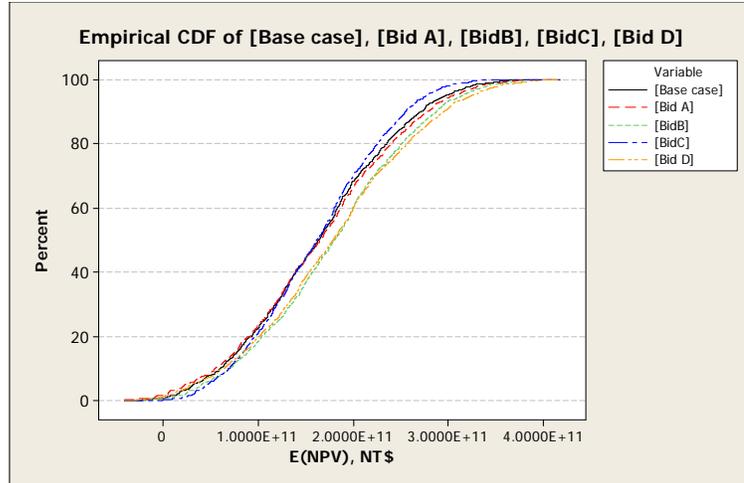
$$F(x) \leq G(y) \text{ for every } x \quad (7.3.2)$$

*And  $F(x_0) < G(y_0)$  for some  $x_0$*

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), this 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):

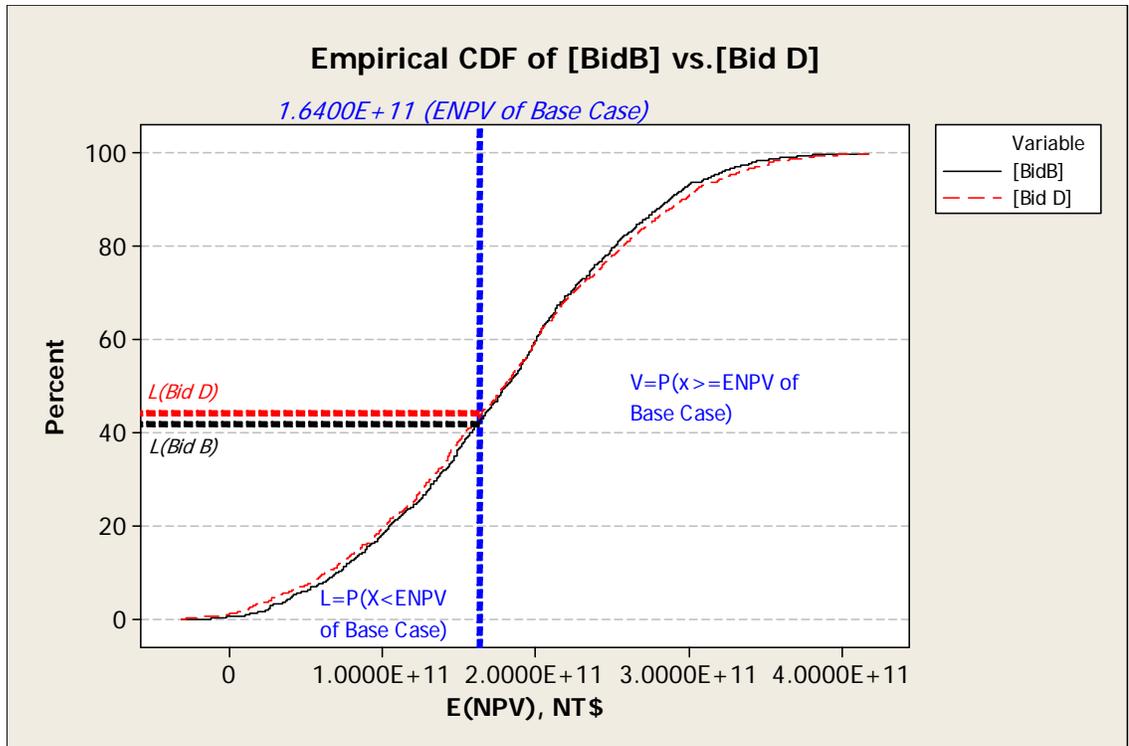
$$R_{el} = L / (L + V) \quad (7.4.3)$$

where

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

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

$NPV_{BC}$ : 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**

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

## 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 modeling. 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. This 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 modeling including: boundary adequacy tests, structure assessment tests, dimensional consistency tests, parameter assessment tests, extreme condition analysis, integration error tests, behavior reproduction tests, and sensitivity analysis. In Table 8.1, this researcher summarized these tests by displaying measure of performance and the results of measures that are addressed in detail in the following sections.

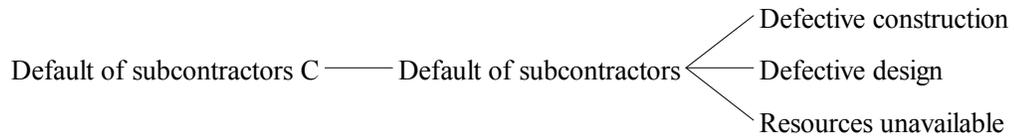
### 8.1 Boundary Adequacy Tests

Boundary adequacy tests were used to assess the appropriateness of the model boundary for the model purpose (Sterman, 2000). Before starting SD quantitative modeling, this 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, this 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.

This researcher used Vensim, a software package, for system dynamics modeling. 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 this 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)	$F(t) \leq 0, t \leq T_c$ $F(t) \geq 0, t \geq T_c$ 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 <sup>2</sup> -adj/ s (mean-squared error)	$\geq 80\%$
			P-value	$< \alpha=0.05$
			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	$> \alpha=0.05$

8.5	<b>Extreme Condition Analysis</b> <small>(Barlas, 1996; Lee et al., 2005; Nguyen &amp; Ogunlana, 2005; Sterman, 2000; Tvedt, 1996)</small>	Risk degree	$1 \leq Rd \leq 25$ ?	Yes
		NPV time profiles with 95% C.I. over project life	Implausible changes?	No
8.6	<b>Integration Error Tests</b> <small>(Barlas, 1996; Lee et al., 2005; Sterman, 2000)</small>	$\Delta NPV/\Delta T$ (year 2036)	Time step $\Delta T$	<ul style="list-style-type: none"> <li>• <math>\Delta NPV/\Delta T = 16.59</math>, when <math>0.08333331 &lt; \Delta T \leq 1</math>;</li> <li>• <math>\Delta NPV/\Delta T = 3.92</math>, where <math>0.0078125 \leq \Delta T \leq 0.0833333</math></li> </ul>
		NPV time-profiles over project life	Time step $\Delta T$	<ul style="list-style-type: none"> <li>• Unstable and sensitive when where <math>0.08333331 &lt; \Delta T \leq 1</math>;</li> <li>• Stable when time where <math>0.0078125 \leq \Delta T \leq 0.0833333</math></li> </ul>
8.7	<b>Behavior Reproduction Tests</b> <small>(Ferreira, 2002; Hao, 2002; Kazeli et al., 2003; Lee et al., 2005; Martin, 2002; Nguyen &amp; Ogunlana, 2005; Tvedt, 1996)</small>	% 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	<p>Monte-Carlo multi-variate Sensitivity Analysis</p> <p>(Ferreira, 2002; Hao, 2002; Kazeli et al., 2003; Lee et al., 2005; Martin, 2002; Nguyen &amp; Ogunlana, 2005; Tvedt, 1996)</p>	NPV time profiles with 95% C.I.	Implausible changes	No
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## 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 (Stermann, 2000). The purpose of the whole SD decision model created by this 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.

**Table 8.1.1 Model Boundary Chart for a Long-Term NPV Model of Risk Interactions**

Exogenous Risk Variables	Endogenous Risk Variables	Excluded
<p> <b>Default of subcontractors C</b>  <b>Default of subcontractors O</b>  <b>Downside economic events C</b>  <b>Downside economic events O</b>  <b>Force Majeure C</b>  <b>Force Majeure O</b>  <b>Greater environmental expectation C</b>  <b>Greater environmental expectation O</b>  <b>Latent defect C</b>  <b>Latent defect O</b>  <b>Political interference C</b>  <b>Political interference O</b>  <b>Unforeseen site conditions C</b>  <b>Variability of exchange rate</b>  <b>Variability of inflation rate</b>  <b>Variability of interest rate</b>  <b>Variability of less demand</b>  <b>Variability of tax rate</b>  <b>Equity fraction</b> </p>	<p>           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         </p>	<p>           Social benefits            Ecological impact            GDP growth            National economic loss         </p>

This 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 this researcher have passed the model checking.



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

As for the structure of feedback loops for risk interactions, this 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.

**Table 8.2 The Partial Display of The Loop List for ‘Default of Subcontractor’3 Risk Variable**

<p>Loop Number 1 of length 6</p> <ul style="list-style-type: none"> <li>Default of subcontractors <ul style="list-style-type: none"> <li>Resources unavailable</li> <li>Risk degree</li> <li>Time delay effect</li> <li>Increased completion time</li> <li>Workpackage duration</li> <li>Risk adjusted construction completion time</li> </ul> </li> </ul> <p>Loop Number 2 of length 9</p> <ul style="list-style-type: none"> <li>Default of subcontractors <ul style="list-style-type: none"> <li>Defective construction</li> <li>Failed commission tests</li> <li>Contract breach</li> <li>Has the Contract terminated?</li> <li>Risk degree</li> <li>Time delay effect</li> <li>Increased completion time</li> <li>Workpackage duration</li> <li>Risk adjusted construction completion time</li> </ul> </li> </ul> <p align="center">...</p>
--

Structure is the set of physical and information interconnections that generates behavior (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,  $F(t) \leq 0$ , at the construction phase ( $t \leq T_c$ : construction completion time) and positive,  $F(t) > 0$ , at the operation phase ( $t > T_c$ ). 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.



## 8.4 Parameter Assessment Tests

The parameter assessment test is used to estimate whether the values of a parameter are reasonable (Sterman, 2000). This 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			

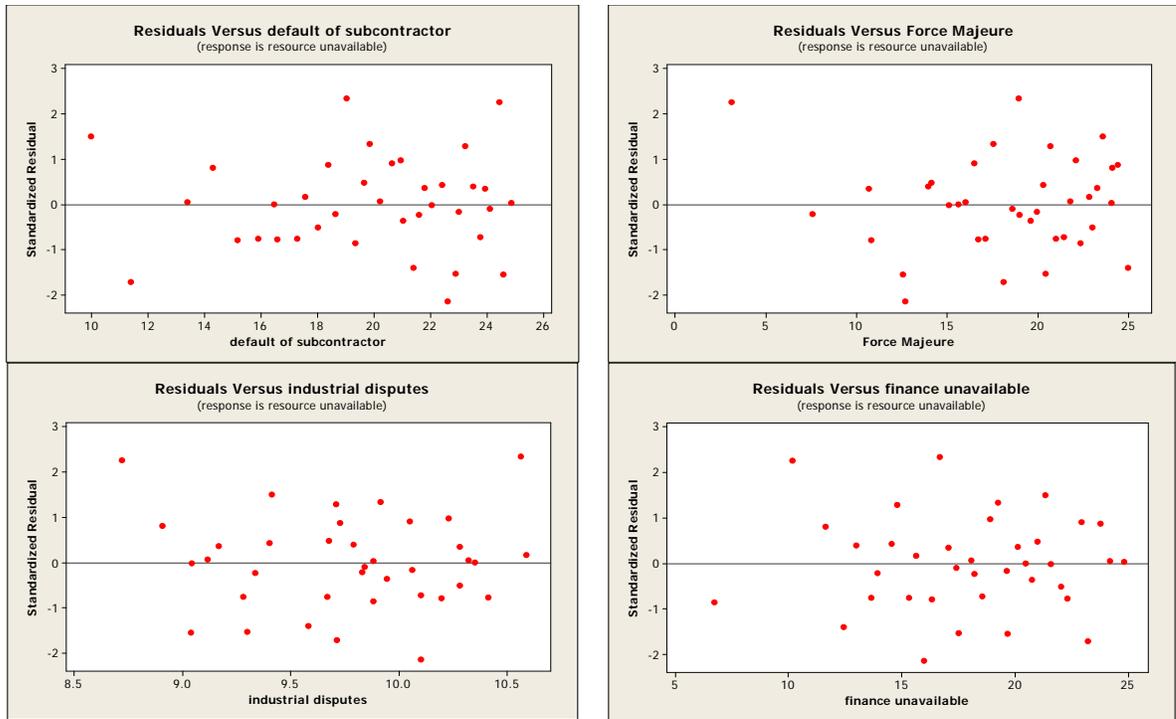
From the above ANOVA table, the p value for regression was close to 0. The p value for each model coefficient test is close to 0 as well. It appears that both coefficients and regression relationship between predictors and response are statistically significant at  $\alpha = 0.05$ . The four predictors account for 96.4% ( $R\text{-Sq (adj)} = 96.4\%$ ) 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.

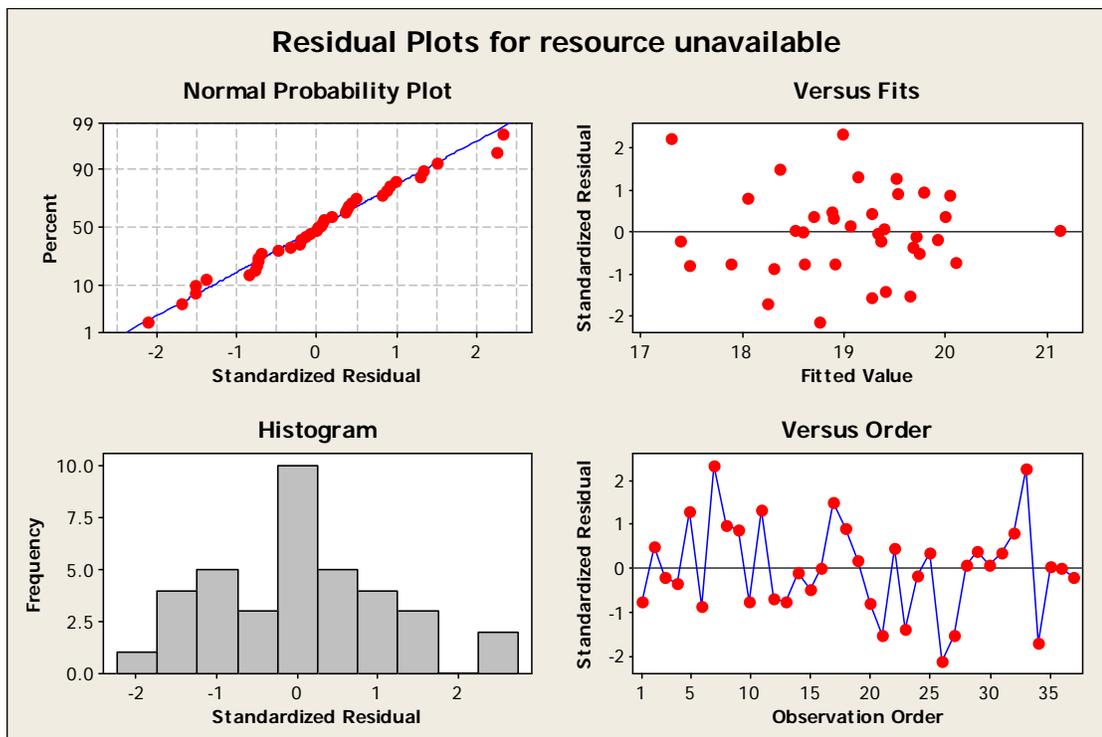
In addition to the above tests, the following plots were conducted to exam if the models were adequate and the assumptions of regression were met. Figure 8.4.1 shows a plot of the residuals versus the predictor, which was used to examine whether there was any non-random pattern where a predictor variable 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 this 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 a 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, this 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:

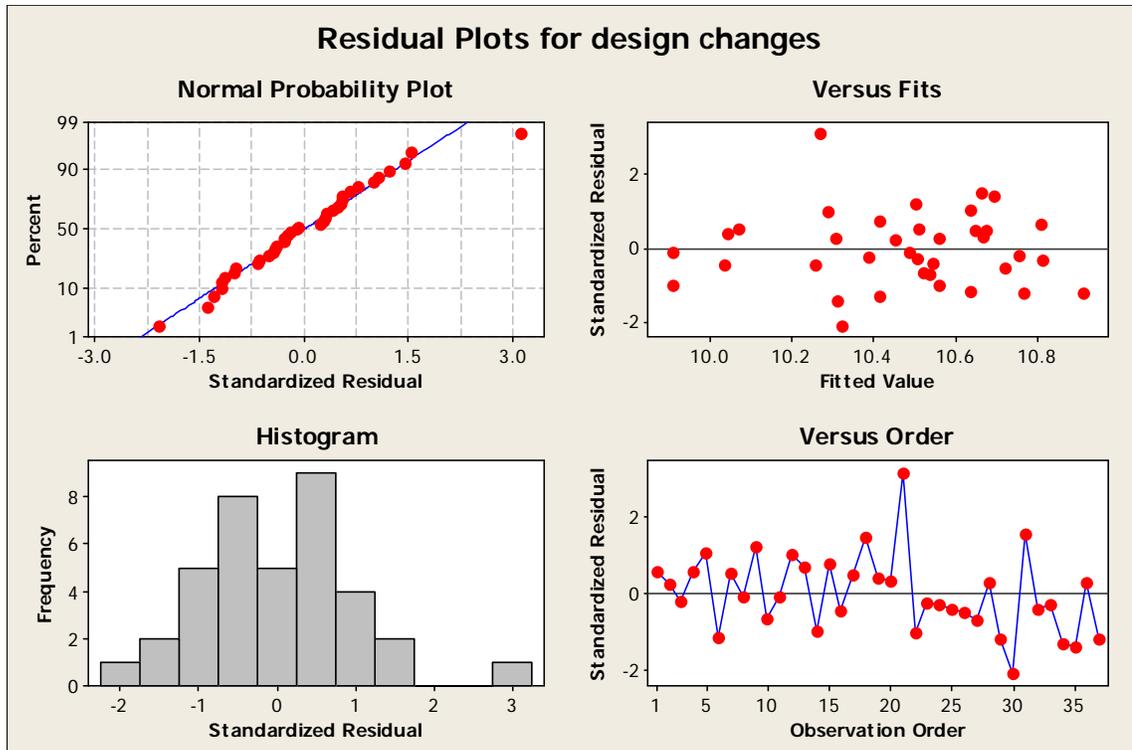
**Table 8.4 The Comparison of Regression Models ‘With Suspect Outliers’ and ‘Without Suspect Outliers’**

With suspect outliers	<p>The regression equation is  <math>\text{design changes} = 3.56 + 0.249 \text{ scope changes} + 0.218 \text{ contractual disputes}</math></p> <table border="1"> <thead> <tr> <th>Predictor</th> <th>Coef</th> <th>SE Coef</th> <th>T</th> <th>P</th> </tr> </thead> <tbody> <tr> <td>Constant</td> <td>3.5577</td> <td>0.7522</td> <td>4.73</td> <td>0.000</td> </tr> <tr> <td>scope ch</td> <td>0.24873</td> <td>0.04094</td> <td>6.08</td> <td>0.000</td> </tr> <tr> <td>contract</td> <td>0.21826</td> <td>0.03340</td> <td>6.54</td> <td>0.000</td> </tr> </tbody> </table> <p>S = 0.1615    R-Sq = 72.2%    R-Sq(adj) = 70.6%</p>	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
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																	
Without suspect outliers	<p>The regression equation is  <math>\text{design changes} = 3.38 + 0.257 \text{ scope changes} + 0.222 \text{ contractual disputes}</math></p> <table border="1"> <thead> <tr> <th>Predictor</th> <th>Coef</th> <th>SE Coef</th> <th>T</th> <th>P</th> </tr> </thead> <tbody> <tr> <td>Constant</td> <td>3.3813</td> <td>0.6100</td> <td>5.54</td> <td>0.000</td> </tr> <tr> <td>scope ch</td> <td>0.25652</td> <td>0.03290</td> <td>7.80</td> <td>0.000</td> </tr> <tr> <td>contract</td> <td>0.22183</td> <td>0.02685</td> <td>8.26</td> <td>0.000</td> </tr> </tbody> </table> <p>S = 0.1289    R-Sq = 81.5%    R-Sq(adj) = 80.4%</p>	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
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																	

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:  $\text{design changes} = 3.38 + 0.257 \text{ scope changes} + 0.222 \text{ contractual disputes} + \text{Nor} \sim (0, 0.248)$ , when we remove the outliers from collected data.

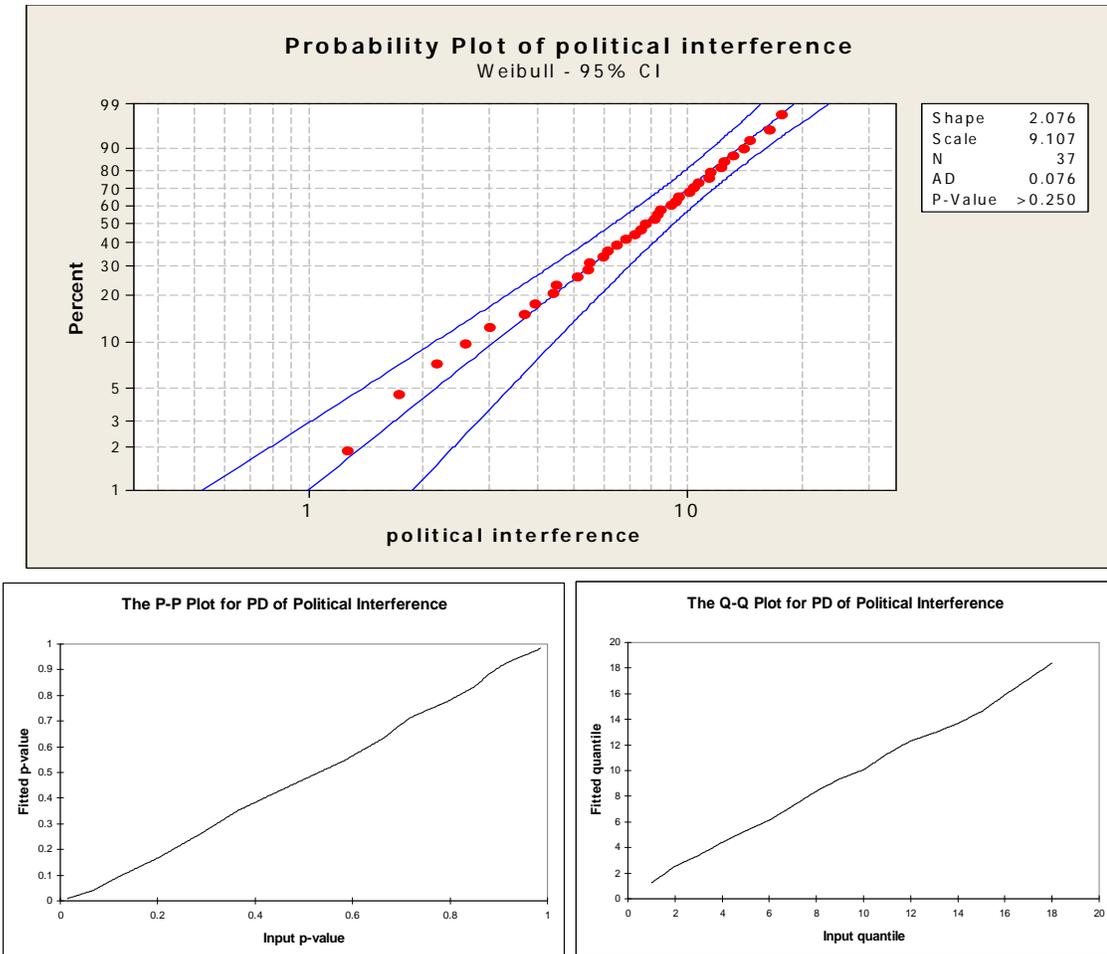
There are 44 multiple regression models used to address risk relationship parameters which are all tested by the above approaches. The results showed that all of the regression models were adequate and the regression assumptions were met.



**Figure 8.4.3 the Residual Plots for ‘Design Changes’ Regression Model with Suspect Outliers**

Another parameter assessment test was conducted for exogenous risk variables. This 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  $\alpha = 0.05$ . 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  $\alpha = 0.05$ . From the above diagnostic plots, this 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, this researcher quantified and scaled the expected risk effect of risk events with the risk degree ranged from 1 to 25. The maximum risk degree of 25 and minimum risk degree 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 degree for resource unavailable, performance unavailable and financial unavailable endogenous risk variables were still ranged between 1 and 25 when the risk degree for exogenous risk variables had a maximum value of 25. Figure 8.5.2 indicates the risk degree 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 degree 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, this researcher observed that the output patterns were still in reality.

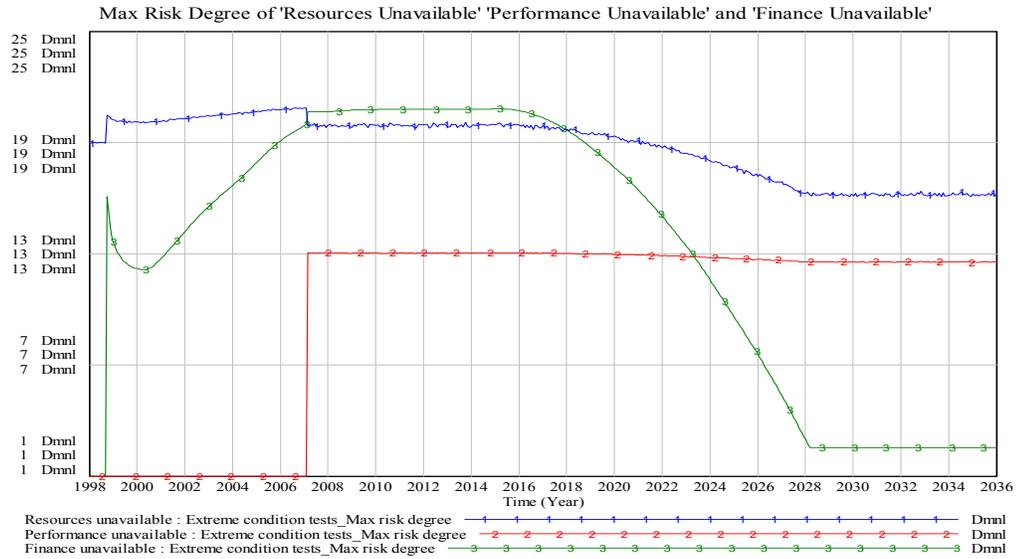
When the setup for risk degree is other than the range values from 1 to 25, the output for these variables is not feasible or reasonable. Moreover, the simulation results indicate an ERROR message like “Unable to converge simultaneous loop at time...”. This error message arose from variables that have 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 ...."

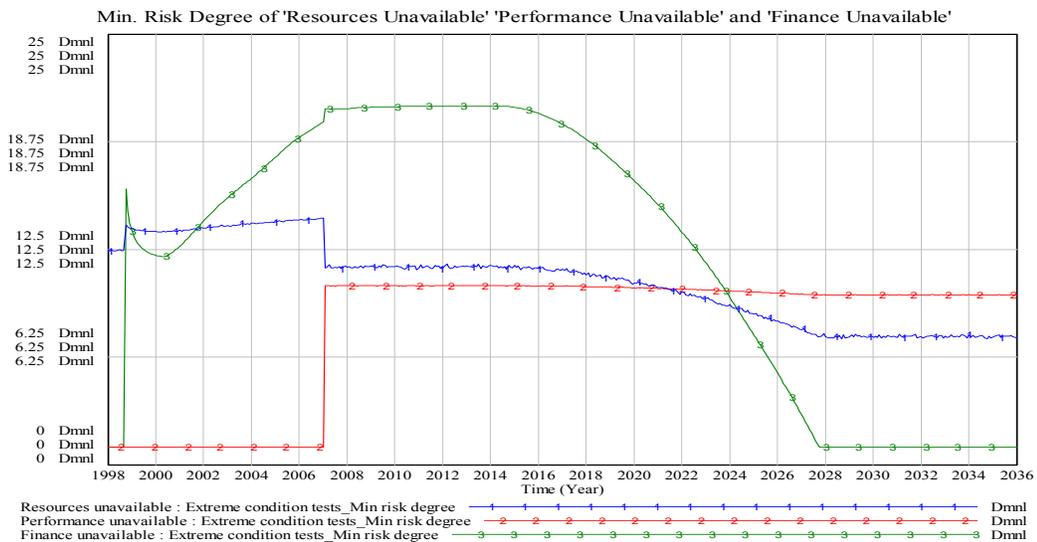
In addition, it yields unreasonable outputs for variable DeT ('the number of trains that would likely delay on-time service' stated in the section 6.2.3 and Appendix VII3) when 'performance unavailable' has gone beyond their specified low/high range. For instance, the value of 'the number of trains' 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 behavior when the extreme values of all of parameters were simultaneously sampled. This is addressed in Section 8.8: sensitivity analysis.



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



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

## 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). This 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, this researcher used an integration method to try different time steps to examine whether there was major difference between them.

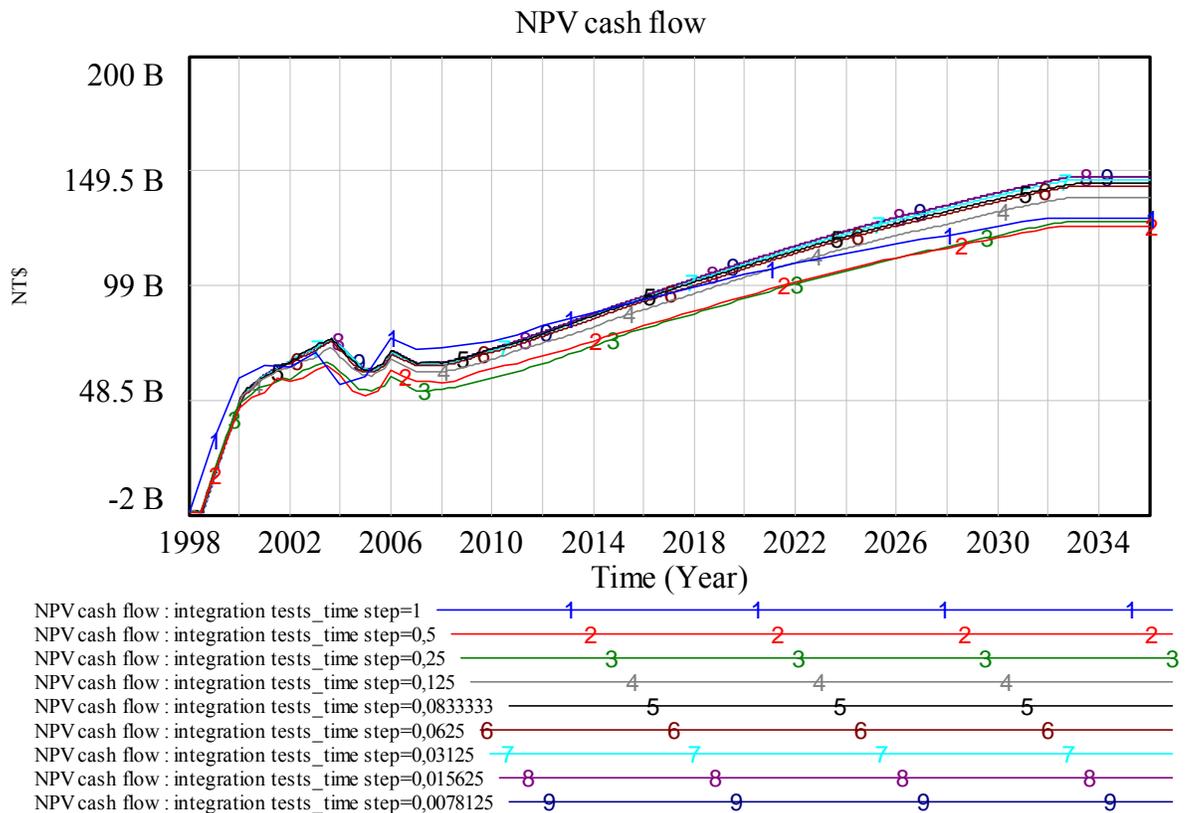
This researcher used the Vensim software package to build SD models for the risk network and bidding proposal benchmarking. This analysis showed six integration technique options that traded off speed and accuracy; these option were: (a) Euler, (b) Diff, RK4 Auto, (c) RK4 Fixed, (d) RK2 Auto, (e) RK2 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 this 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 this researcher do not involve oscillation output behavior. Therefore, the Euler integration was suitable and was chosen for this research.

This 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  $\Delta T$  was 1 and minimum was 0.0078125. This 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). This researcher tested  $\Delta T$  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, this researcher calculated the NPV changes in year 2036 against  $0.08333331 < \Delta T \leq 1$  and  $0.0078125 \leq \Delta T \leq 0.0833333$ . Apparently,  $\Delta NPV / \Delta T = 16.59$  where  $0.08333331 < \Delta T \leq 1$  was significantly more than  $\Delta NPV / \Delta T = 3.92$  where  $0.0078125 \leq \Delta T \leq 0.0833333$ . In addition, this 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.

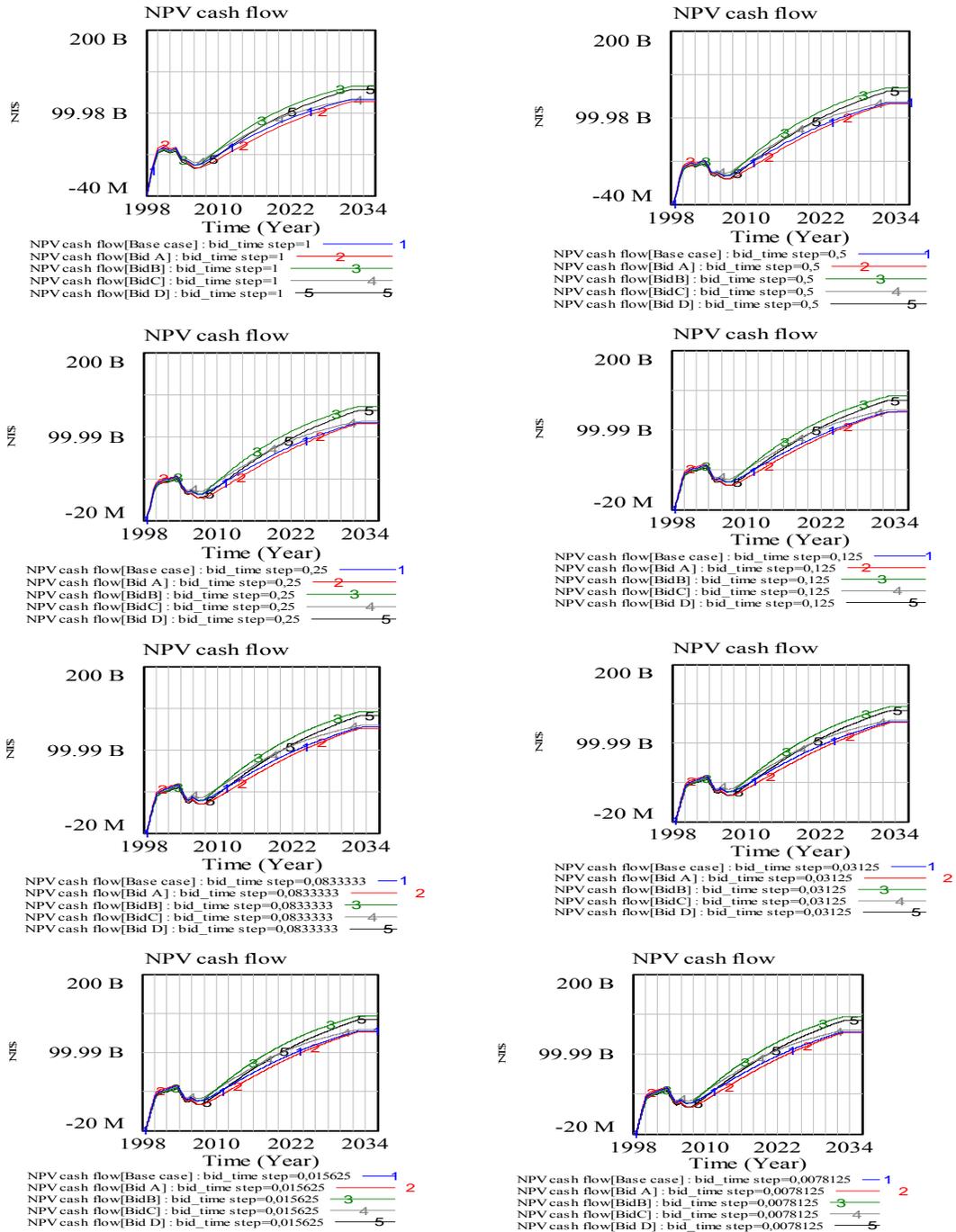


**Figure 8.6.1 The Integration Tests for NPV Changes by Time Step for Risk**

**Table 8.6.1 The Integration Tests on Time Step**

<b>Time Step <math>\Delta T</math> (unit: year)</b>	<b>1</b>	<b>0.5</b>	<b>0.25</b>	<b>0.125</b>	<b>0.0833333 (base case)</b>	<b>0.0625</b>	<b>0.03125</b>	<b>0.015625</b>	<b>0.0078125</b>
<b>NPV in Year 2036 (unit: NT\$ billions)</b>	128.52	125.10	127.19	137.92	143.73	142.74	145.74	147.10	146.97
<b>Time Step <math>\Delta T</math></b>					<b>0.08333331 &lt; <math>\Delta T</math> &lt;= 1</b>			<b>0.0078125 &lt;= <math>\Delta T</math> &lt;= 0.0833333</b>	
<b>Average <math>\Delta NPV/\Delta T</math> (year 2036)</b>					16.59			3.92	

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



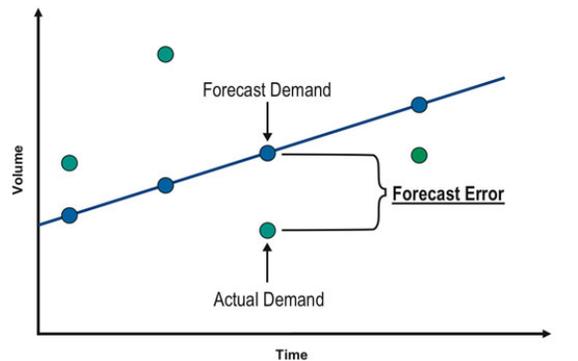
**Figure 8.6.2 The Integration Tests on NPV Changes by Time Step for Bidding Proposals Model**

## 8.7 Behavior Reproduction Tests

The behavior reproduction test was used to assess the ability of the model to reproduce the behavior of a system (Serman, 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 behavior 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:

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



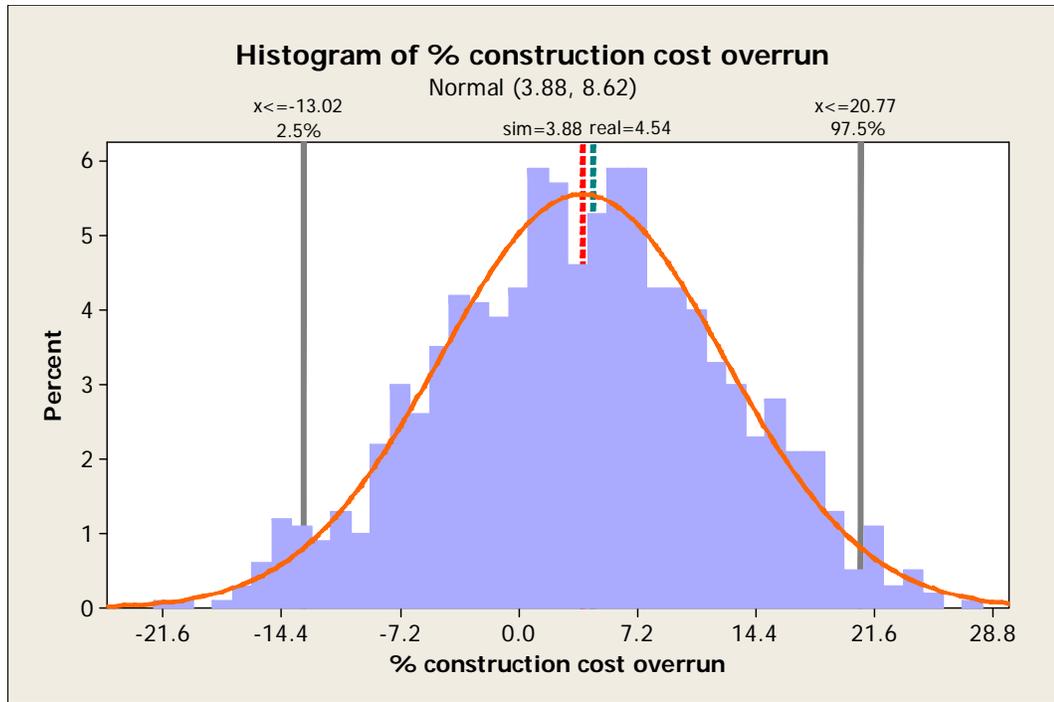
**Figure 8.7 The Forecast Error**

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

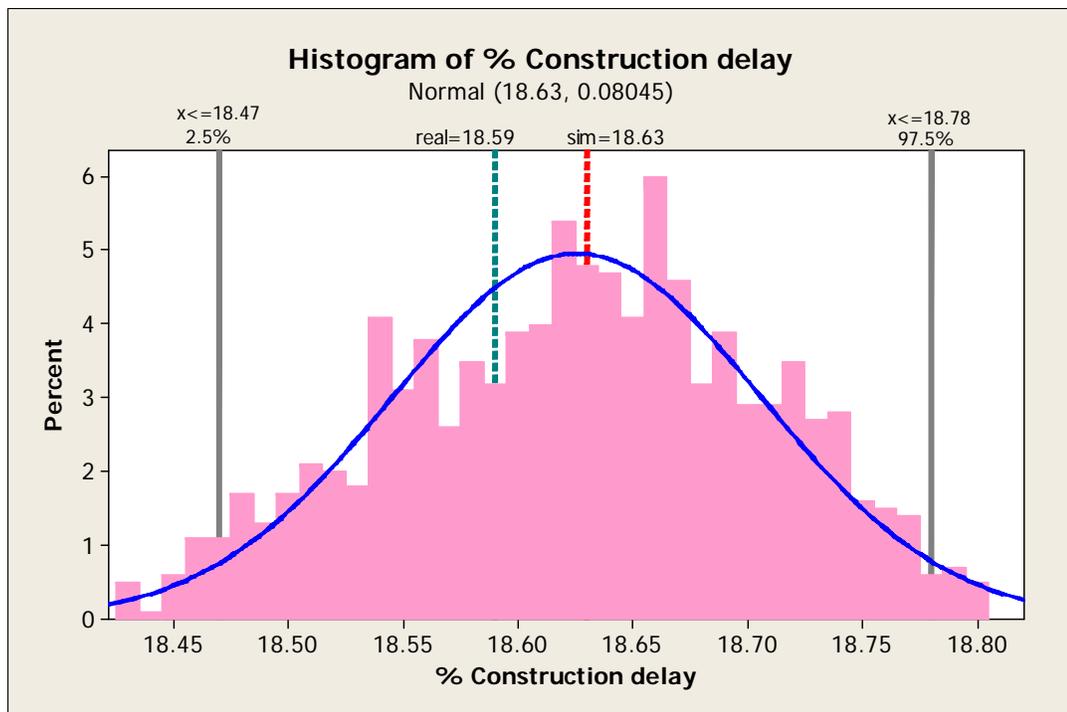
$$\text{Forecast Accuracy} = \text{maximum of } (1 - \text{Forecast Error}, 0) \quad (\text{Bozarth and Handfield, 2006})$$

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 is 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  $\alpha=0.05$ .

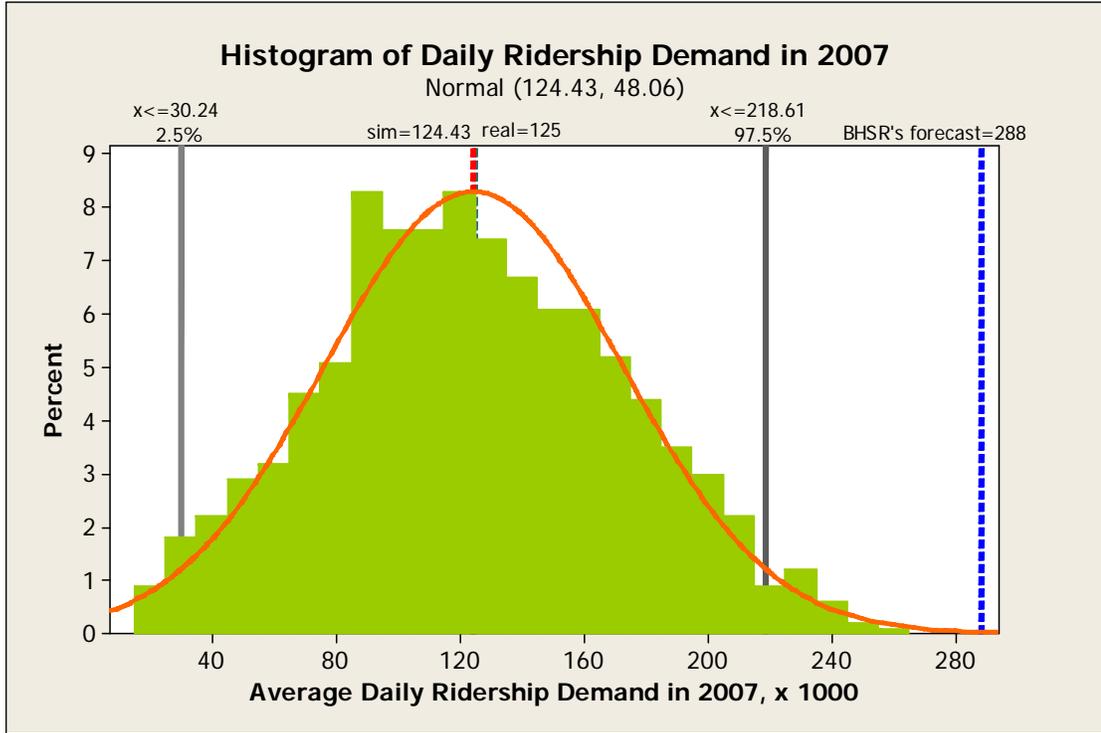
Concerning construction delay, the actual construction delay percentage was approximately 18.59% (Bureau of High Speed Rail, 2007). Figure 8.7.2 indicates the simulation result for construction delay percentage with 18.63% for mean and (18.47%, 18.78%) for a 95% confidence interval. The forecast error was approximately 15.59% for construction delay, which is 84.41% for high accuracy. In addition, the test of hypotheses with a 95% confidence interval indicated that the 95% confidence contained the null hypotheses value (the actual construction delay percentage). It meant that there was no significant evidence to reject the null hypothesis and that the simulation value was equal to the actual construction delay percentage of  $\alpha =0.05$ .



**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 Construction Delay Percentage**



**Figure 8.7.3 Discrepancy between Simulated and Real Data for Average Daily Ridership Demand in Year 2007**

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 8.7.3, 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 means 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 is 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 this 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, this researcher concluded that the model created can robustly predict the expected outcomes for both construction and operation phases and thereby suggests a valid model.

## 8.8 Sensitivity Analysis

The sensitivity analysis test was used to test the robustness of the model behavior in uncertain conditions. Numerical sensitivity, behavior 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. Behavior mode sensitivity is used to evaluate whether the behavior 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. This 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:

- Behavior 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 behavior 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 shows that the base case is raised in the beginning due to continual funding. It

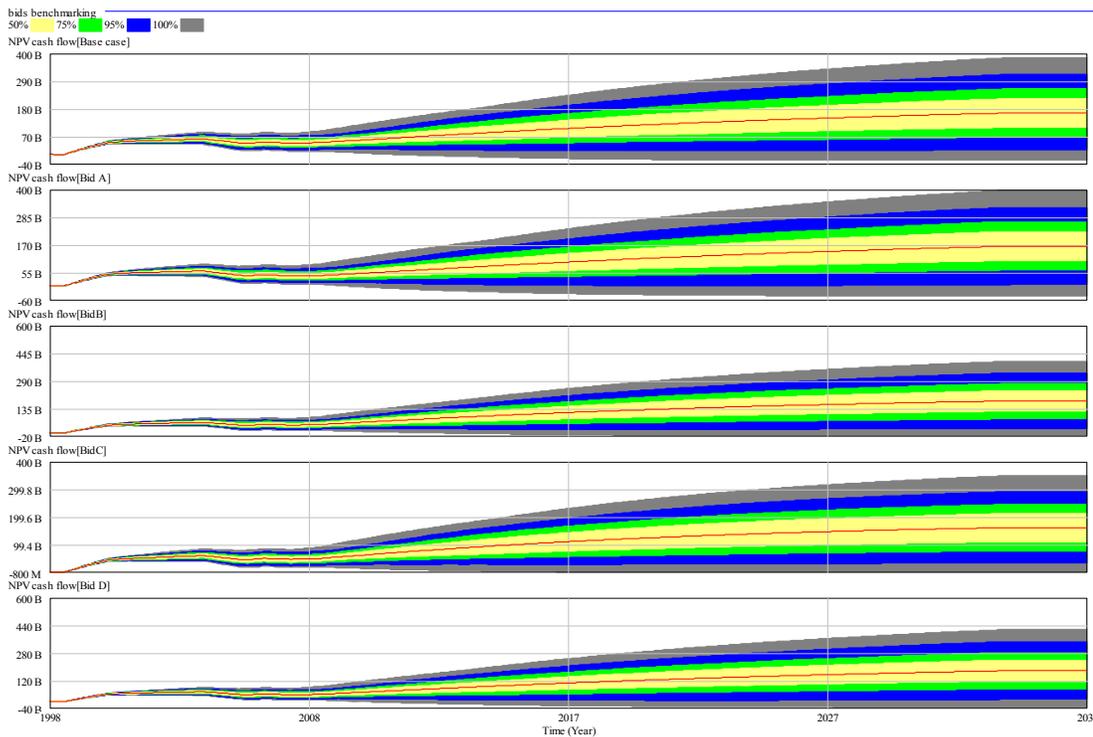
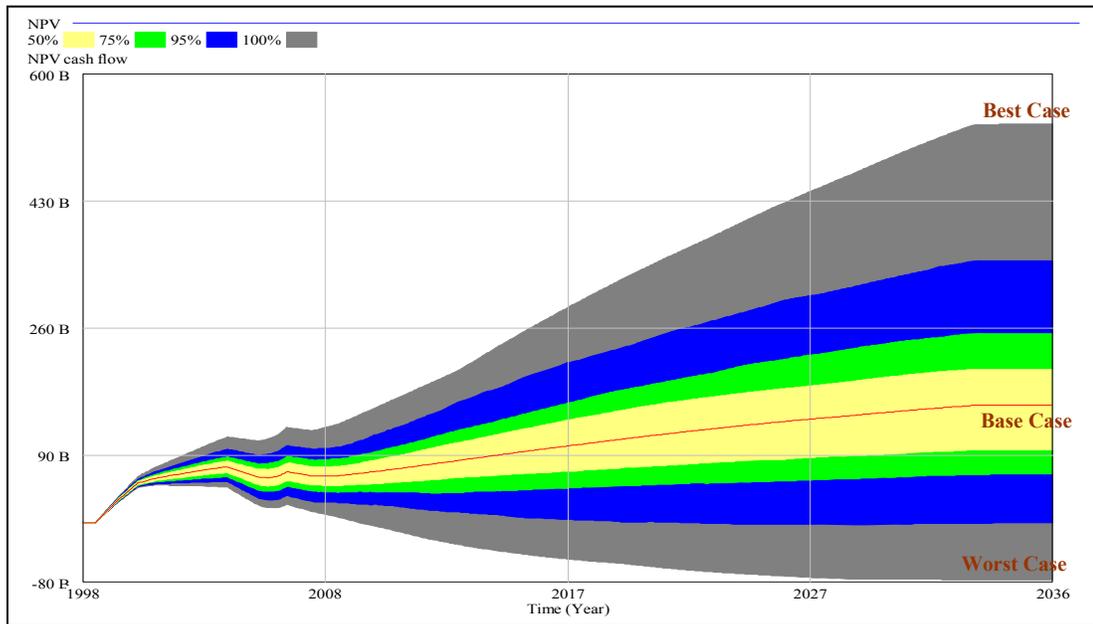
then began to decline during the latter half of construction phase due to the investment of lots of capital for construction. Once the project began operations with a stable revenue stream, it began to climb until the end of concession period in year 2036 with NPV value at NT\$156.49 billion. A notable 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 is a widened difference between the best case and worst case in 2036, which means a high degree of uncertainty exists over the long-term life of the project. The best case event 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 events 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 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 cannot provide required services without enough capital to pay for operation labor, material or equipment.

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

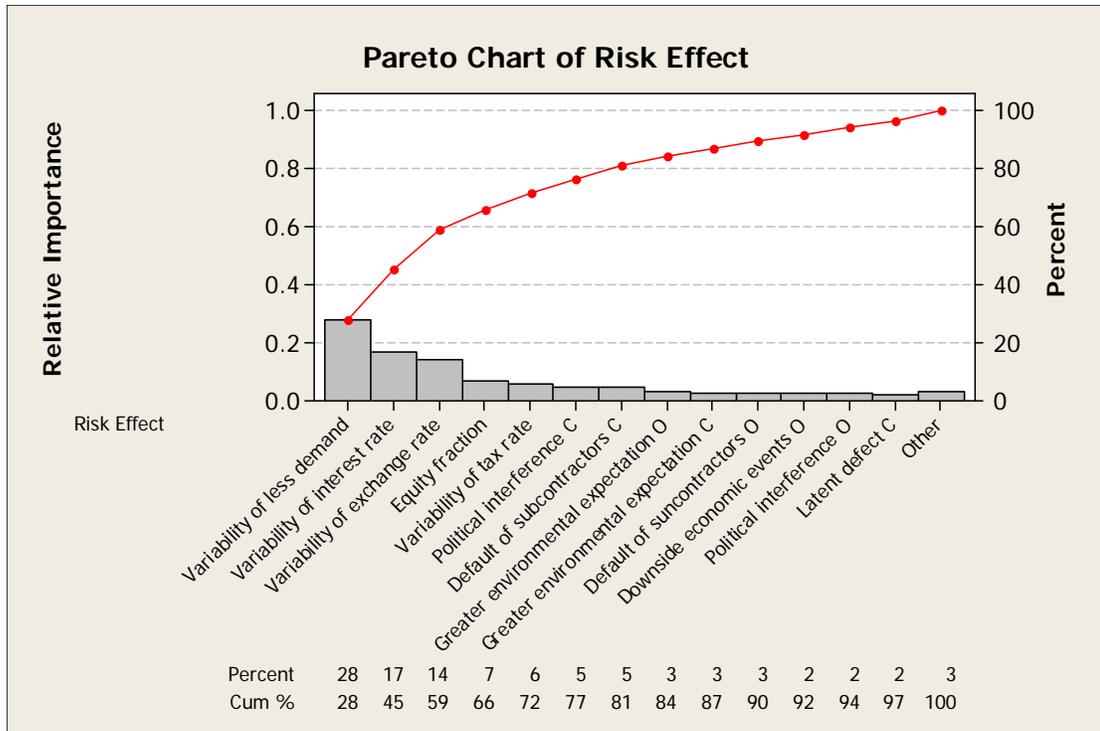
that the width of 100% confidence bound for bidding proposal model at the end of concession period 2036 reduced to two thirds of that for risk network model. This is because the interactions of downside reinforce feedback has been controlled and reduced by balance feedback arising from the actions of 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 behavior 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  $\alpha = 0.05$ .



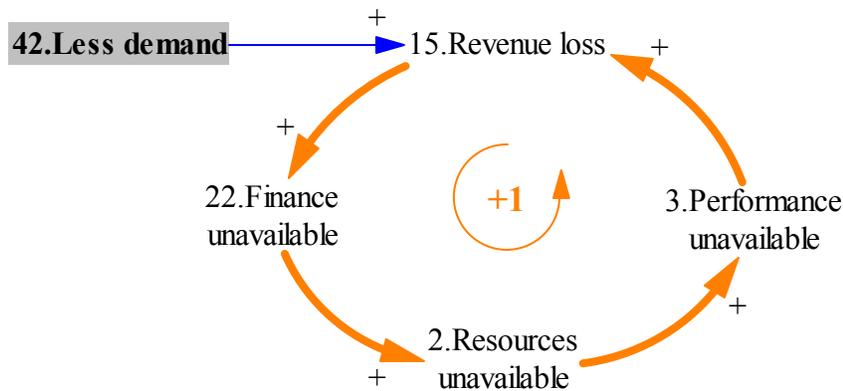
**Figure 8.8.2 The Multivariate Sensitivity Analysis for The Project NPV of Bidding Proposal Model**



**Figure 8.8.3 The Pareto Chart for the Relative Importance of Risk Effects on Project NPV**

Figure 8.8.3 also shows 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 network model and causal loop diagrams, this researcher observed that this was 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’, 8051 ones in risk variable ‘resources unavailable’, and 5263 ones in risk variable ‘performance unavailable’. The interactions of reinforce-feedback loops accumulate and enlarge thereby compounding effects over time. This can interpret the SD model behavior on why the curve of worse case shown in Figure 8.8.1 declined largely over the concession period to cause a broad difference from the best case at the end of 2036.

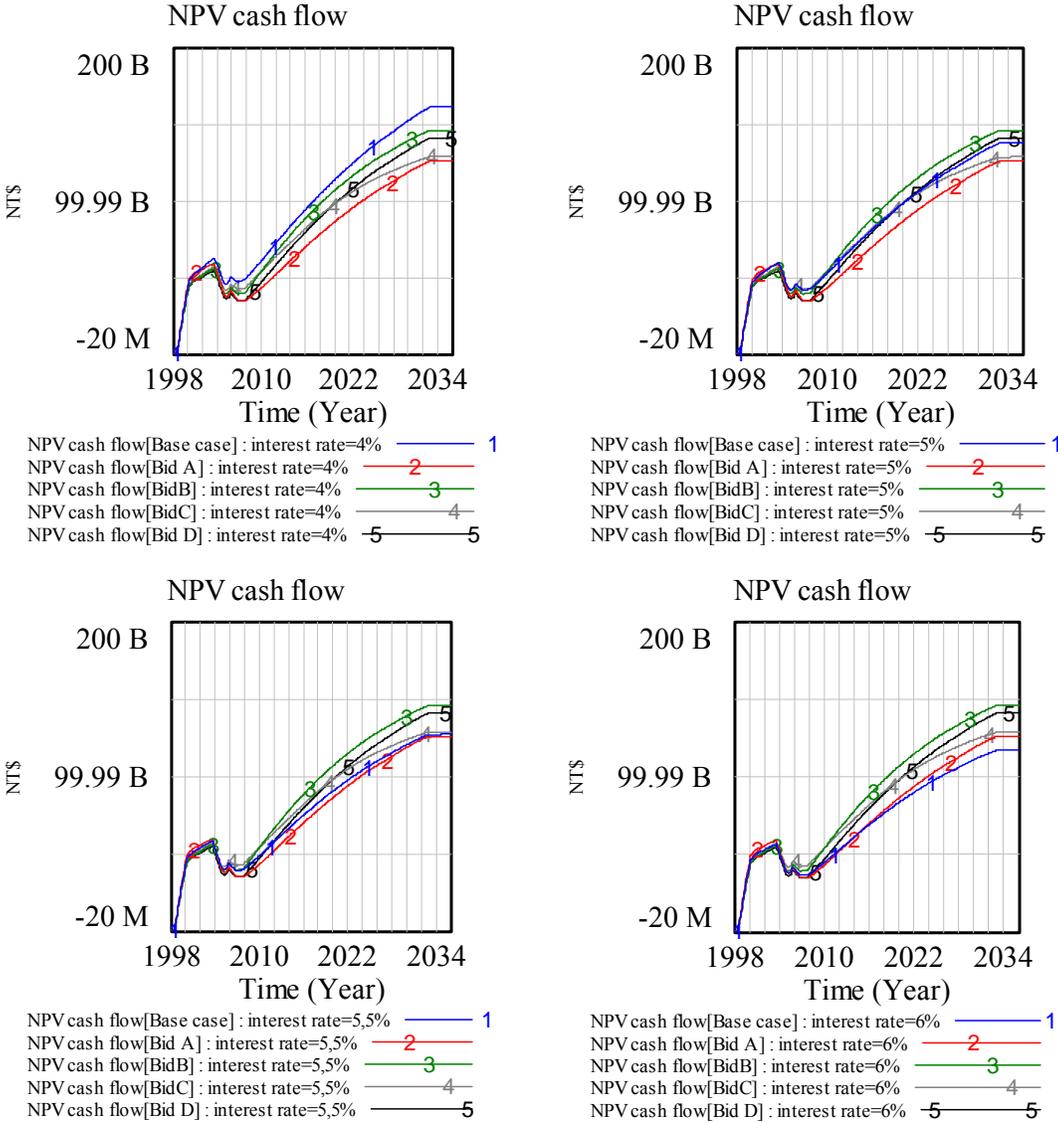
Currently the project contractor THSRC has encountered financial difficulties by two risk events. First, the high interest rate for debt is making the fact that the operating revenues cannot cover the large debt invested during the construction stage. Second, the global financial crisis emerged since 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 7.2. Moreover, the trend for THSR at the moment seems to be towards the worst case shown in Figure 7.1 and vicious circle shown in Figure 7.3. This truth has proved the research results.



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

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.



**Figure 8.8.5 Policy Sensitivity Analysis for 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, this 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, this 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 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. This 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.

# 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 contractor-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 contractor-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? This 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 contractor-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? This researcher needed to explore and model the interrelationships of risks.

4. The contractor-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? This researcher needed to infer mathematic equations for risk interrelationships.

5. Officials using the current contractor-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? This researcher needed to estimate probability distribution of both exogenous risk variables and the overall project NPV. This researcher needed to apply suitable decision rules to rank range values of NPV between bidding proposals as well.

The objective of this researcher was to develop a theoretical approach to building the decision model for the selection of PPP project bidding proposals which was expected to let the public sector choose right concessionaire who is capable of cost-effectively managing project risks to demonstrate value for money. Based on this objective, this researcher started looking into the common issues of the current approaches on contractor selection/bid evaluations in current literature survey. These issues were then converted into seven research questions that were relevant to the improvement of the current approaches. Therefore, the researcher investigated different aspects of issues and phenomena using the small-N research as stated by Flynvbjerg (2006) to determine what needed to be addressed and how to evaluate these seven research

questions. The Taiwan high speed rail (THSR) project was employed as a case to demonstrate the development of proposed theoretical approach. 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.

**Table 9.1 The Research Results for 7-Research Questions**

Research Questions	Research Answers/ Findings	Reliability and Validity
1. What are the generic types of risks inherent in the PPP transport projects over project life?	52 generic risk factors	<ul style="list-style-type: none"> <li>• Cross-checking the multiple sources of evidence</li> <li>• Well defined risk factors</li> <li>• Well documented data</li> </ul>
2. How can we model the interdependencies and interactions of risk events over the PPP transport project life?	52 causal loop diagrams	<ul style="list-style-type: none"> <li>• Cross-checking the multiple sources of evidence</li> <li>• Boundary adequacy test and model structure assessment</li> <li>• Well documented data</li> </ul>
3. How can we quantify the qualitative risk effects?	37 samples for risk effect rating	<ul style="list-style-type: none"> <li>• Well defined questionnaire and rating scale</li> <li>• Well documented data</li> </ul>
4. How can we quantify the risk interrelationships?	31 multiple-regression models	<ul style="list-style-type: none"> <li>• Residual plots</li> <li>• R-sq and p-values statistic tests</li> </ul>
5. How can we estimate the probability distribution of risk effects?	13 fitted theoretical probability distribution of exogenous risk variables.	<ul style="list-style-type: none"> <li>• The Probability Plot/P-P plot /Q-Q plot</li> <li>• Anderson-Darling statistic or Chi-Sq statistic tests</li> </ul>
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	<ul style="list-style-type: none"> <li>• Behavior Reproduction Test</li> <li>• Monte-Carlo multi-variant Sensitivity Analysis</li> <li>• Extreme Conditions tests, etc.</li> </ul>
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 first research question: What are the generic risks inherent over a PPP project life? this 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.

To address the second research question: How can the interdependencies and interactions of risk events be modeled over PPP project life cycle? this researcher explored and modeled the physical 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 physical interdependencies and interactions for each risk factor. By interviewing the project experts and key participants, this 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 modeling to address dynamic risk interactions over project concession period. This 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? this 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 degree 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, this 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? this researcher inferred and quantified physical 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. This 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. This 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? this 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 this 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? this researcher estimated the probability distribution of project NPV with overall compounding downside and beneficial effects over project life using System Dynamics modeling and Monte Carlo simulation. This researcher used a risk network model applying System Dynamics techniques to estimate risk interaction effects on NPV over time. This 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 this 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 behavior 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? this 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 this 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. This 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. This 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.

Based on the seven research questions, this researcher established that the SD model was validated through a series of approaches so that it can be applicable to a rail transit PPP project like high-speed rail PPP project selection. Although the risk profile of a large scale PPP project is unique from project to project (Bloomfield et al., 1998; Dey & Ogunlana, 2004; Gerrard, 2001), the methodology developed for bidding proposal selection is still applicable to any type of large-scale PPP infrastructure project. As Yin (2003) cited, research relies on analytical generalization (generalize theories) to generalize a set of research findings/results to a broader theory on the PPP project contractor-selection, rather than statistical generalization (enumerate frequencies) to the PPP project populations or universes. Based on the research, this researcher has generated conclusions from Table 9.1 suggest that each research finding had resulted from each of small-N research and was reliable and valid to each corresponding research question through processing. By aggregating these validated small-N research methods, this researcher has formed a broad

and complete theoretical approach to answer all of research questions (Flyvbjerg, 2006; Jacobs, 1961; Yin, 2003). Since the research questions reflect all of the common key issues of current project contractor/bid-selection method regardless of the type of PPP project, this researcher reasonably concluded that the developed theoretical approaches would be applicable to build a decision model to improve the current contractors/bids-selection methods for any type of PPP project. The theoretical approach 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 modeling techniques.
3. Measure risk effect and probability: Measure and quantify qualitative risk effects through a questionnaire survey with a risk rating matrix by a group of expert judgments; infer risk effect probability distribution by probability fitting; estimate and quantify risk interrelationship by multiple-regression analysis.
4. Reduce measure errors of risk effects: Reduce measure errors and ensure data reliability by use of a standardized rating matrix with clear definitions for project experts to consistently rate risk effects; perform the probability plot/P-P plot /Q-Q plot with Anderson-Darling statistic or Chi-square statistic tests to ensure the theoretical probability distribution fit exogenous risk variables well; conduct residual plots with R-sq and  $p$  values tests to ensure multiple-regression models explain and represent risk effect interrelationships well.
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 modeling 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 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 Contributions

With this research, this 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.

This researcher developed causal loop diagrams to address the cause-effect interrelationship between risk variables discussed in Chapter 4. This 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 this 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.

This 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), Grimsey 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.

This 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**

Although the Taiwan high speed rail (THSR) was used as an application case to apply and demonstrate the proposed theoretical approach, this 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, this 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 this researcher heavily relied on the current literature and this data was limited. Therefore, this researcher used pseudo-data to model risk-reduction effects of bidding proposals. Moreover, THSR is a transit project. Thus, the CBA analysis was conducted from the perspective of a transit project.

### **9.4 Future Work**

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 behavior reproduction tests addressed in chapter 8, this 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.

This research scaled a range of values from 1 to 25 to express the expected risk effect (risk degree) of a risk variable. The questionnaires were sent to the experts and key participants of Taiwan High Speed Rail project to measure and rate the risk degree. Based on the collected samples from the questionnaire survey, this research used multiple regression models to express possible functional relations among risk variables. Both regression analysis as stated in section 6.3.1 and extreme condition analysis as stated in

section 8.5 are based on the defined range of values from 1 to 25. As a result, only one non-linear regression model was allowed for relational expressions (section 6.3.1). This research didn't examine sensitivity to both regression analysis and extreme condition analysis over the scaled range of values. The resulting model with significant terms is likely going to change for different scaled range of values. Further, there might be more non-linear regression models that are allowed for relational expressions when the scaled range of values changes. Therefore, this research suggests that in the future the scaled range of values used to express the expected risk effect should be examined to see whether it is sensitive to the selection of a regression model.

Although this researcher has established that the theoretical approach has proved to be valid in building a decision support model for bidding proposal selection, this theory still requires further research to assure its realistic representation. A field investigation with project managers to examine the approach in practice would be necessary. This research is intended to be an overview evaluation in terms of economic view, organizational view, and legal view.

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## Appendix

### Appendix I Risk Factors Collected from Literature Survey

#### I.1 Empirical Studies

<b>Table I.1.1 Li (2005)'s Three Levels of Risk Factors</b>		
<b>Risk Levels</b>	<b>Risk Factors</b>	<b>Risk Events</b>
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

<b>Table I.1.2 Hodge(2004)'s Risk Categories and Risk Events</b>	
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	

<b>Table I.1.3 Ghosh &amp; Jintanapananont (2004)'s Risk Factors Influencing Rail Projects</b>	
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

<b>Table I.1.4 Thomas (2003)'s Risk Category for BOT Road Projects</b>	
<b>Project Phase</b>	<b>Risk category</b>
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**

<b>Risk factors</b>	<b>Risk subfactors</b>
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**

<b>Project risk group</b>	<b>Project risk areas</b>	<b>Project risk type description</b>
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 Akintove et al (2001)'s PFI/PPP Project Risk Factors**

<ul style="list-style-type: none"> <li>• Site acquisition</li> <li>• Delay in feasibility studies/planning approval</li> <li>• Design and construction risks (i.e. cost/overruns; poor technical solution)</li> <li>• Commissioning and operating risks (including maintenance)</li> <li>• Occupation demand (revenue) and usage risks over time</li> <li>• Obsolescence / Technology risk</li> <li>• Residual value risk</li> <li>• Economic risks (including: fall in revenue; financiers pulling out, etc.)</li> <li>• Legislative / Regulation risks (e.g., future planning regulations, health and safety features etc.)</li> <li>• Taxation risks (Change in taxes/laws)</li> <li>• Bid process / Complicated negotiations</li> <li>• Political (long time governmental support of international projects)</li> <li>• Corruption</li> <li>• Consortium structure</li> <li>• Local partner</li> <li>• Project management ability</li> <li>• Existing infrastructure</li> <li>• Raw material (supply, availability, etc.)</li> <li>• Financing (foreign exchange)</li> <li>• Force majeure</li> <li>• Operation and maintenance failure</li> <li>• Market competition</li> <li>• Revenue tariffs/demand change</li> <li>• Project performance</li> <li>• Foreign exchange/inflation</li> <li>• Financing risks</li> </ul>
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**Table I.1.8 Shen et al. (2001)'s Risk List Associated with Sino-foreign Joint Ventures Typed PFI/PPP Construction Projects**

<b>(1) Financial risks</b>
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
<b>(2) Legal risks</b>
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
<b>(3) Management risks</b>
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
<b>(4) Market risks</b>
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
<b>(5) Policy and Political risks</b>
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
<b>(6) Technical risks</b>
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
Obsolescence 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

<b>Table I.1.9 Wang (2000)'s List of Risks Associated with BOT Projects in Different Infrastructure Sectors</b>
<b>All sectors</b>
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)
<b>Power sector</b>
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
<b>Transport Sector (Road)</b>
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)
<b>Transport Sector (Tunnel and Bridge)</b>
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

<b>Transport Sector (Rail)</b>
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
<b>Transport Sector (Airport and Port)</b>
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
<b>Process plant</b>
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)
<b>Telecommunication</b>
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**

<b>Table I.2.1 The UK Government's General Types of Risk (HM Treasury, 2003)</b>	
<b>Types of Risk</b>	<b>Descriptions</b>
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
<b>Site risks</b>	
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.
<b>Design, Construction and Commissioning risks</b>	
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.
<b>Sponsor and Financial risks</b>	
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.

<b>Operating risks</b>	
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.
<b>Market risks</b>	
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.
<b>Network and Interface risks</b>	
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.
<b>Industrial Relations risks</b>	
Industrial relations and civil common	Risk of strikes, industrial action or civil commotion causing delay and cost to the project.
<b>Legislative and Government Policy risks</b>	
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.
<b>Force Majeure risks</b>	
Force majeure	The risk that inability to meet contracted service delivery (pre or post completion) is caused by reason of force majeure events.
<b>Asset Ownership risks</b>	
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.

<b>Table I.2.3 The South Africa Government's Risk Categories (South Africa, 2000)</b>	
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 1<sup>st</sup> Division of BHSR (function: design and supervision)
- The 2<sup>nd</sup> Division of BHSR (function: civic engineering)
- The 3<sup>rd</sup> Division of BHSR (function: mechanical/electrical engineering)
- The 4<sup>th</sup> Division of BHSR (function: contract performance)
- The 5<sup>th</sup> Division of BHSR (function: land acquisition)
- The 6<sup>th</sup> Division of BHSR (function: safety and environment)
- ICBC (function: project financing)

The liaison is Mrs Chung; Email: [public@nthsr1.hsr.gov.tw](mailto: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 were 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 13<sup>th</sup> 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)
(53) Land unavailable	5 <sup>th</sup> Division of BHSR	M1	11/06/07	110607_1.mp3
(54) Resources unavailable	1 <sup>st</sup> , 4 <sup>th</sup> Division of BHSR	M2/M3	13/06/07	130607_2.mp3
(55) Performance unavailability	1 <sup>st</sup> , 4 <sup>th</sup> Division of BHSR	M2/M4	15/06/07	150607_3.mp3

(56)	Scope changes	1 <sup>st</sup> , 4 <sup>th</sup> Division of BHSR	M5/M4	18/06/07	180607_4.mp3
(57)	Defective design	1 <sup>st</sup> Division of BHSR	M6	19/06/07	190607_5.mp3
(58)	Design changes	1 <sup>st</sup> Division of BHSR	M6	19/06/07	190607_6.mp3
(59)	Construction cost overrun	1 <sup>st</sup> Division of BHSR	M2	21/06/07	210607_7.mp3
(60)	Construction delay	1 <sup>st</sup> Division of BHSR	M2	21/06/07	210607_8.mp3
(61)	Defective construction	2 <sup>nd</sup> Division of BHSR	M7	19/06/07	190607_9.mp3
(62)	Construction changes	2 <sup>nd</sup> , 4 <sup>th</sup> Division of BHSR	M7/M4	19/06/07	190607_10.mp3
(63)	Complex system interface/ integration	3 <sup>rd</sup> , 4 <sup>th</sup> Division of BHSR	M8/M9	25/06/07	150607_11.mp3
(64)	Failed commissioning tests	1 <sup>st</sup> Division of BHSR	M6	26/06/07	260607_12.mp3
(65)	Low operating productivity	4 <sup>th</sup> Division of BHSR	M9	27/06/07	270607_13.mp3
(66)	Mis-pricing	4 <sup>th</sup> Division of BHSR	M10	27/06/07	270607_14.mp3
(67)	Revenue loss	4 <sup>th</sup> Division of BHSR	M10	27/06/07	270607_15.mp3
(68)	System breakdown	3 <sup>rd</sup> Division of BHSR	M8	28/06/07	280607_16.mp3
(69)	High maintenance frequency	3 <sup>rd</sup> Division of BHSR	M8	28/06/07	280607_17.mp3
(70)	Accidents and safety issues	6 <sup>th</sup> Division of BHSR	M11	02/07/07	020707_18.mp3
(71)	Price escalation	1 <sup>st</sup> , 4 <sup>th</sup> Division of BHSR	M12/M10	03/07/07	030707_19.mp3
(72)	Complex technologies	1 <sup>st</sup> , 3 <sup>rd</sup> Division of BHSR	M6/M8	04/07/07	040707_20.mp3
(73)	Poor cooperation/ coordination	1 <sup>st</sup> Division of BHSR	M12	05/07/07	050707_21.mp3
(74)	Finance unavailable	1 <sup>st</sup> , 4 <sup>th</sup> Division of BHSR/ ICBC	M14/M10/M13	09/07/07	090907_22.mp3
(75)	Refinancing liabilities	1 <sup>st</sup> , 4 <sup>th</sup> Division of BHSR/ ICBC	M14/M10/M13	10/07/07	100707_23.mp3
(76)	Insolvency of contractor	1 <sup>st</sup> , 4 <sup>th</sup> Division of BHSR	M14/M10	10/07/07	100707_24.mp3
(77)	Ownership change delay	1 <sup>st</sup> , 4 <sup>th</sup> Division of BHSR	M14/M15	10/07/07	100707_25.mp3
(78)	Tax increases	4 <sup>th</sup> Division of BHSR	M16	12/07/07	120707_26.mp3
(79)	Insurance increases	4 <sup>th</sup> Division of BHSR	M16	12/07/07	120707_27.mp3
(80)	Contractual disputes	4 <sup>th</sup> Division of BHSR	M15	16/07/07	160707_28.mp3
(81)	Inflexible contract arrangements	4 <sup>th</sup> Division of BHSR	M15	17/07/07	170707_29.mp3
(82)	Delay in contract change negotiation	4 <sup>th</sup> Division of BHSR	M15	17/07/07	170707_30.mp3
(83)	Contract breach	4 <sup>th</sup> Division of BHSR	M15	16/07/07	160707_31.mp3
(84)	Contract remedies/ penalties	4 <sup>th</sup> Division of BHSR	M15	16/07/07	160707_32.mp3
(85)	Default of subcontractor	1 <sup>st</sup> , 4 <sup>th</sup> Division of BHSR	M2/M15	18/07/07	180707_33.mp3
(86)	Inspection and testing delay	1 <sup>st</sup> , 4 <sup>th</sup> Division of BHSR	M6/M9	19/07/07	100707_34.mp3
(87)	Latent defect	4 <sup>th</sup> Division of BHSR	M15	23/07/07	230707_35.mp3
(88)	Shorter asset life	1 <sup>st</sup> , 4 <sup>th</sup> Division of BHSR	M2/M4	24/07/07	240707_36.mp3
(89)	Less residual values	1 <sup>st</sup> , 4 <sup>th</sup> Division of BHSR	M2/M4	24/07/07	240707_37.mp3
(90)	Termination liabilities	1 <sup>st</sup> , 4 <sup>th</sup> Division of BHSR	M14/M15	16/07/07	160707_38.mp3
(91)	Higher level of inflation rate	1 <sup>st</sup> Division of BHSR/ ICBC	M14/M17	25/07/07	250707_39.mp3
(92)	Volatility of exchange rate	1 <sup>st</sup> Division of BHSR/ ICBC	M14/M17	25/07/07	250707_40.mp3
(93)	Higher level of interest rate	1 <sup>st</sup> Division of BHSR/ ICBC	M14/M17	25/07/07	250707_41.mp3
(94)	Variability of less demand	1 <sup>st</sup> , 4 <sup>th</sup> Division of BHSR/ ICBC	M14/M17	26/07/07	260707_42.mp3
(95)	Higher competition	1 <sup>st</sup> , 4 <sup>th</sup> Division of BHSR/ ICBC	M14/M17	26/07/07	260707_43.mp3

(96) Downside economic events	1 <sup>st</sup> , 4 <sup>th</sup> Division of BHSR/ ICBC	M14/M17	26/07/07	260707_44.mp3
(97) Political interference	1 <sup>st</sup> Division of BHSR	M18	30/07/07	300707_45.mp3
(98) Unsuitable regulatory policy	1 <sup>st</sup> Division of BHSR	M18	31/07/07	310707_46.mp3
(99) Approval delays	1 <sup>st</sup> Division of BHSR	M18	01/08/07	010807_47.mp3
(100) Law/policy changes	1 <sup>st</sup> , 4 <sup>th</sup> Division of BHSR	M18/M15	02/08/07	020807_48.mp3
(101) Unforeseen site conditions	2 <sup>nd</sup> Division of BHSR	M19	06/08/07	060807_49.mp3
(102) Greater environmental expectation	6 <sup>th</sup> Division of BHSR	M20	08/08/07	080807_50.mp3
(103) Industrial disputes	1 <sup>st</sup> Division of BHSR	M18	09/08/07	090807_51.mp3
(104) Force Majeure	1 <sup>st</sup> , 6 <sup>th</sup> Division of BHSR	M21/M11	13/08/07	130807_52.mp3

# Appendix III SD Model Variables and Parameters

(There is a partial list of model 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[Bid B]=Bidding cost of LT control scheme[Base case]\*(1-(Fraction of LT risk transfer C[Bid B]+Fraction of LT risk transfer O[Bid B])/2)+Bidding cost of LT control scheme[Bid B]

Adjusted bidding cost of LT control scheme[Bid C]=Bidding cost of LT control scheme[Base case]\*(1-(Fraction of LT risk transfer C[Bid C]+Fraction of LT risk transfer O[Bid C])/2)+Bidding cost of LT control scheme[Bid C]

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[Bid B]=Bidding cost of PI control scheme[Base case]\*(1-(Fraction of PI risk transfer C[Bid B]+Fraction of PI risk transfer O[Bid B])/2)+Bidding cost of PI control scheme[Bid B]

Adjusted bidding cost of PI control scheme[Bid C]=Bidding cost of PI control scheme[Base case]\*(1-(Fraction of PI risk transfer C[Bid C]+Fraction of PI risk transfer O[Bid C])/2)+Bidding cost of PI control scheme[Bid C]

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

## A. 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.

## B. 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 1<sup>st</sup> Division of BHSR (function: design and supervision)
- The 2<sup>nd</sup> Division of BHSR (function: civic engineering)
- The 3<sup>rd</sup> Division of BHSR (function: mechanical/electrical engineering)
- The 4<sup>th</sup> Division of BHSR (function: contract performance)
- The 5<sup>th</sup> Division of BHSR (function: land acquisition)
- The 6<sup>th</sup> 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](mailto: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.

## C. How

The questionnaire survey was conducted by the following procedure:

6. 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.
7. 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.
8. 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.
9. Without a clear standardised-definition, the sampled data for risk degree 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 Degree’, 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.
10. There are 34 risk variables stated in Chapter 7 that are the function of risk degree. They are listed in questionnaire for rating risk degree for the expected risk effect.
11. To meet a meaningful statistically large-sample condition (Anderson et al., 2002), 30-35 valid samples are expected to be returned for this 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 this 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.

#### **D. 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 25<sup>th</sup> of Nov. An additional 1 week will be given to those respondents who have not responded within the survey period.

#### **E. 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.
- The 'risk degree' is referred to represent how significant of the expected risk effect of a risk event, which is scaled to 1-25 points from the least significant to the most significant.
- Please refer to the attached Table 1: 'The Reference Matrix for Rating Risk Degree (modified from (Australia Government, 2005; Cooper D. et al., 2005))', which is used to guide the respondents to rate risk degree. The 'risk degree' 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 point '21'. That is the risk degree for a specific risk event is 21.
- The 5-dimension for Impact and Likelihood is defined as Table 2 (modified from (Australia Government, 2005; Cooper D. et al., 2005)).
- 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 degree 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](mailto: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 1<sup>st</sup> Division of BHSR (function: design and supervision)
  - The 2<sup>nd</sup> Division of BHSR (function: civic engineering)
  - The 3<sup>rd</sup> Division of BHSR (function: mechanical/electrical engineering)
  - The 4<sup>th</sup> Division of BHSR (function: contract performance)
  - The 5<sup>th</sup> Division of BHSR (function: land acquisition)
  - The 6<sup>th</sup> 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 Degree**

1. Basing on the definitions described in the attached Table 1-3, what is the risk degree (1-25) for the expected risk effect of the risk event '*land unavailable*' at Construction phase?

I	Construction Phase				
VH	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)
H	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)
M	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)
L	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)
VL	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)
L	VL	L	M	H	VH

2. Basing on the definitions described in the attached Table 1-3, what is the risk degree (1-25) for the expected risk effect of the risk event '*resource unavailable*' at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	VH
H	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	H
M	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	M
L	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	L
VL	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 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 risk degree (1-25) for the expected risk effect of the risk event '*scope change*' at Construction phase and Operation?

I	Construction Phase					Operation Phase					I
VH	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	VH
H	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	H
M	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	M
L	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	L
VL	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 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 risk degree (1-25) for the expected risk effect of the risk event '*defective design*' at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	VH
H	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	H
M	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	M
L	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	L
VL	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 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 risk degree (1-25) for the expected risk effect of the risk event '*design changes*' at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	VH
H	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	H
M	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	M
L	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	L
VL	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 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 risk degree (1-25) for the expected risk effect of the risk event '*defective construction*' at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	VH
H	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	H
M	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	M
L	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	L
VL	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 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 risk degree (1-25) for the expected risk effect of the risk event '*construction changes*' at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	VH
H	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	H
M	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	M
L	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	L
VL	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 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 risk degree (1-25) for the expected risk effect of the risk event '*complex system interface/integration*' at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	VH
H	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	H
M	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	M
L	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	L
VL	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 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 risk degree (1-25) for the expected risk effect of the risk event '*failed commissioning tests*' at Construction phase?

I	Construction Phase				
VH	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)
H	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)
M	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)
L	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)
VL	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)
L	VL	L	M	H	VH

10. Basing on the definitions described in the attached Table 1-3, what is the risk degree (1-25) for the expected risk effect of the risk event '*low operating productivity*' at Operation phase?

Operation Phase					I
( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	VH
( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	H
( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	M
( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	L
( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)	VL
VL	L	M	H	VH	L

11. Basing on the definitions described in the attached Table 1-3, what is the risk degree (1-25) for the expected risk effect of the risk event '*system breakdown*' at Operation phase?

Operation Phase					I
( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	VH
( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	H
( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	M
( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	L
( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)	VL
VL	L	M	H	VH	L

12. Basing on the definitions described in the attached Table 1-3, what is the risk degree (1-25) for the expected risk effect of the risk event *'high maintenance frequency'* at Operation phase?

Operation Phase					I
( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	VH
( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	H
( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	M
( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	L
( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)	VL
VL	L	M	H	VH	L

13. Basing on the definitions described in the attached Table 1-3, what is the risk degree (1-25) for the expected risk effect of the risk event *'accidents and safety issues'* at Operation phase?

Operation Phase					I
( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	VH
( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	H
( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	M
( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	L
( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)	VL
VL	L	M	H	VH	L

14. Basing on the definitions described in the attached Table 1-3, what is the risk degree (1-25) for the expected risk effect of the risk event *'complex technologies'* at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	VH
H	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	H
M	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	M
L	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	L
VL	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 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 risk degree (1-25) for the expected risk effect of the risk event *'poor cooperation/coordination'* at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	VH
H	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	H
M	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	M
L	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	L
VL	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 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 risk degree (1-25) for the expected risk effect of the risk event *'finance unavailable'* at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	VH
H	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	H
M	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	M
L	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	L
VL	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 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 risk degree (1-25) for the expected risk effect of the risk event *'insolvency of contractor'* at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	VH
H	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	H
M	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	M
L	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	L
VL	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 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 risk degree (1-25) for the expected risk effect of the risk event *'ownership change delay'* at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	VH
H	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	H
M	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	M
L	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	L
VL	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 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 risk degree (1-25) for the expected risk effect of the risk event *'contractual disputes'* at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	VH
H	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	H
M	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	M
L	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	L
VL	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 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 risk degree (1-25) for the expected risk effect of the risk event '*inflexible contract arrangement*' at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	VH
H	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	H
M	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	M
L	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	L
VL	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 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 risk degree (1-25) for the expected risk effect of the risk event '*delay in contract change negotiation*' at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	VH
H	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	H
M	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	M
L	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	L
VL	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 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 risk degree (1-25) for the expected risk effect of the risk event '*contract breach*' at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	VH
H	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	H
M	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	M
L	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	L
VL	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 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 risk degree (1-25) for the expected risk effect of the risk event '*default of subcontractor*' at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	VH
H	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	H
M	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	M
L	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	L
VL	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 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 risk degree (1-25) for the expected risk effect of the risk event '*latent defect*' at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	VH
H	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	H
M	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	M
L	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	L
VL	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 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 risk degree (1-25) for the expected risk effect of the risk event '*shorter asset life*' at Operation phase?

Operation Phase					I
( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	VH
( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	H
( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	M
( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	L
( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)	VL
VL	L	M	H	VH	L

26. Basing on the definitions described in the attached Table 1-3, what is the risk degree (1-25) for the expected risk effect of the risk event '*downside economic events*' at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	VH
H	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	H
M	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	M
L	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	L
VL	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 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 risk degree (1-25) for the expected risk effect of the risk event '*political interference*' at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	VH
H	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	H
M	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	M
L	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	L
VL	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 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 risk degree (1-25) for the expected risk effect of the risk event *'unsuitable regulatory policy'* at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	VH
H	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	H
M	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	M
L	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	L
VL	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 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 risk degree (1-25) for the expected risk effect of the risk event *'approval delay'* at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	VH
H	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	H
M	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	M
L	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	L
VL	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 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 risk degree (1-25) for the expected risk effect of the risk event *'law/policy changes'* at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	VH
H	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	H
M	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	M
L	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	L
VL	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 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 risk degree (1-25) for the expected risk effect of the risk event *'unforeseen site conditions'* at Construction phase?

I	Construction Phase				
VH	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)
H	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)
M	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)
L	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)
VL	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)
L	VL	L	M	H	VH

32. Basing on the definitions described in the attached Table 1-3, what is the risk degree (1-25) for the expected risk effect of the risk event '*greater environmental expectation*' at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	VH
H	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	H
M	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	M
L	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	L
VL	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)	VL
L	VL	L	M	H	VH	VL	L	M	H	VH	L

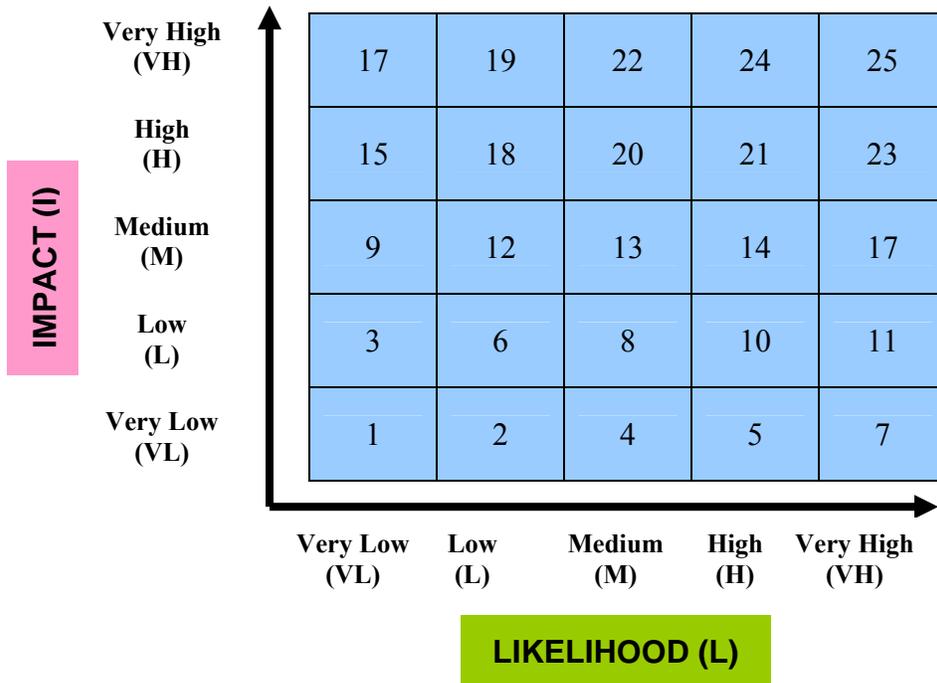
33. Basing on the definitions described in the attached Table 1-3, what is the risk degree (1-25) for the expected risk effect of the risk event '*industrial disputes*' at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	VH
H	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	H
M	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	M
L	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	L
VL	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 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 risk degree (1-25) for the expected risk effect of the risk event '*Force Majeure*' at Construction phase and Operation phase?

I	Construction Phase					Operation Phase					I
VH	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 19)	( <input type="checkbox"/> 22)	( <input type="checkbox"/> 24)	( <input type="checkbox"/> 25)	VH
H	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	( <input type="checkbox"/> 15)	( <input type="checkbox"/> 18)	( <input type="checkbox"/> 20)	( <input type="checkbox"/> 21)	( <input type="checkbox"/> 23)	H
M	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	( <input type="checkbox"/> 9)	( <input type="checkbox"/> 12)	( <input type="checkbox"/> 13)	( <input type="checkbox"/> 14)	( <input type="checkbox"/> 17)	M
L	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	( <input type="checkbox"/> 3)	( <input type="checkbox"/> 6)	( <input type="checkbox"/> 8)	( <input type="checkbox"/> 10)	( <input type="checkbox"/> 11)	L
VL	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)	( <input type="checkbox"/> 1)	( <input type="checkbox"/> 2)	( <input type="checkbox"/> 4)	( <input type="checkbox"/> 5)	( <input type="checkbox"/> 7)	VL
L	VL	L	M	H	VH	VL	L	M	H	VH	L

**Table 1 The Reference Matrix for Rating Risk Effect**



**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**

<b>Risk Event</b>	<b>Definition</b>
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 14<sup>th</sup> 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**

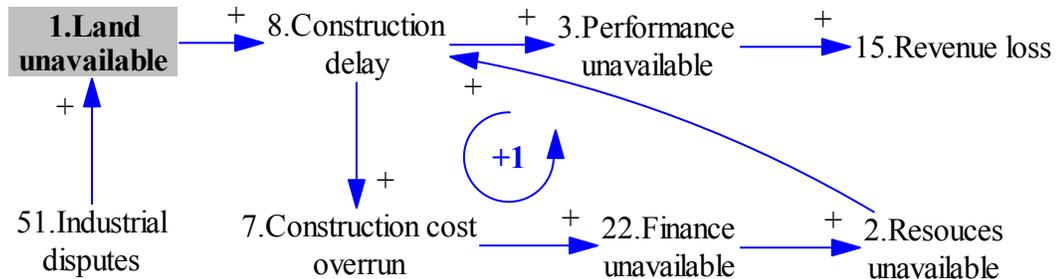
Force Majeure	default of subcontractor	latent defect	downside economic events	political interference	greater environmental expectation
20	23	20	21	5	10
19	16	15	21	9	19
23	15	24	21	10	7
17	24	14	23	4	21
21	25	22	13	3	16
20	16	19	12	7	22
23	24	22	13	5	20
11	18	10	18	2	19
25	19	12	22	10	24
16	21	15	14	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

# Appendix V The Analysis of CLD

## VI. 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**

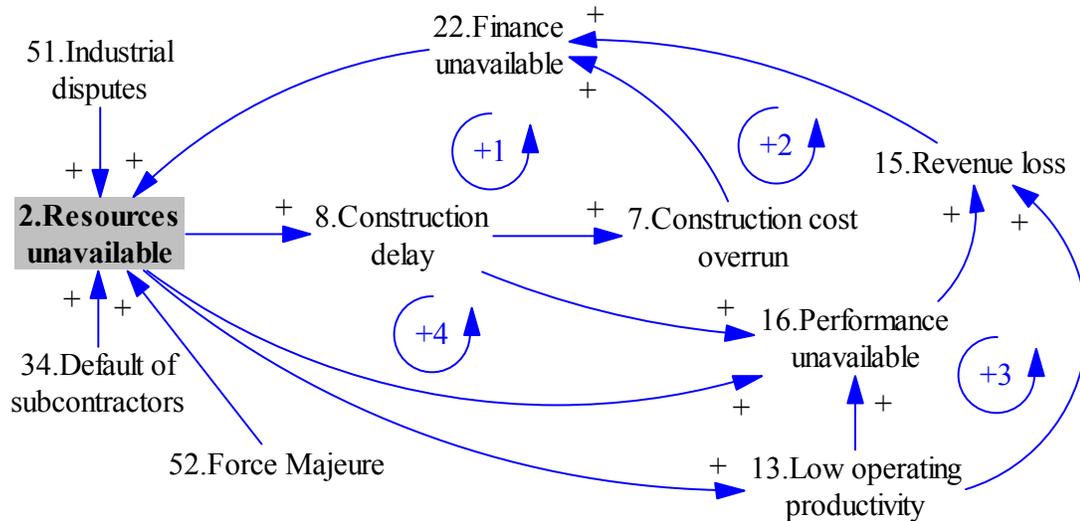
This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. as a BOOT contract for the City Link road infrastructure project in Melbourne. It was one of the Australia's largest public BOOT infrastructure projects, costing AUD\$2.1 billion. Due to delays for land available 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**

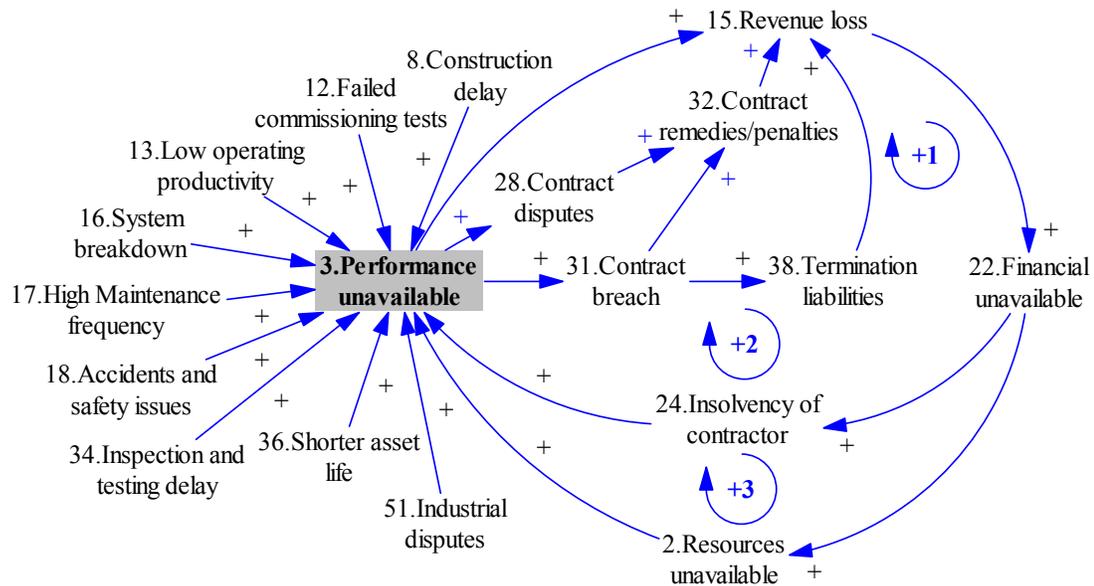
The resources unavailable risk event would be likely to be triggered by the default of subcontractors risk events that the subcontractors are incapable of supplying materials, equipment, and manpower to build or operate the infrastructure (Hodge, 2004; NAO, 2006). The financial unavailable risk event 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.

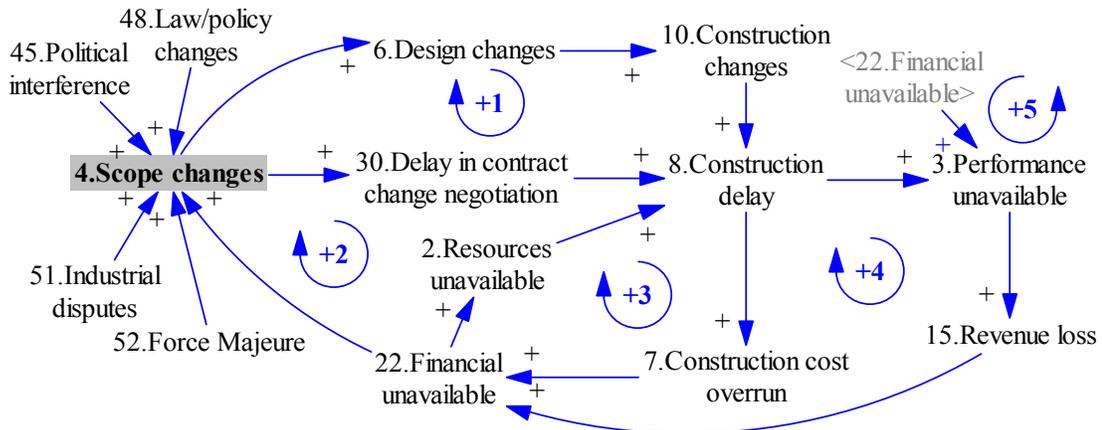
#### V4. Scope changes

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; (e) 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 & Jintanapanant (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

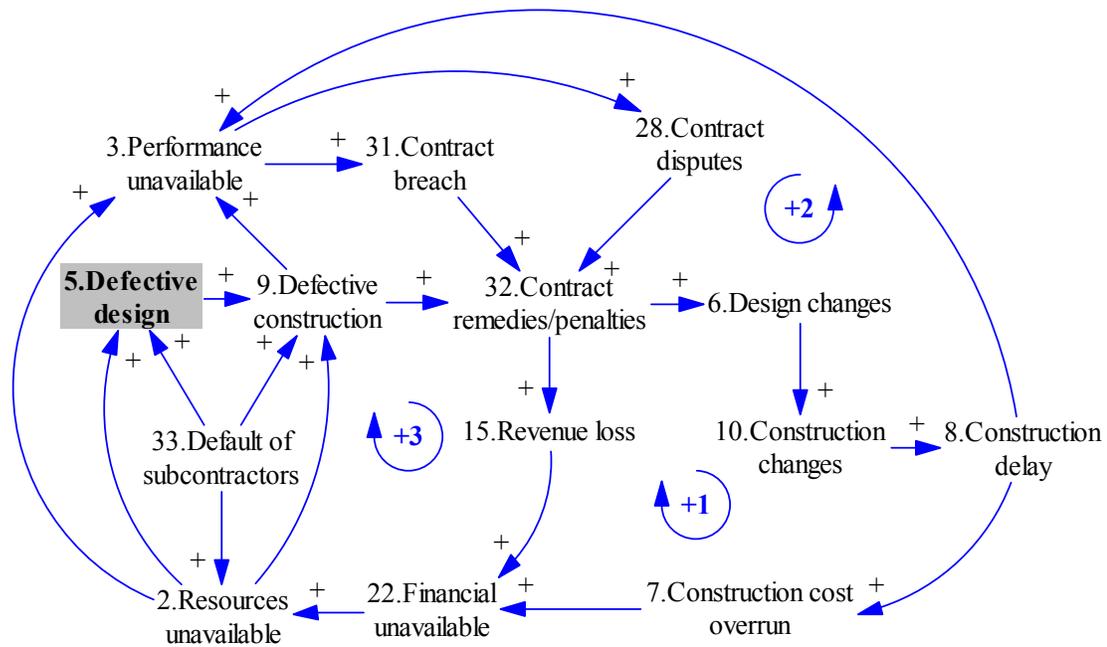
The term “defective design” refers to the probability that the design of facility does not achieve the required output specifications.

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 unavailable 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.



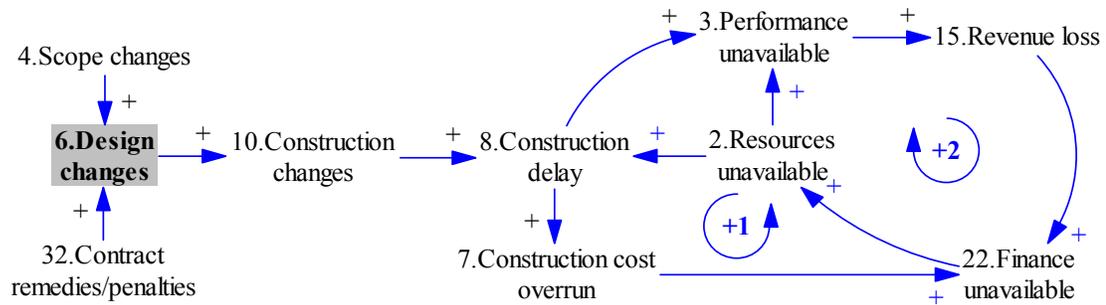
**Figure V5 Cause Loop Diagram for 'Defective Design' Risk Event1**

The defective design risk event would be likely to 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.

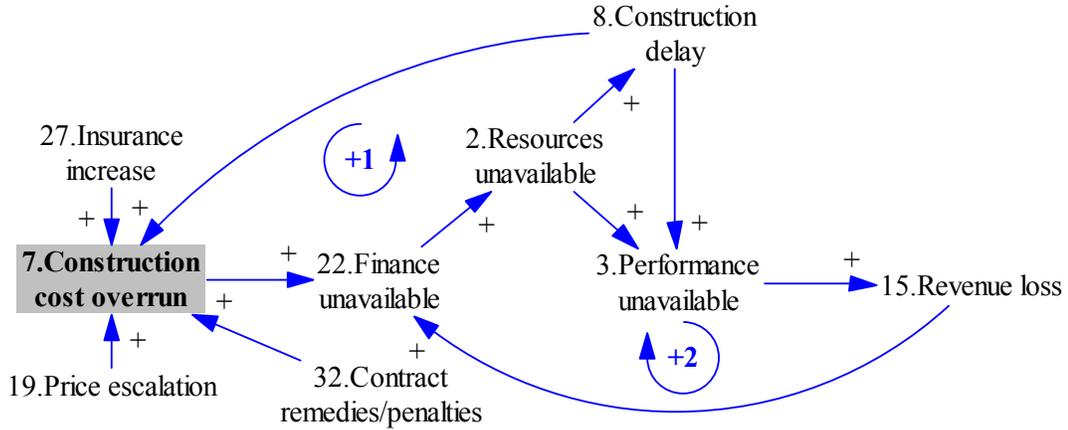
The design changes risk event would possibly be triggered by the risk events such as: (a) scope changes (PAC, 2006a) which result when design or construction parameters need to be changed to meet the new scope requirements; and (b) contract remedies/penalties (Hodge, 2004; PAC, 2006b) because the remedies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



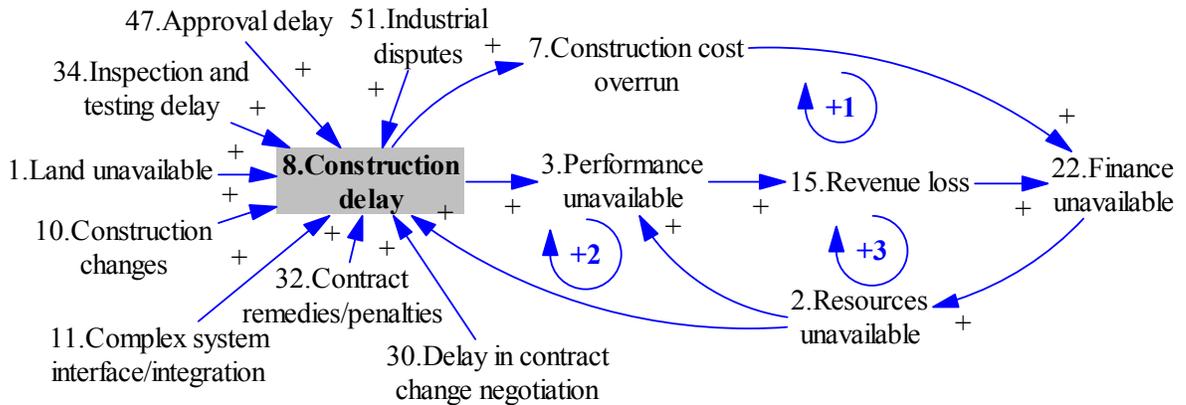
**Figure V7 Cause Loop Diagram for ‘Construction Cost Overrun’ Risk Event**

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.

### 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**

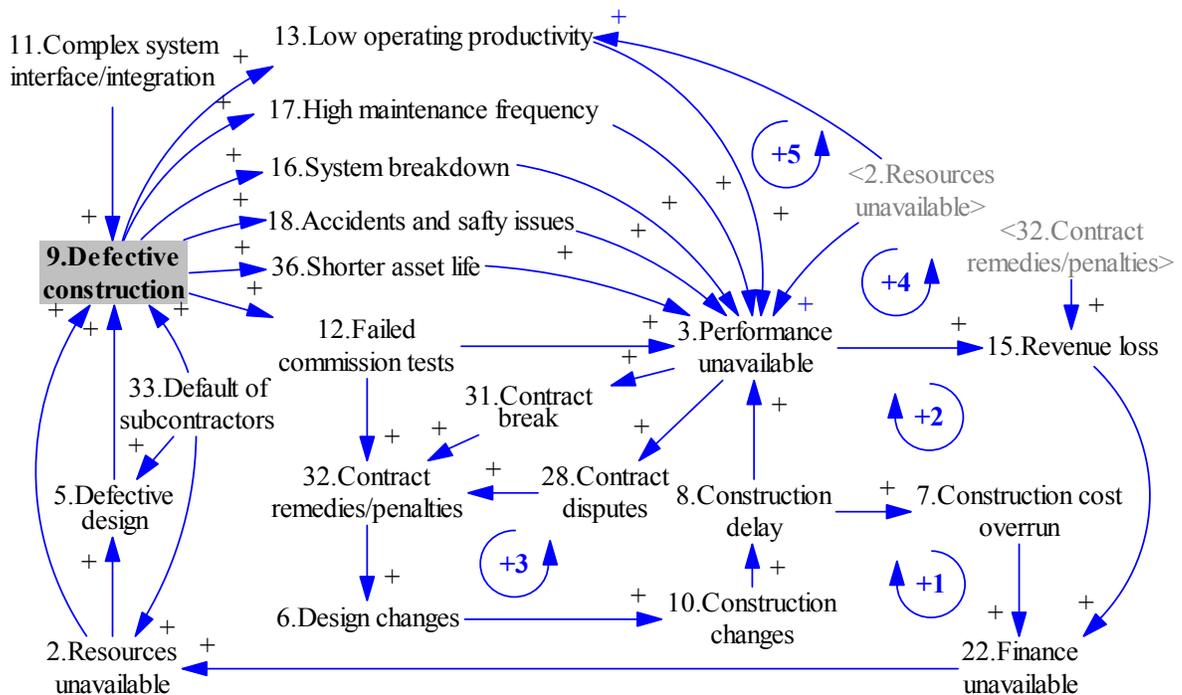
On the other hand, the construction delay events would also cause performance unavailable events since the infrastructure would not be ready to deliver its services. This would lead to revenue loss based on bad credit issues which will result in financial unavailable events. Consequently, the positive 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 & Jintanapanont, 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 & Jintanapanont) 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; (e) 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.

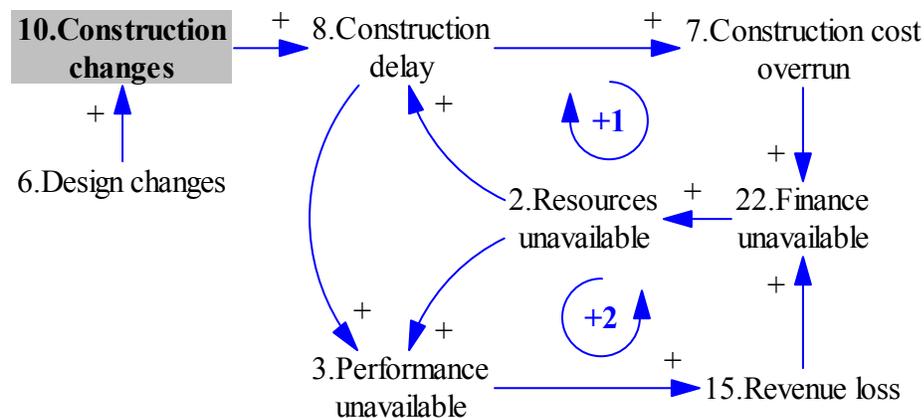
The defective construction events would be likely to be triggered by the following situations: (a) the defective design event (Hodge, 2004) in which the design created cannot meet output specifications; (b) default of subcontractors (EC, 2002; Hodge, 2004; NAO, 2006; PAC, 2002a) so that the construction 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.

### VII. 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.

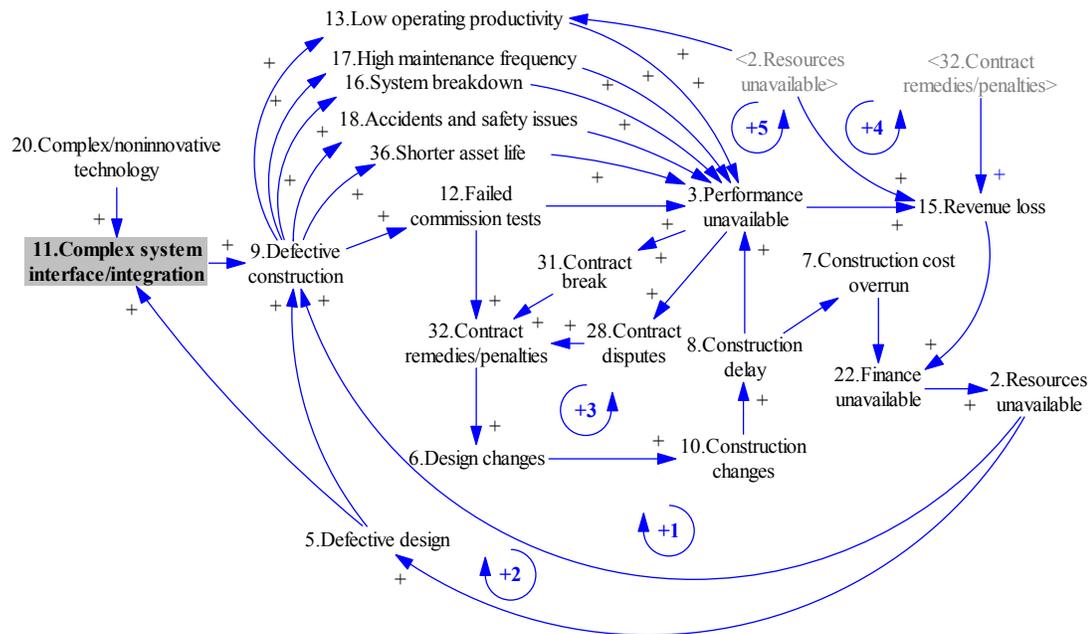
As shown in Figure V11, the complex system interface/integration would likely cause defective construction because the constructed system may be difficult to interface with or may be incompatible with other public systems (PAC, 2002a, 2005a). Then further consequences arise as a result of defective construction 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.

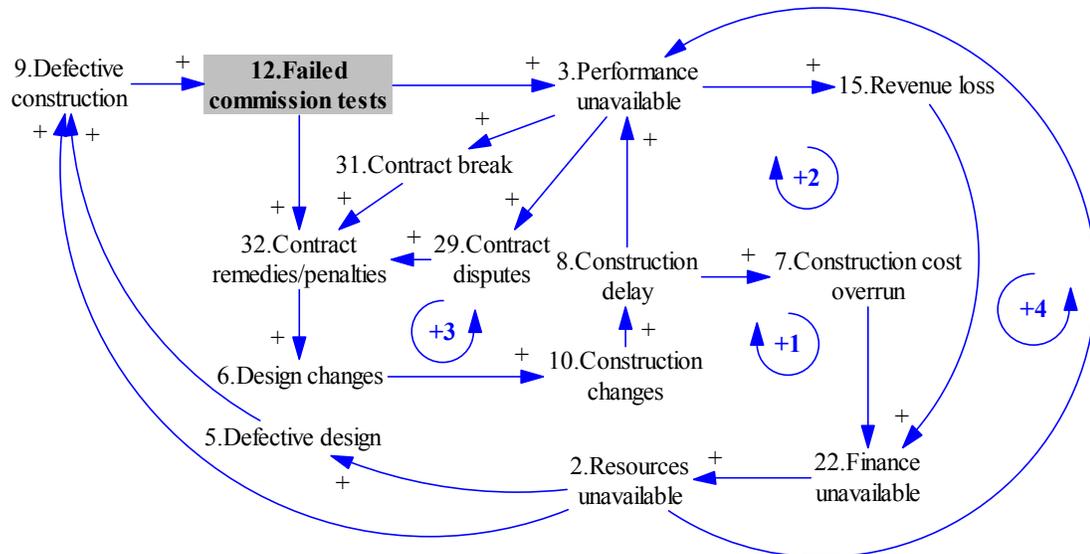
The complex system interface/integration would likely be triggered by the complex/innovative technology when applied technology is not able to solve the system interface/integration issues (NAO, 2006).

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 this 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**

**VI2. 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.

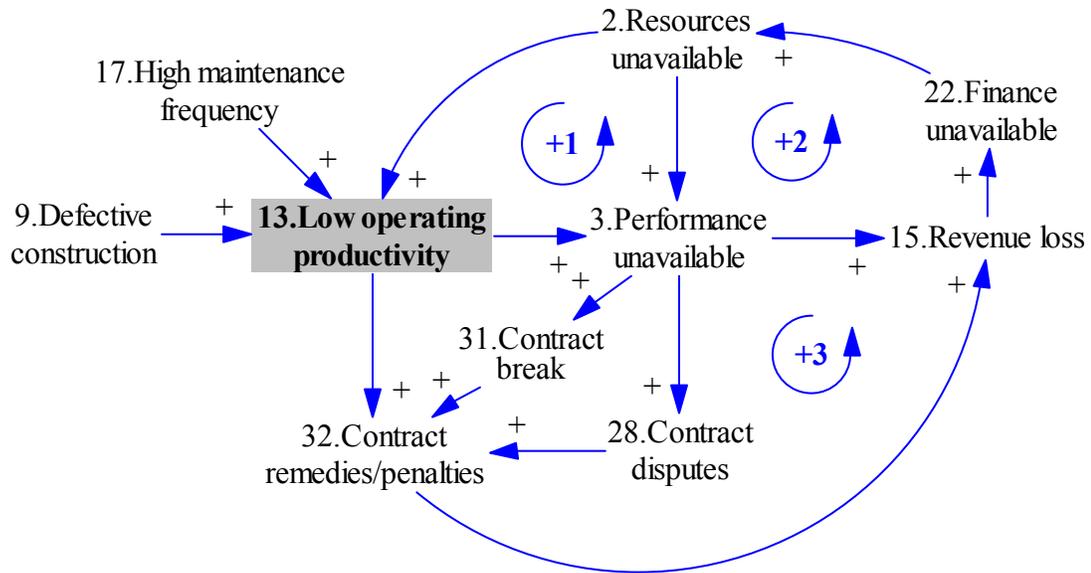
This would lead contract remedies/penalties risks in order to correct defective issues (Hodge, 2004) thus resulting in design changes and construction changes. The more construction changes occur, the more construction delays result. As described, the extra costs incurred in maintaining the existing 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 Event2**

### 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.

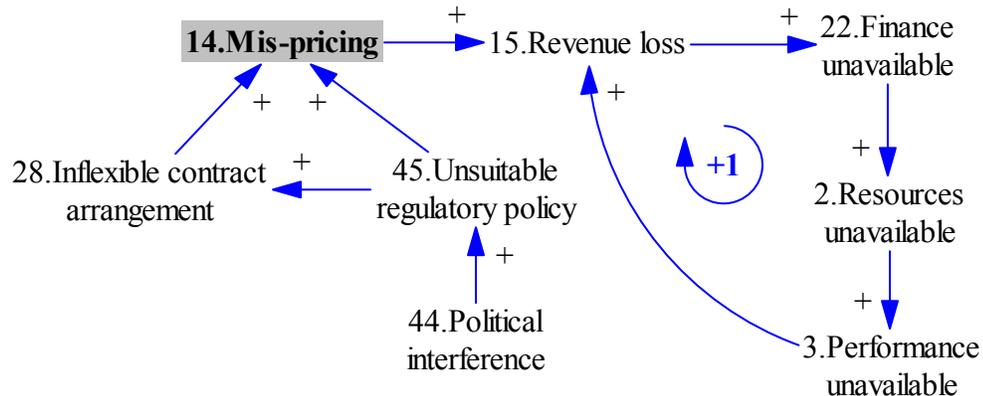
The low operating productivity would be likely to be triggered by such events as: (a) the defective construction as the contracted infrastructure cannot deliver the services as required in the PPP contract (EC, 2004a; Ghosh & Jintanapakanont, 2004); (b) the resources unavailable events occurring that 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 Event3**

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).

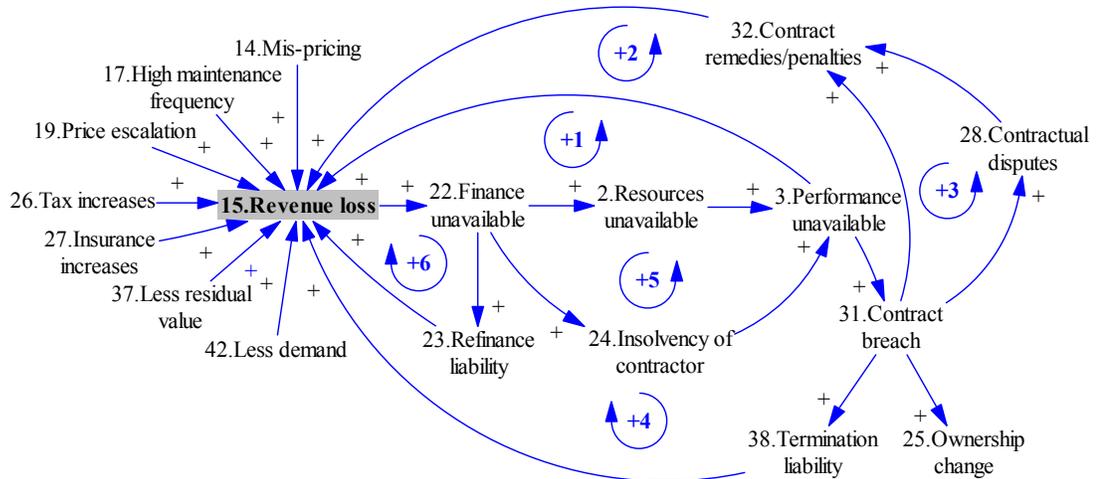
This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As shown in the European Committees case studies on the ASA and Rethmann project in Hungary, this PPP solid waste management project officials need to collect service fees from the population and the subcontractors (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 this 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 & Jintanapanont, 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).

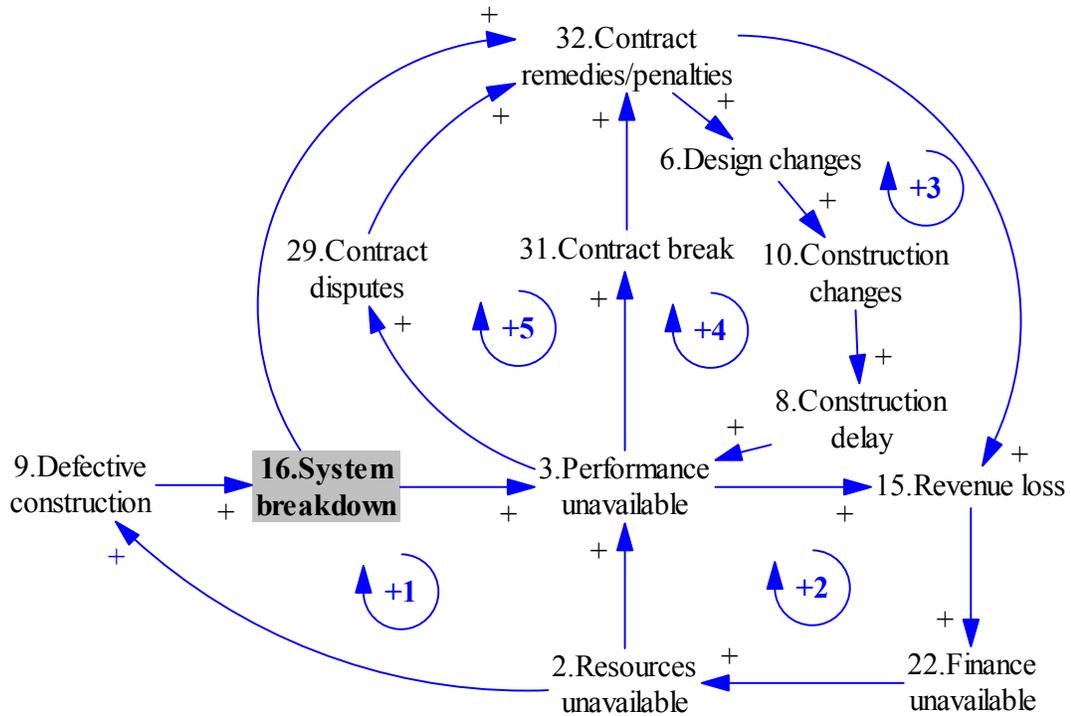
This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. The members of the UK Public Account Committee (PAC) reflected that the channel tunnel rail link project (the Link) lost revenues due to less demand for the use of the completed project (PAC, 2006a). Hodge (2004) 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 & Jintanapanont, 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 2) 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**

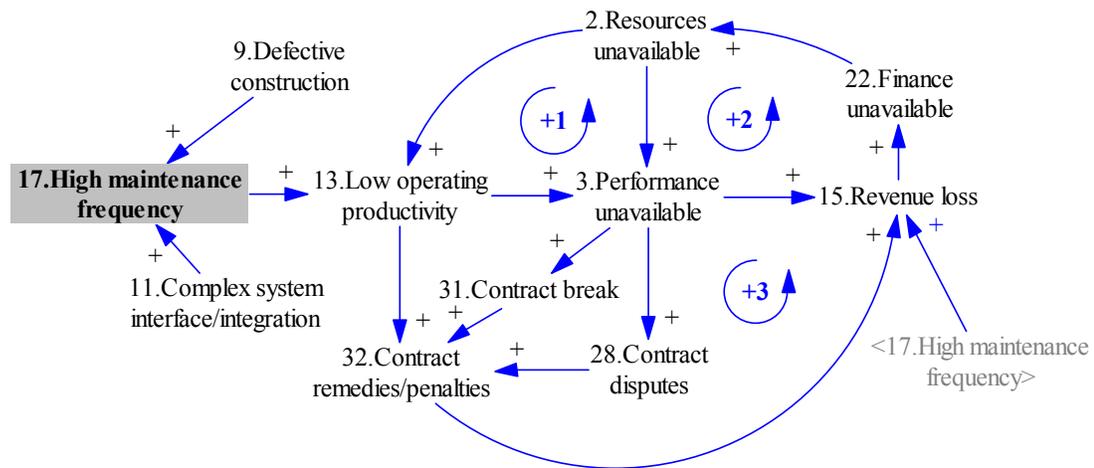
This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for the cases, Hodge (2004)'s case study in the Melbourne City Link indicated that the tunnel was closed due to the defective construction on cracking and leaking. In addition, the Ghosh & Jintanapanont (2004)' 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**

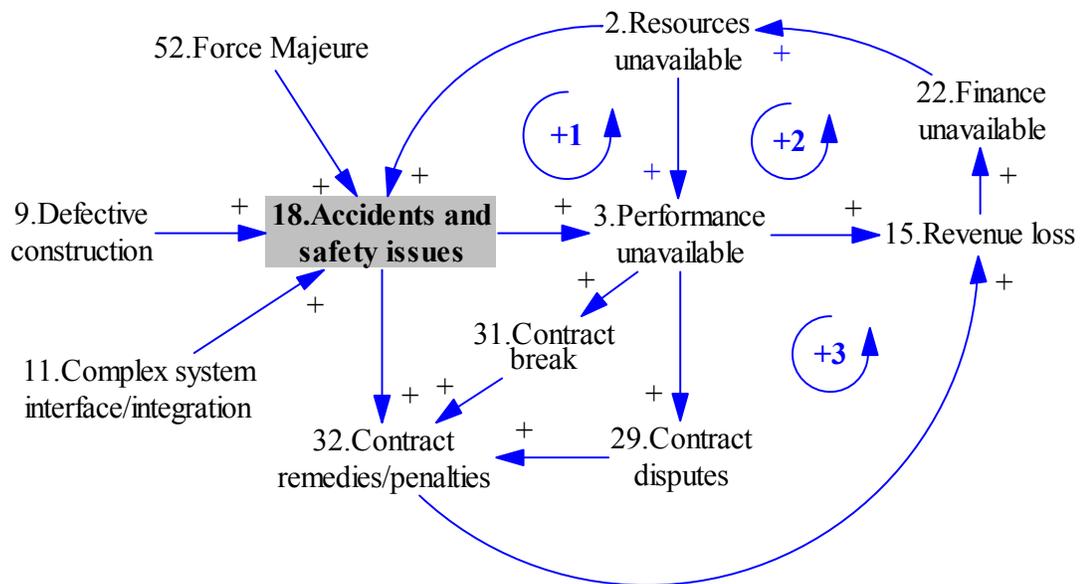
This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. In addition, the Ghosh & Jintanapakanont (2004)’ case study in the Thailand Underground Rail Project reflected that the high maintenance frequency has significant impact on services delivery.

**VI8. 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 to 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).

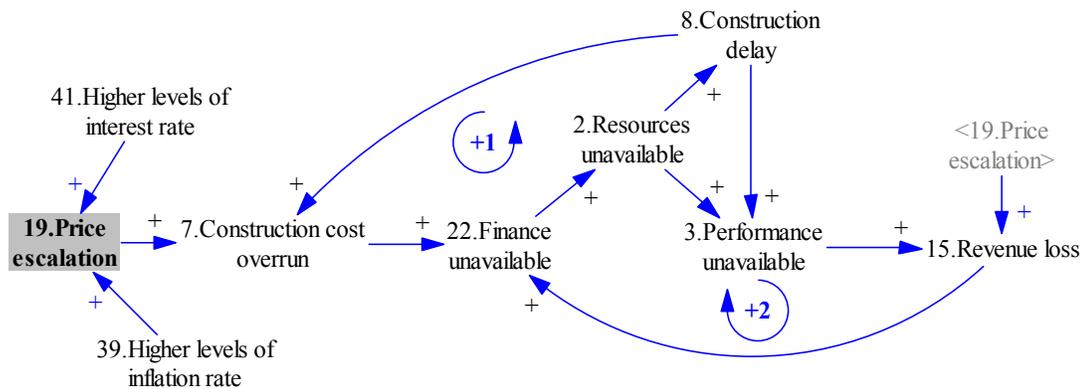


**Figure V18 Cause Loop Diagram for 'High Maintenance Frequency' Risk Event**

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, Infrococ, 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



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).

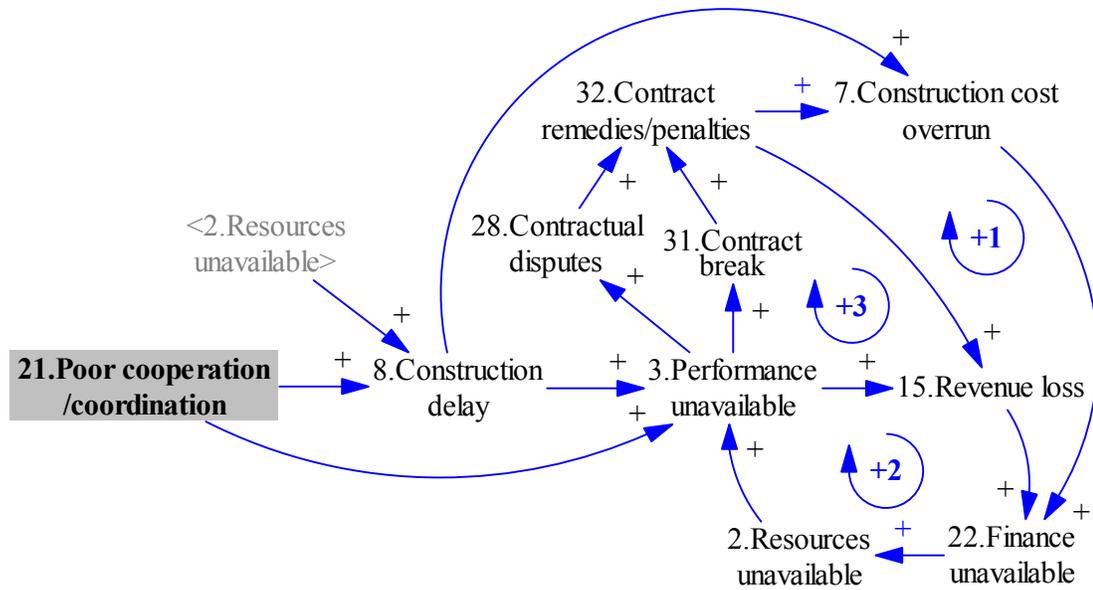
Moreover, as occurred in PFI contract for the National Physical Laboratory, the project contractor could not meet the highly-complex technical challenging requirements and then fail to deliver the required performance. Consequently it would lead to contract default and termination (NAO, 2006).

### ***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.

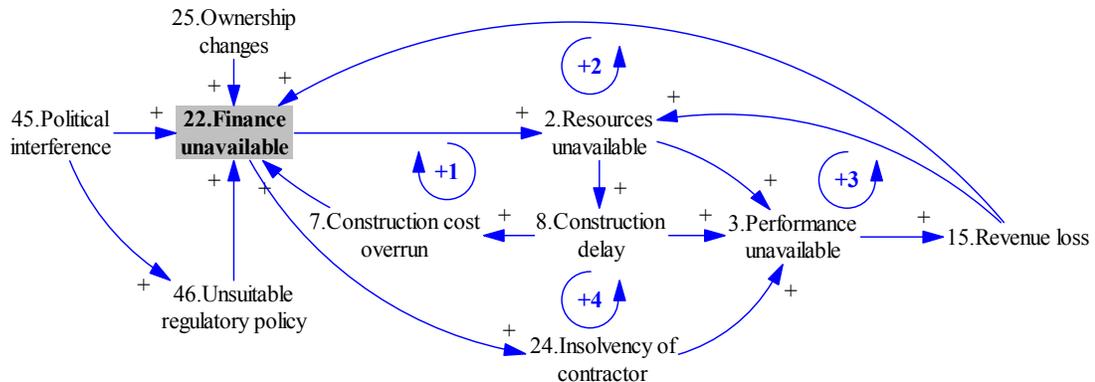
This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for case, the European Commission's report (EC, 2002) on the London Underground criticized that the operating company, LUL, must cooperate with the infrastructure companies, Infracos, one another in performing 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 joint 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).

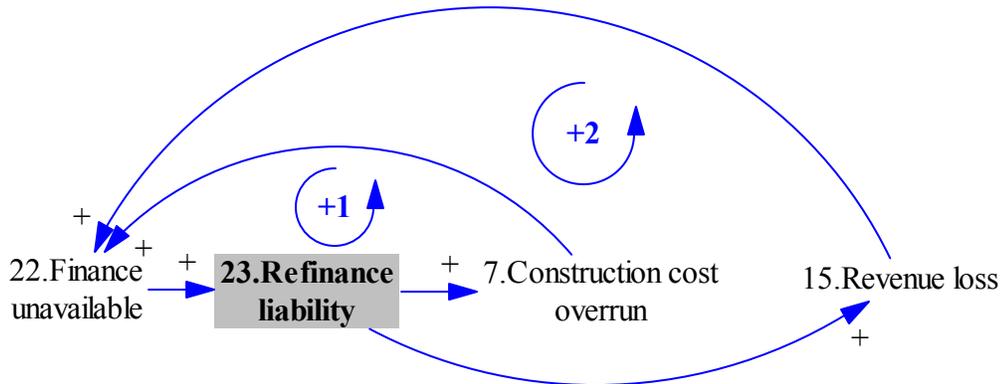
This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for the case of this risk, for example, it may happen in Channel Tunnel Rail Link. The UK Public Account Committee (PAC) warned that the future demand for the Link project is less than the projected leads to 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

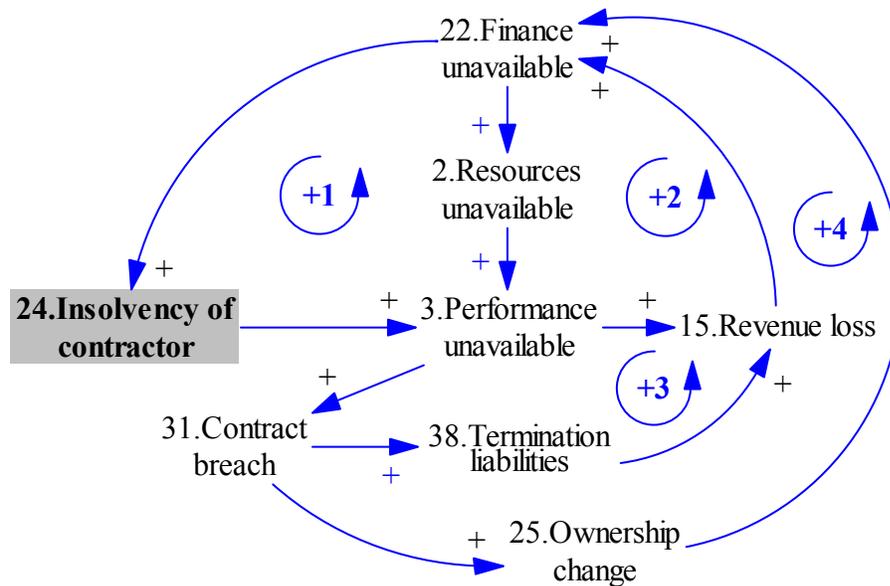
international air traffic volume (PAC, 2003c). To solve this problem, it is necessary to make re-financing for NATS to have a much more robust financial capability, enabling it to make further vital investment to expand the capacity of air traffic control to meet future growth and limit delays. However, 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.



**Figure V24 Cause Loop Diagram for ‘Insolvency of Contractor’ Risk Event**

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.

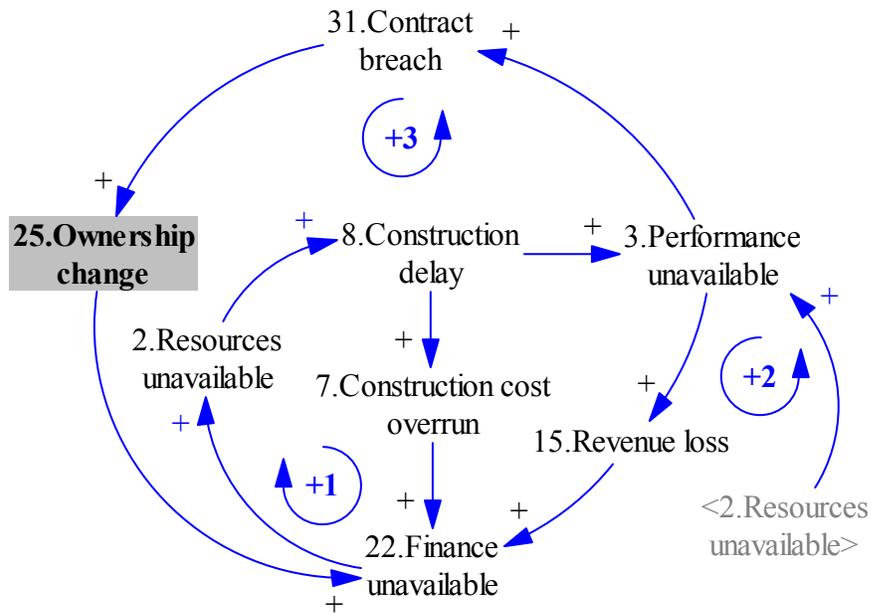
**V25. Ownership change**

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).



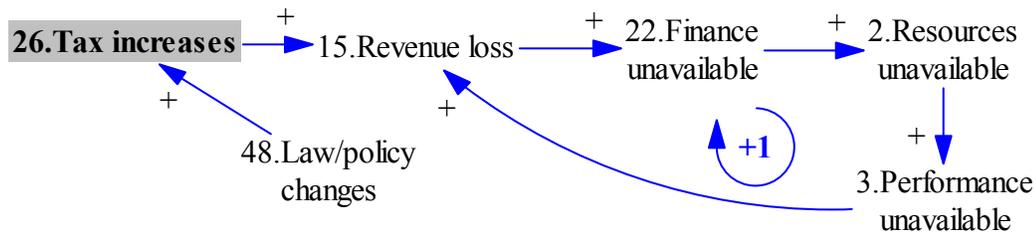
**Figure V25 Cause Loop Diagram for ‘Ownership Change’ Risk Event**

**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).

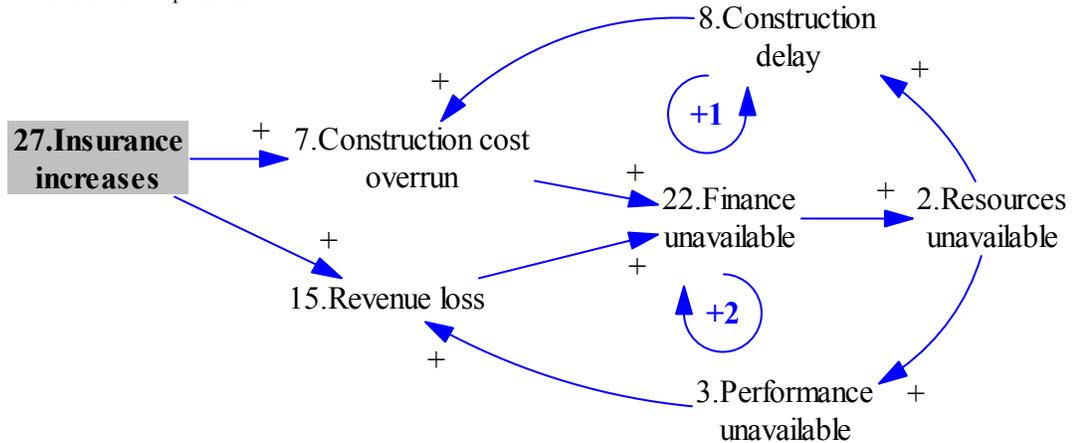


**Figure V26 Cause Loop Diagram for ‘Tax Increase’ Risk Event**

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



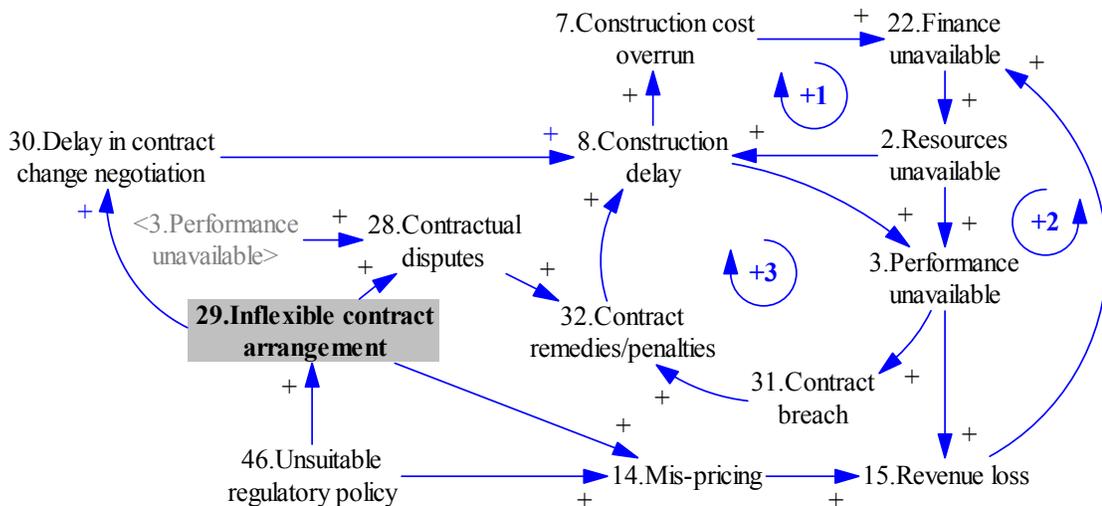
This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for the cases, the Hodge (2004)'s case study on the Melbourne City Link indicated that the project contractor, Transurban, initiated an AUD\$37 million claim against the government authority for compensation 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).



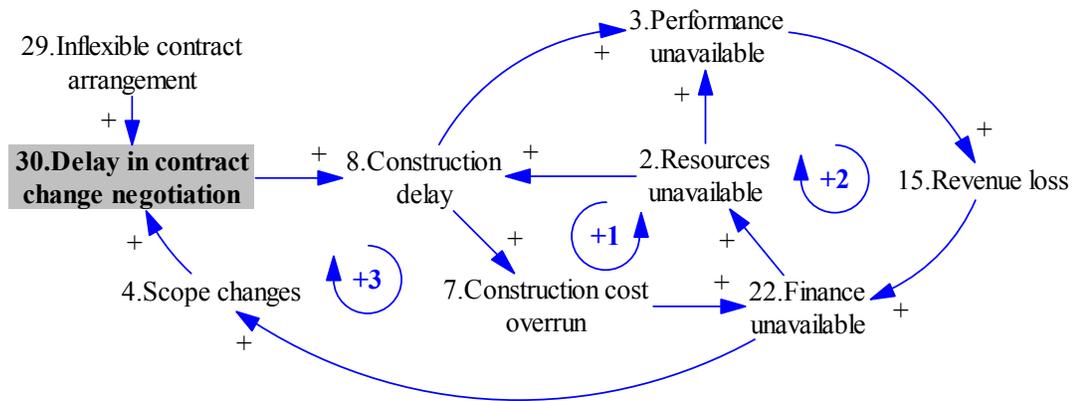
**Figure V29 Cause Loop Diagram for 'Inflexible Contract Arrangement' Risk Event**

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 Nesserbar "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**

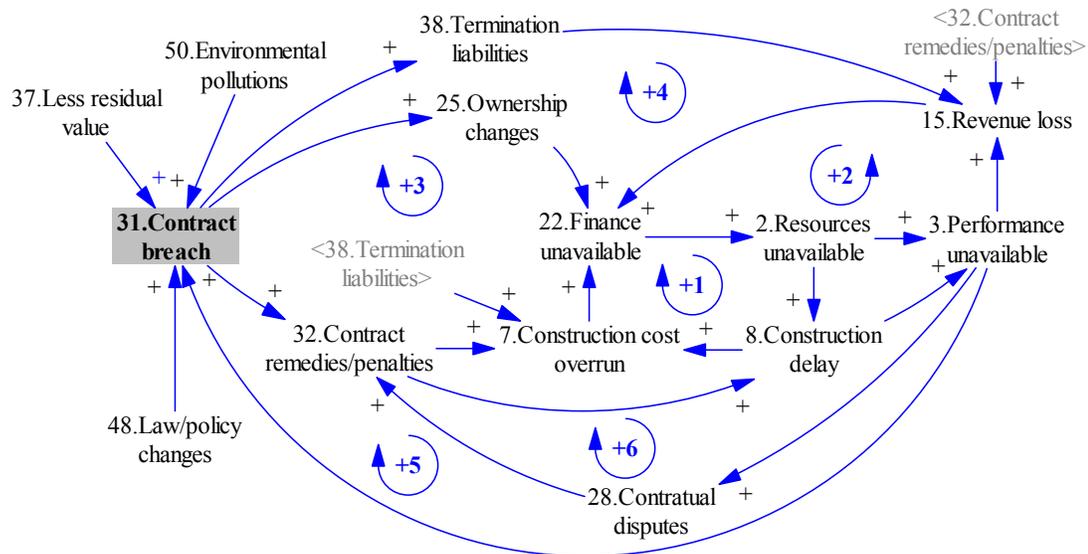
As shown in Figure V30, the 'delay in contract change negotiation' would be likely to directly cause 'construction delay' (Hodge, 2004; NAO, 2004b; PAC, 2003c) at construction stage and 'performance unavailable' at operating stage as well since the construction work and operation service cannot be started 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 not 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 breach.' 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).

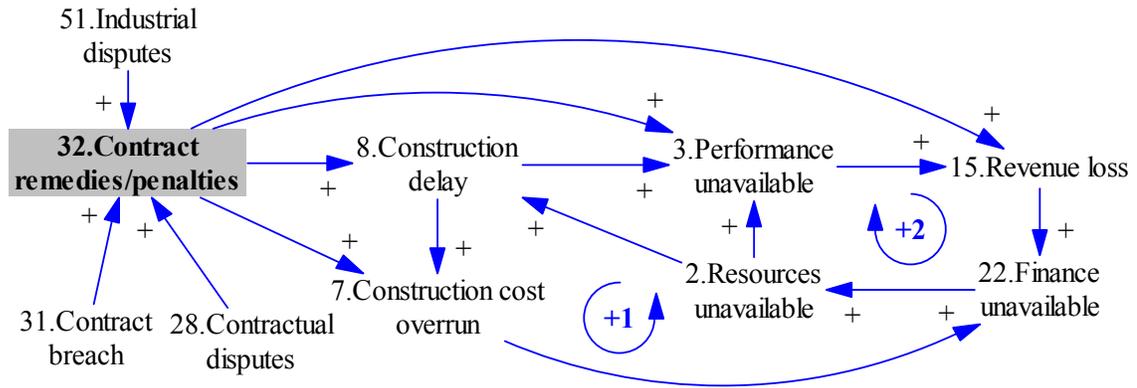
This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for the cases, the Work Bank's case study report (The Work Bank, 1999) indicated that if the BOT concession contracts for the North-South Expressway (NSE) and the Kuala Lumpur-Karak Highway (Malaysia) are terminated 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**

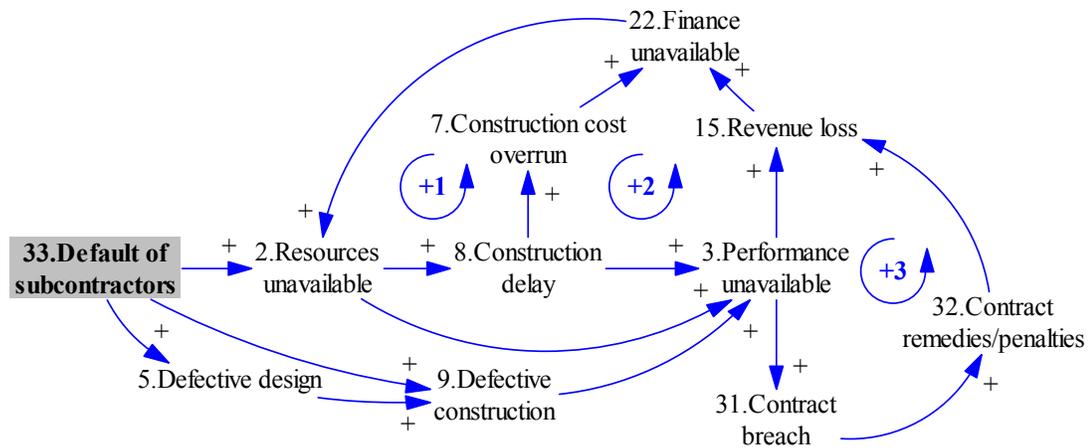
As shown in Figure V32, the 'contractual remedies/penalties' would be likely to directly cause 'construction delay' and 'construction cost overrun' at construction stage, and 'performance unavailable' and 'revenue loss' at operation stage as well since the additional time and costs to fix problems that 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.



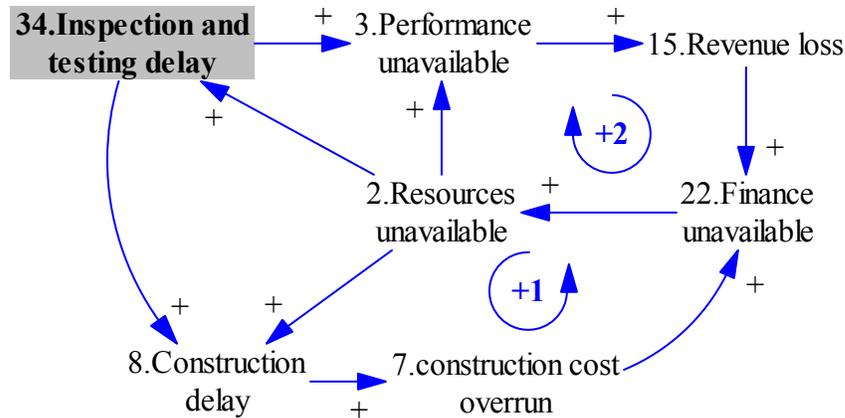
**Figure V33 Cause Loop Diagram for ‘Default of Subcontractors’ Risk Event**

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 Commission’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, Infracore’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).

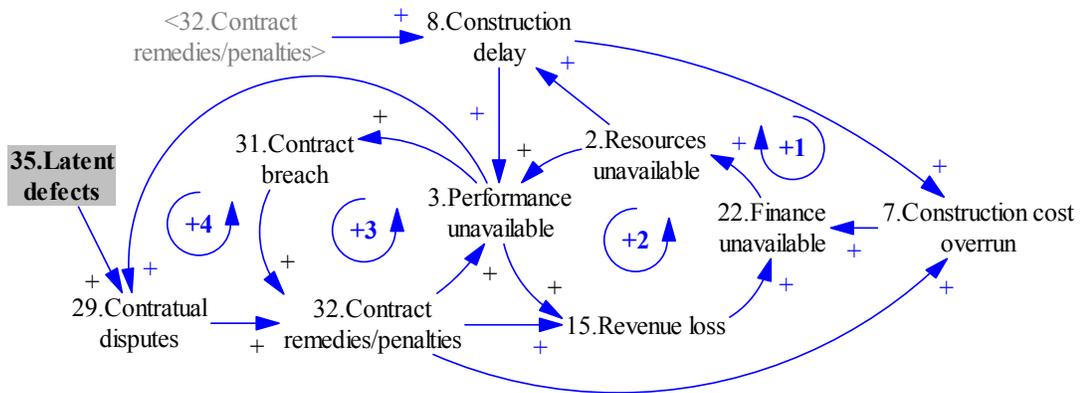
This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As Ghosh & Jintanapakanont (2004)' case study in the Thailand Underground Rail Project, the delay due to the third party is one of the most important components for project delivery delay.

### 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.

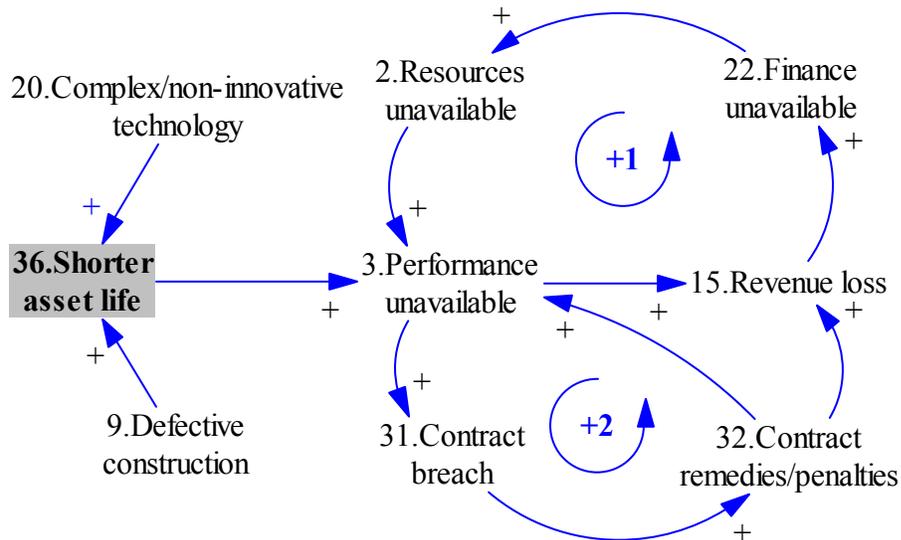
This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for the case, the European Commission's report (EC, 2002) on the London Underground indicated that the PPP infrastructure contractor, SSL Infracore, would be liable for the consequences of latent defects in 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.

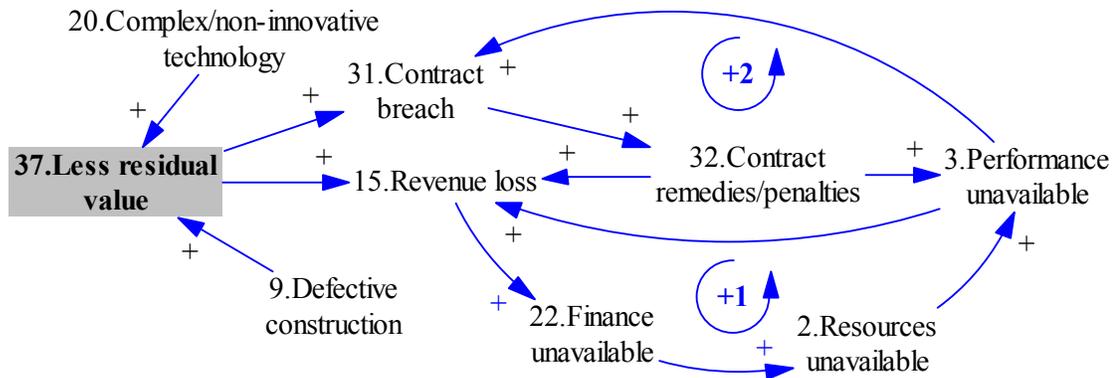
The 'shorter asset life' would be likely to be triggered by 'defective construction' (EC, 2002; NAO, 2004a) that the quality of construction cannot meet contract requirement so that it would be likely to reduce the planned asset life; 'complex/non-innovative technology' since the asset is difficult to 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, Infrocros, 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**

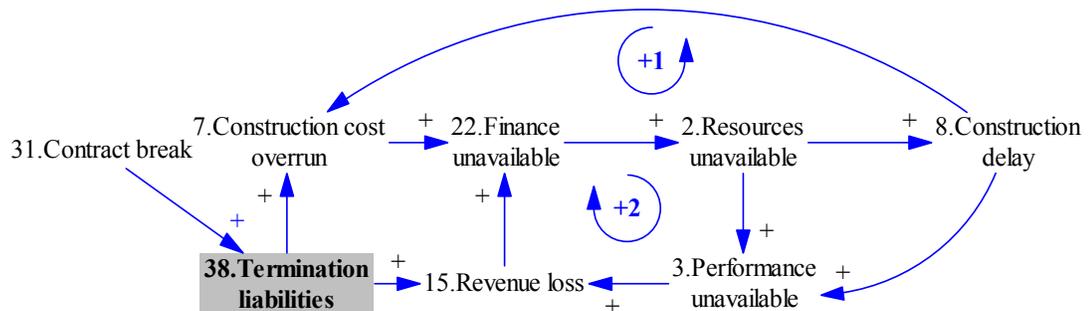
As shown in Figure V37, the ‘less residual value’ would be likely to directly cause ‘revenue loss’ because the value of infrastructure is less than contract requirement (EC, 2002; NAO, 2004a). As previously stated, this would create a vicious circle (the positive loop 1) to cause more risk in ‘finance 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, Infrocros, 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, Infrocros, 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**

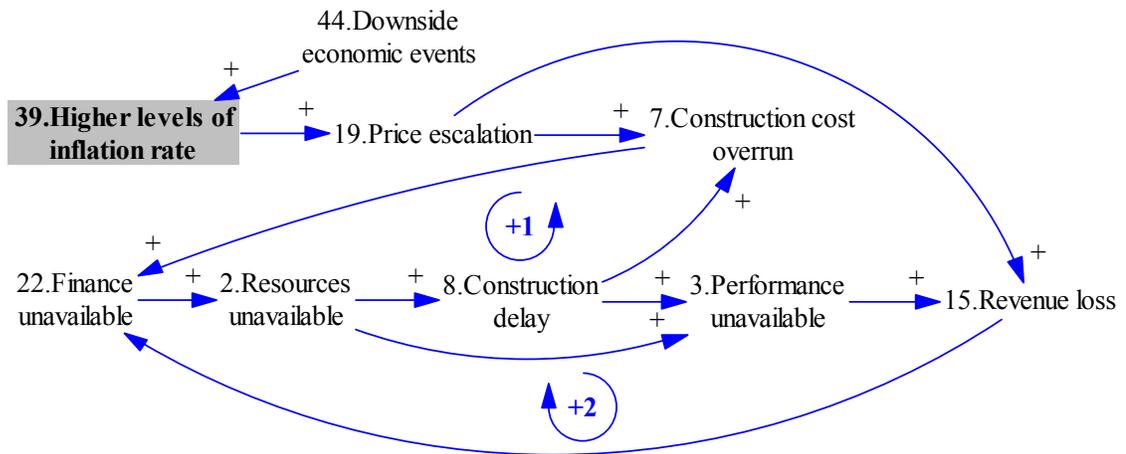
As shown in Figure V38, the ‘termination liabilities’ would be likely to directly cause ‘revenue loss’ because the possible service disruption arisen from ‘contract breach’ (NAO, 2006) would increase the government’s liabilities at taxpayer’s costs, which would be likely to result in ‘construction cost 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.

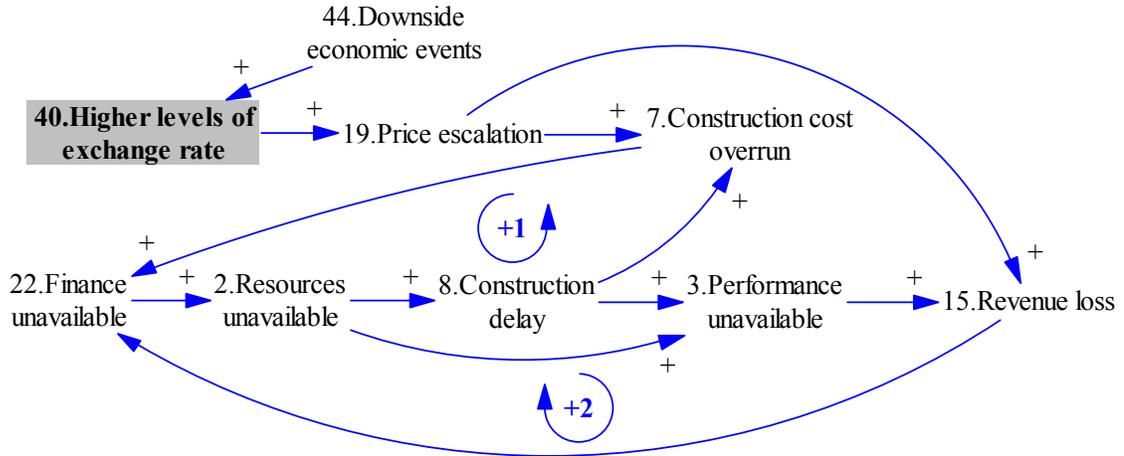
The ‘higher levels of inflation rate’ would be likely to be triggered by ‘downside economic events’ that the inflation rate increases due to the impact of specific downside economic events (The Work Bank, 1999).

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 & Jintanapanont (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**

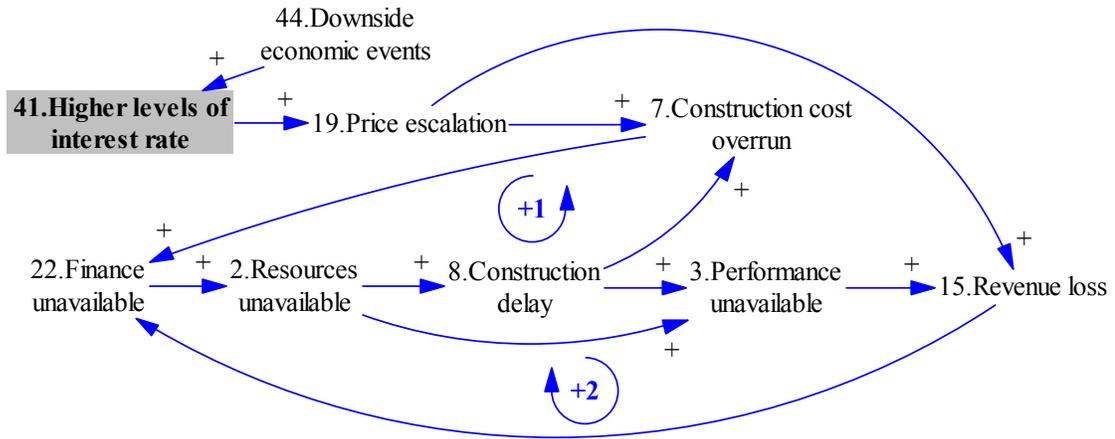
As shown in Figure V40, the 'higher levels of exchange rate' would be likely to directly cause 'price escalation' that increases the costs for construction and operation (EC, 2002; Lu, 2004). This would cause 'construction cost overrun' at construction stage, and 'revenue loss' at operation stage as 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 & Jintanapanont (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**

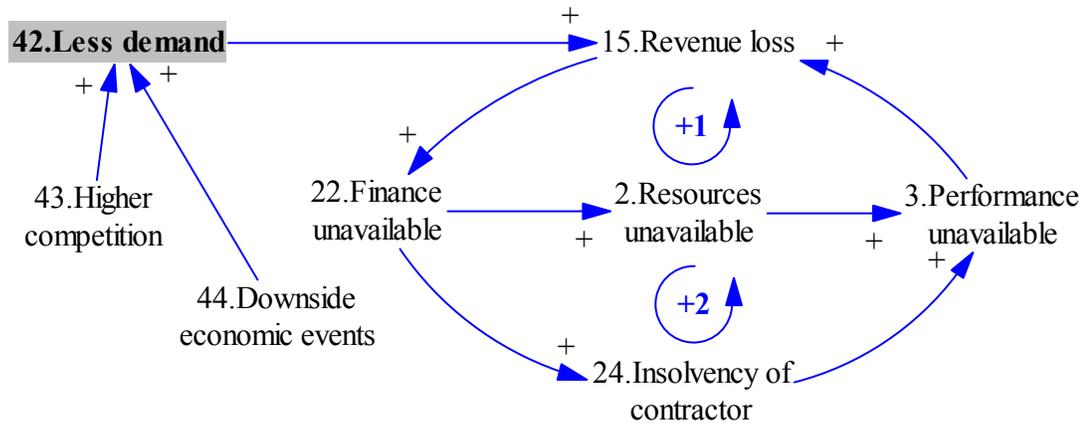
As shown in Figure V41, the 'higher levels of interest rate' would be likely to directly cause 'price escalation' that increases the costs for construction and operation (Lu, 2004). This would cause 'construction cost overrun' at construction stage, and 'revenue loss' at operation stage as well (Smith, 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.

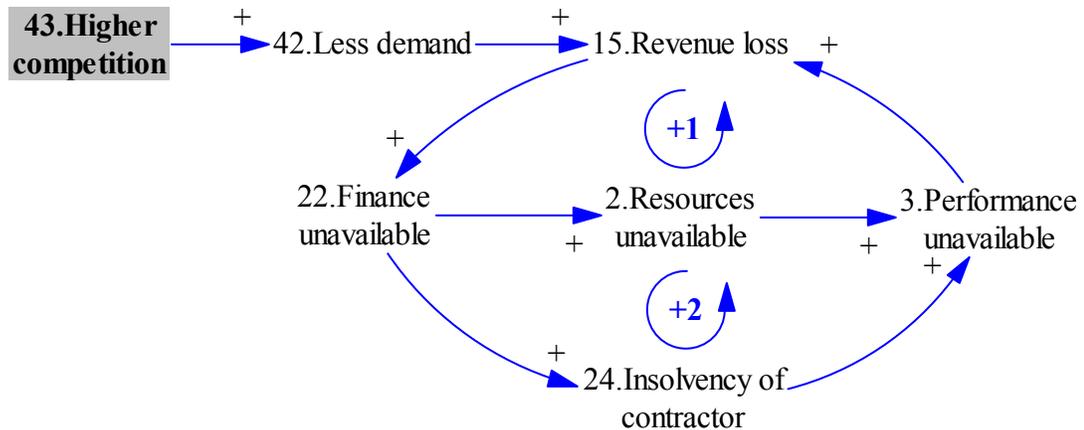
This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. It has ever happened in Channel Tunnel Rail Link. The UK Public Account Committee (PAC) reported that in 1996 the Department for Transport (DfT) awarded a contract to London & Continental Railways Limited (LCR), 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**

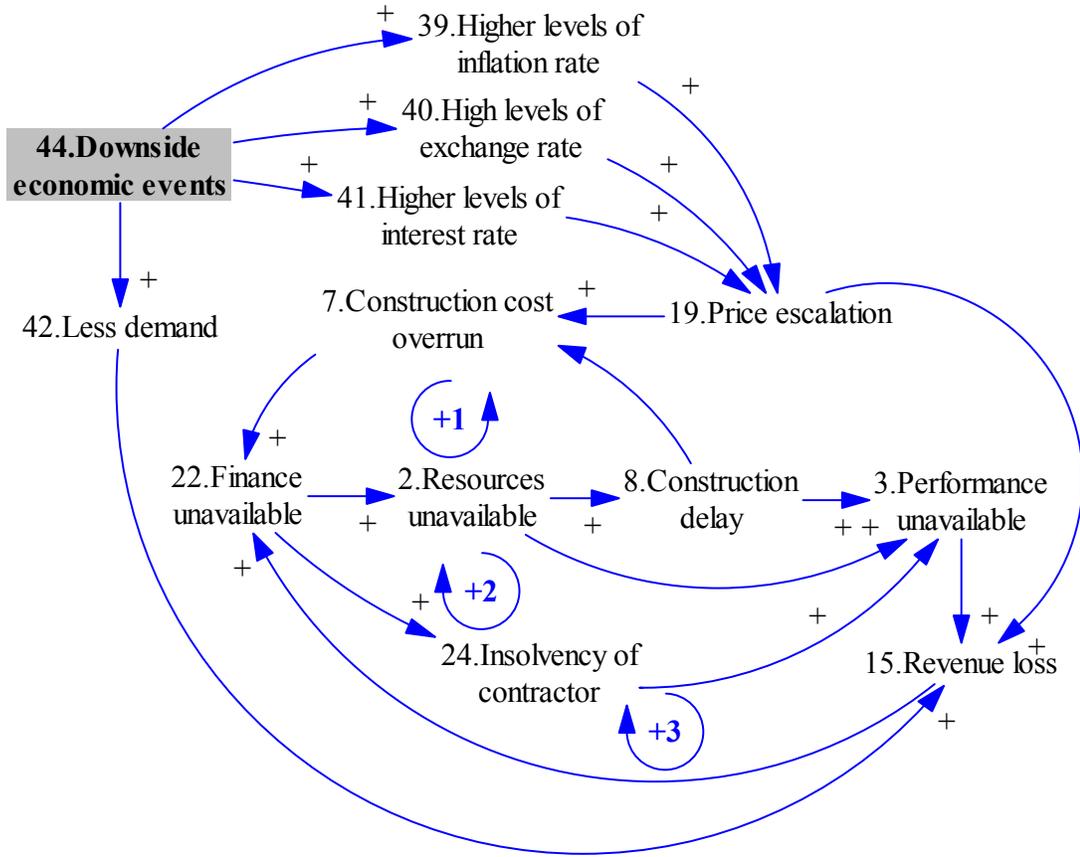
The 'downside economic events' refers to the possibility that the demand for the services generated by a project may be less than projected due to the impact of specific downside economic events, which results in revenue below projections.

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.

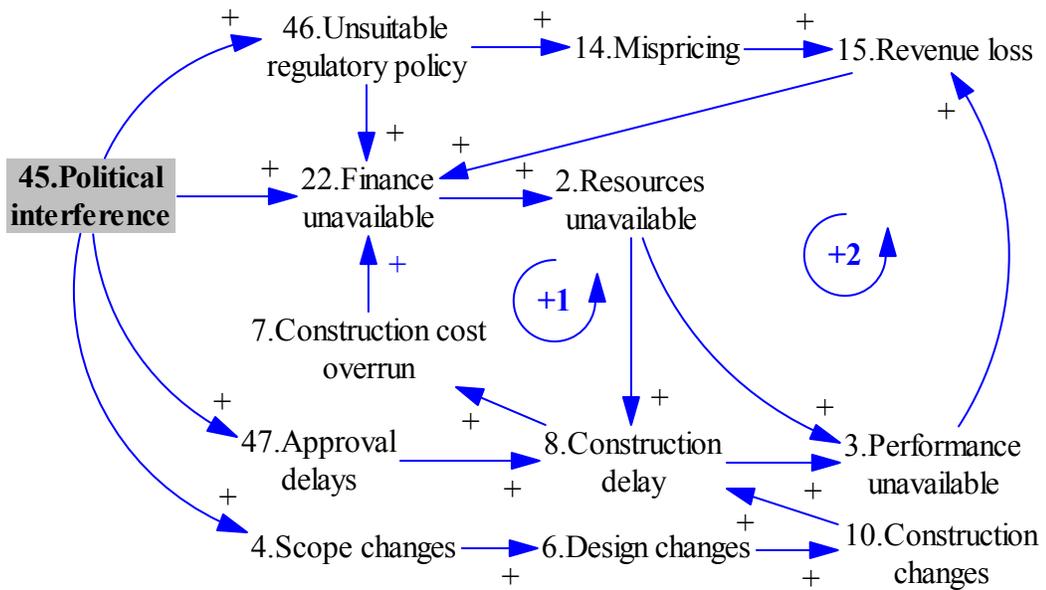
This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. As for the cases, the Work Bank's case study report (The Work Bank, 1999) indicated that the effects of the Asian Economic Crisis during 1997-98 had great impact on the PPP toll road projects. As a result, the 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**

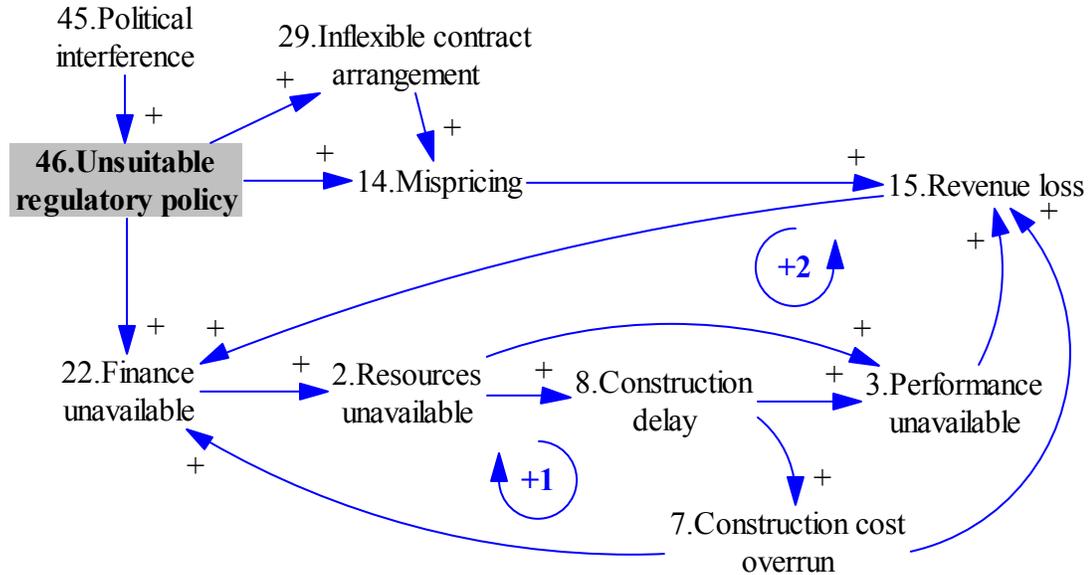
As shown in Figure V45, the ‘political interference’ would be likely to directly cause ‘unsuitable regulatory policy’ (EC, 2004b) since the politics is easy to adversely affect the public decision-making for regulatory policy under an uncertain political and legal environment. This would be likely to 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 World Bank’s case study report (The World 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**

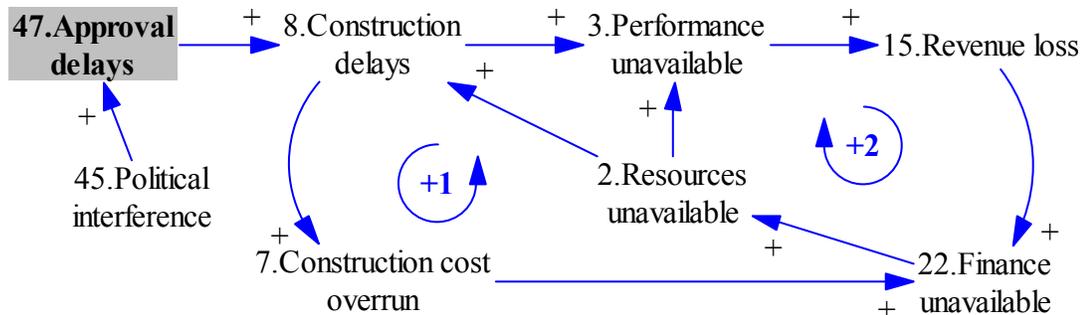
The ‘unsuitable regulatory policy’ would be likely to be triggered by ‘political interference’(EC, 2004b) since the politics is easy to adversely affect the public decision-making for regulatory policy under an uncertain political and legal environment.

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.”

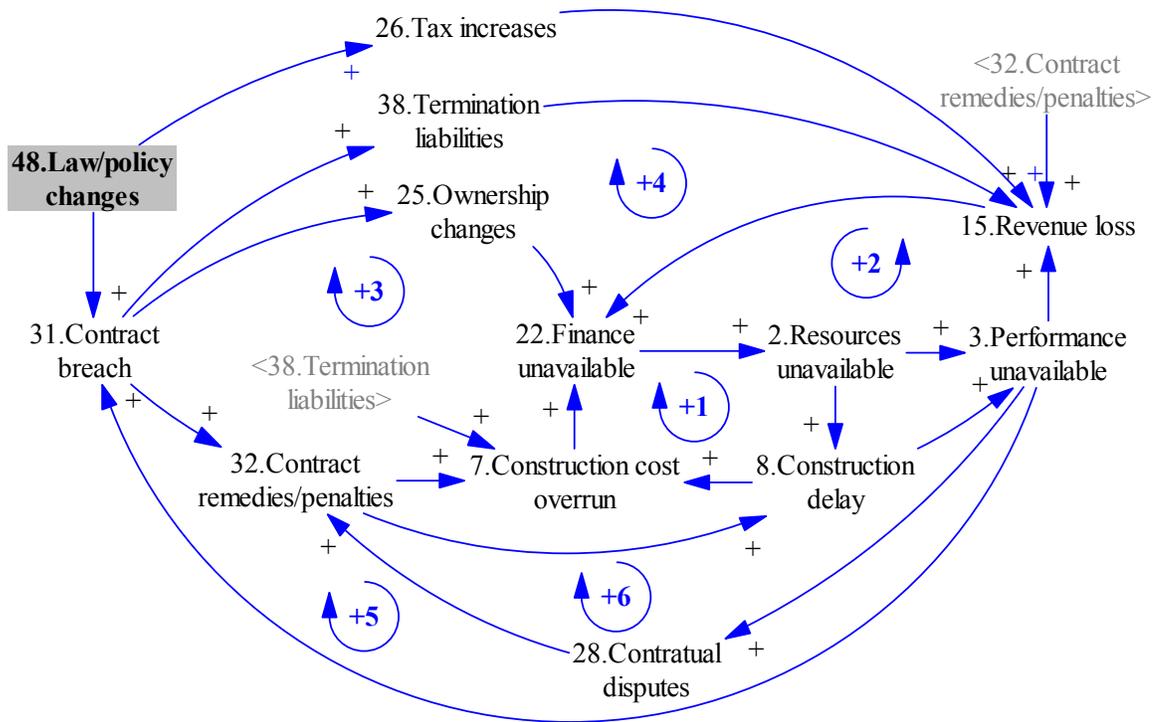
This risk has been described in the secondary data sources listed in Table 4.1.1 and 4.1.2. One of the cases is the PPP project for National Airport Traffic Services (NATS) described above. Lu (2004)’s case study on the Water and Wastewater Infrastructure in Southern China indicated that it is not easy 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.

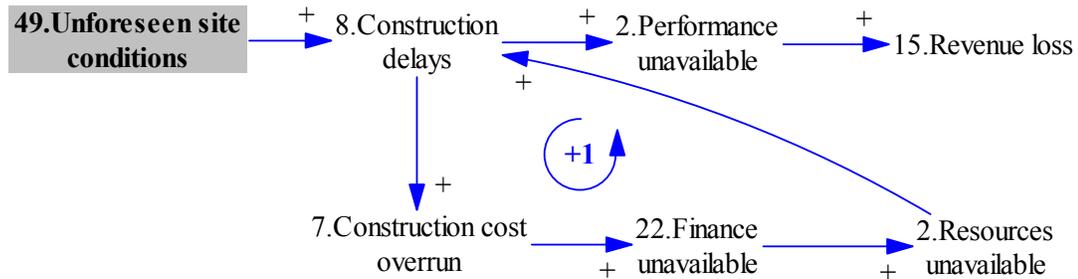


**Figure V48 Cause Loop Diagram for ‘Law/Policy Changes’ Risk Event**

**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.

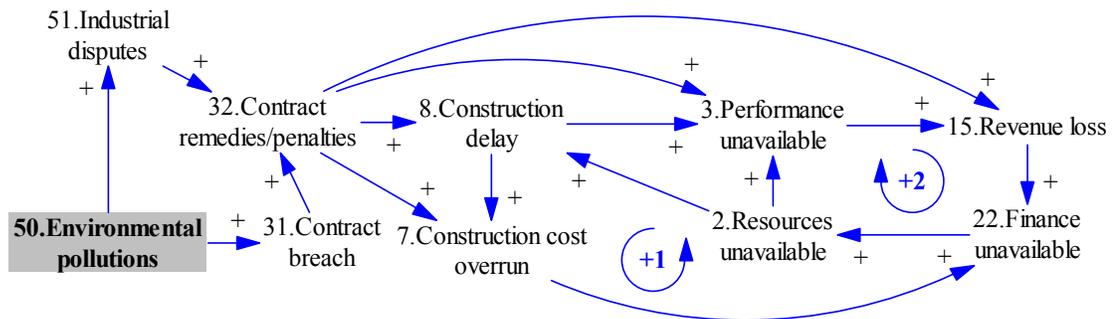


**Figure V49 Cause Loop Diagram for ‘Unforeseen Site Conditions’ Risk Event**

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/Demarc 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 & Jintanapanont (2004)’ case study in the Thailand Underground Rail Project indicated that this risk will be against environment protection and regulation policy.

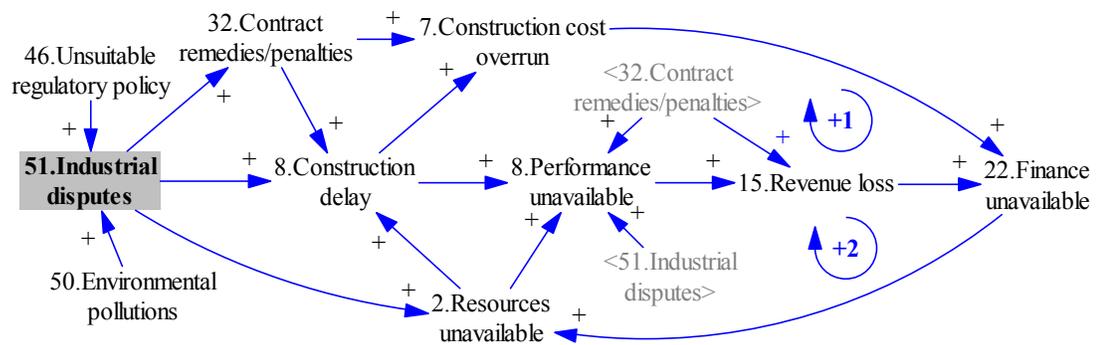
**V51. Industrial disputes**

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 & Jintanapanont, 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 & Jintanapanont (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.



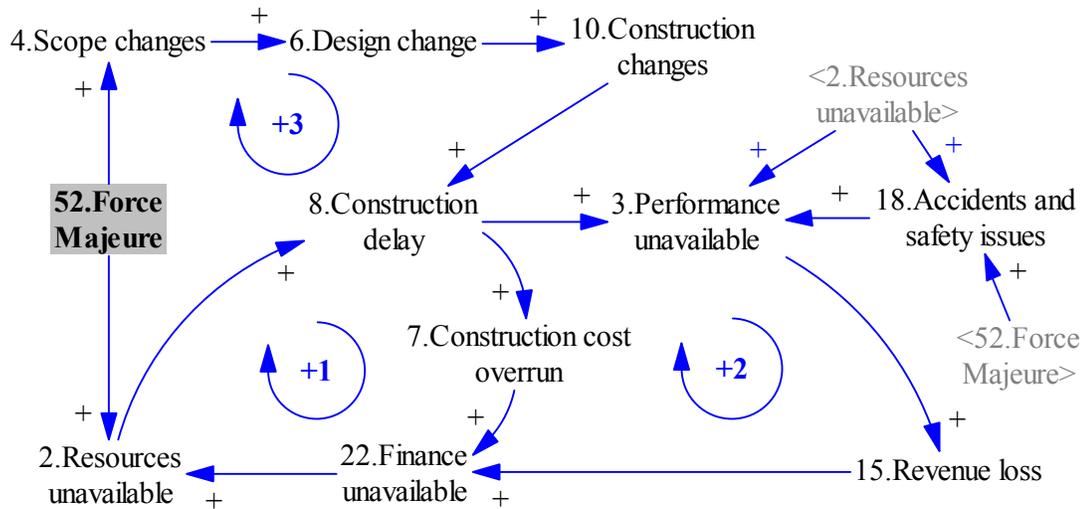
**Figure V51 Cause Loop Diagram for ‘Industrial Disputes’ Risk Event**

**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 & Jintanapanont (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

## VII. '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:

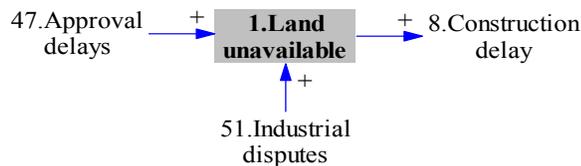
“The overall length of lands for the whole route of THSR runs through the west corridor of Taiwan is about 345 kilometers. Among of them, the private lands occupy about 789 hectares, which were acquired by expropriation, whereas the public lands occupy about 101 hectares, which were acquired by appropriation. 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 VII to fit the THSR project.



**Figure VII The Direct Cause and Consequence for 'Land Unavailable'<sup>4</sup>**

## 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 Bauaktiengesellschaft 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, this 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:

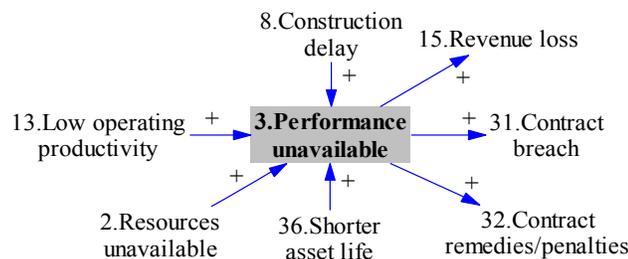
“There would be lots of challenges to start running this state-of-the-art project. The preliminary condition is that **all of work package should be completed and passed the inspection & commissioning tests on schedule** for operation. **Annual delay to start operation would be likely to cost about NT\$19.3 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, this 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's**

#### 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’6**

#### V15. ‘Defective Design’ on THSR

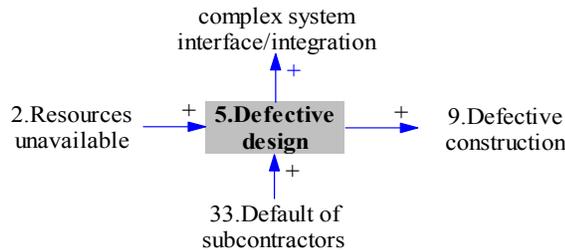
As discussed in the Section V5 and the CLD shown in Figure V5, the defective design would lead to a defective system that would potentially cause defective construction and performance unavailable events, possibly catalyzed by defaults of subcontractors and resources unavailable events. Relative to the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



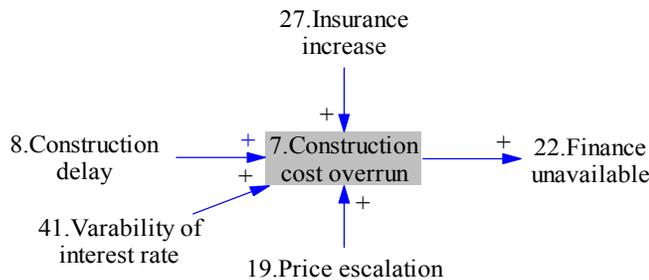
**Figure VI5 The Modified Direct Cause and Consequence for ‘Defective Design’**

**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**

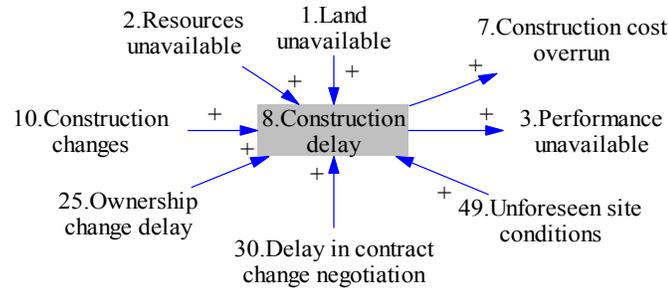
As described in Section VI8, VI9, VI22, VI27, VI40 and VI41, obviously all of additional costs arising from risk events such as ‘construction delay’ ‘variability of interest rate’ ‘price escalation’ and ‘insurance increases’ would likely cause ‘construction cost overrun’ at construction stage which would 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**

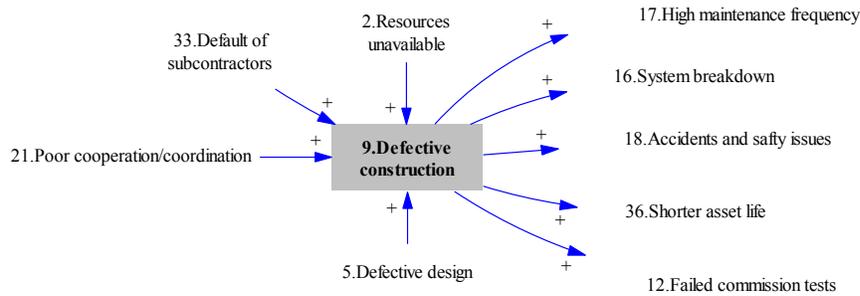
As described in Section VII, VI2, VI10, VI25, VI30, VI38 and VI49, we conclude that the ‘construction delay’ would be directly caused by ‘land unavailable’ and ‘resources unavailable’ ‘construction changes’ ‘delay in contract change negotiation’ ‘ownership change delay’ and ‘unforeseen site conditions.’ 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**

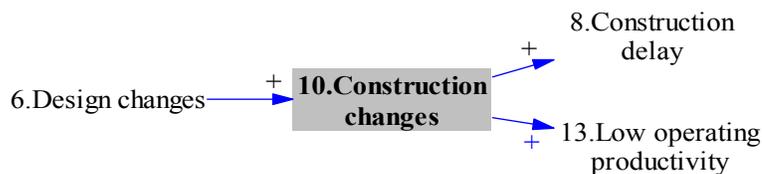
As described in the Section VI2, VI3, VI5, and VI33, we conclude that the ‘defective construction’ is usually caused by ‘defective design’ and ‘resources unavailable’ ‘default of subcontractors’ and ‘poor cooperation/coordination’, and usually leads to ‘failed commission tests’ ‘system breakdown’ ‘high 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**

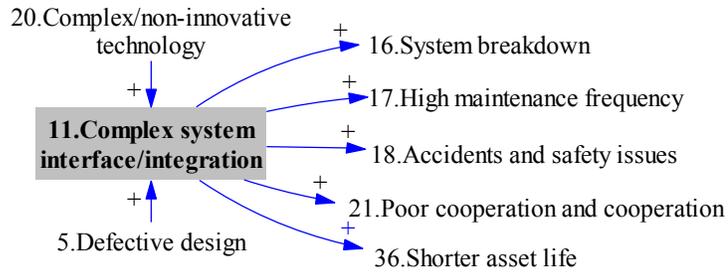
As described in Section VI5, Section VI6 and Section VI28, apparently the ‘construction changes’ would be caused by ‘design changes’ and easy to lead to ‘construction delay’ and ‘low operating productivity’. Thus the direct causes and consequences of ‘construction changes’ illustrated in Figure V10 are modified as Figure VI10 to fit the THSR project.



**Figure VI10 The Modified Direct Cause and Consequence for ‘Construction Changes’**

**VIII. ‘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 VII1 to fit the THSR project.



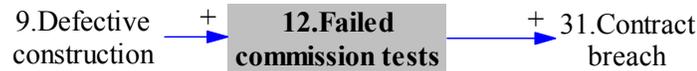
**Figure VII1 The Modified Direct Cause and Consequence for ‘Complex System Interface/Integration’**

**VII2. ‘Failed Commissioning Tests’ on THSR**

As discussed in Section VI2 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.”

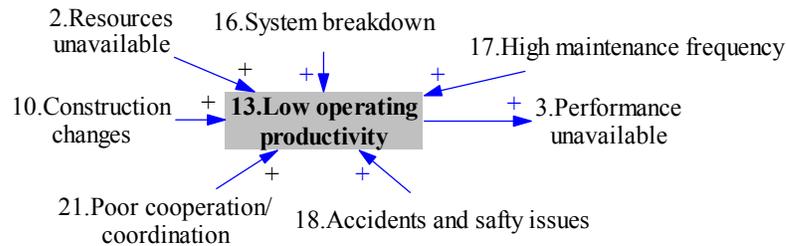
As described in Section VI3 and VI9, and the above interview statement, the ‘defective construction’ would absolutely fail commissioning tests to meet contract requirements (‘contract breach’), and would lead to further action on fix defective construction. Thus, the direct cause and consequence of ‘failed commissioning test’ illustrated in Figure V12 are modified as Figure VII2 to fit the THSR project.



**Figure VII2 The Modified Direct Cause and Consequence for ‘Failed Commissioning tests’**

**VII3. ‘Low Operating Productivity’ on THSR**

As described in the Section VI2, VI3, VI10 and VII1, 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 VII3 to fit the THSR project.



**Figure VII3 The Modified Direct Cause and Consequence for ‘Low Operating Productivity’**

**VII4. ‘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.”

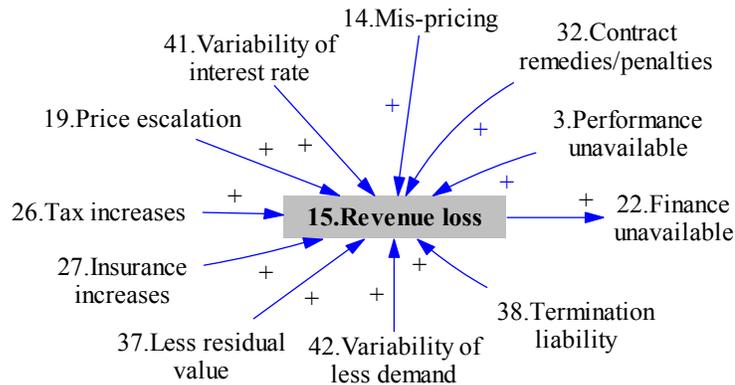
Thus, the direct cause and consequence of ‘mis-pricing’ illustrated in Figure V14 are modified as Figure VI14 to fit the THSR project..



**Figure VI14 The Modified Direct Cause and Consequence for ‘Mis-pricing’**

**VII5. ‘Revenue Loss’ on THSR**

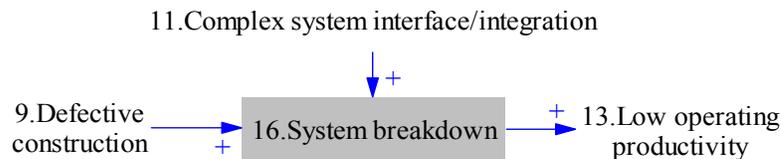
As described in the Section VI3, VI32, VI14, VI41, VI19, VI26, VI27, VI37, VI42, and VI38, obviously all of additional costs or losses arising from risk events at operation stage such as ‘performance unavailable’ ‘contract remedies/penalties’ ‘mis-pricing’ ‘variability of interest rate’ ‘price escalation’ ‘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’**

**VII6. ‘System Breakdown’ on THSR**

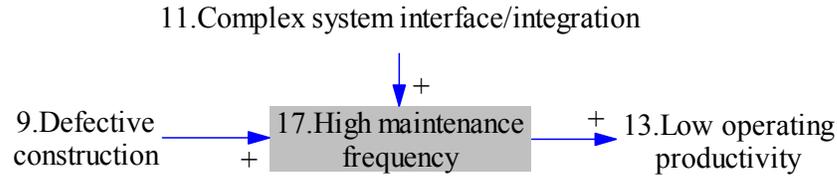
As described in the Section VI9, VII1 and VII3, we conclude that the ‘defective construction’ and ‘complex system interface/integration’ would cause ‘system breakdown’ that would further lead to ‘low operating productivity’ that performance capability is lower than the contract requirements. Thus, the 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’**

**VII7. ‘High Maintenance Frequency’ on THSR**

As described in the Section VI9, VII1 and VII3, 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.



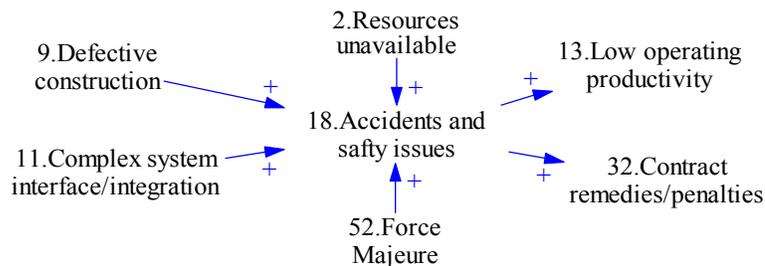
**Figure VI17 The Modified Direct Cause and Consequence for ‘High Maintenance Frequency’**

**VII8. ‘Accidents and Safety Issues’ on THSR**

As described in the Section VI2, VI9, VII1 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’**

**VII9. ‘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**.”

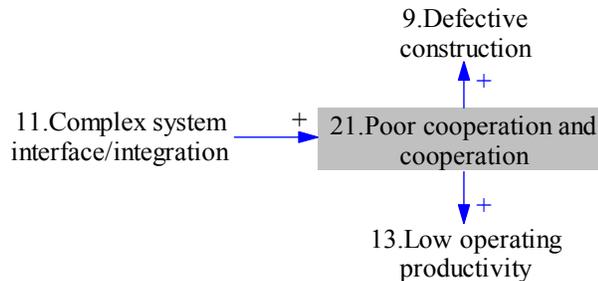
According to the above statements, the direct cause and direct consequence of ‘complex technologies’ are ‘political interference’ and ‘complex system interface/integration’ respectively. Thus the CLD for ‘complex technologies’ illustrated in Figure V20 can basically fit the THSR project well.

**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**

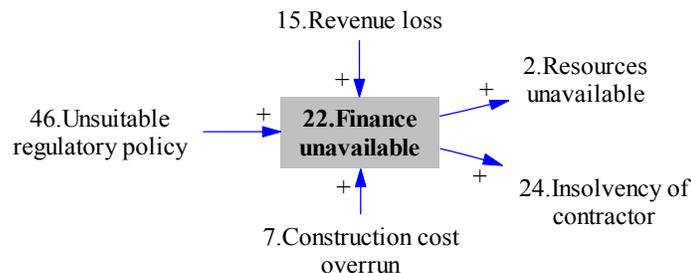
As discussed in the Section V22 and the CLD shown in Figure V22 , the ‘finance unavailable’ would cause that project are not available on the money amounts and on the conditions anticipated to perform project, which would be possibly caused by ‘unsuitable regulatory policy’ ‘political interference’ ‘construction 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

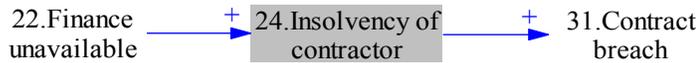
As discussed in Section V23 and Figure V23, the 'finance unavailable' would be likely to cause 'refinancing liabilities' that the materially reduces the private sector's finance costs but increase the public sector's liabilities. As for THSR project, Mr A1, the 1st Division of BHSR, Ministry of Transportation 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.



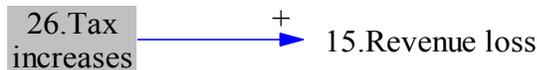
**Figure VI25 The Modified Direct Cause and Consequence for ‘Ownership Change Delay’**

**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’. 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.

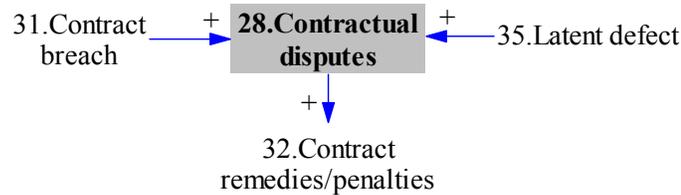
**VI28. ‘Contractual Disputes’ on THSR**

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:

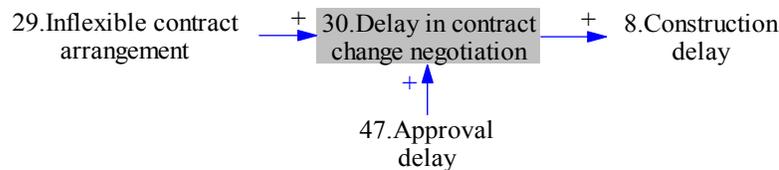
“THSR contract is one of the most important infrastructure projects in the recent 10 years, which will have huge positive economic effects to reduce the metropolitan development difference between the south Taiwan and south Taiwan. Even though the concessionaire has the ownership of THSR during concession period, for public interests, *the government’s 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’**

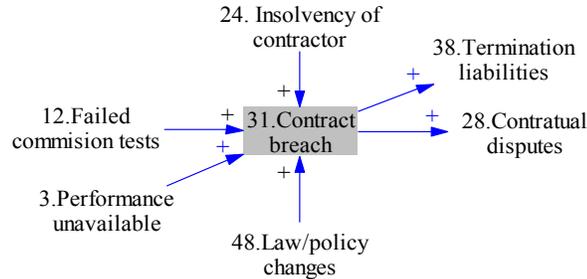
**VI31. ‘Contract Breach’ on THSR**

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.”

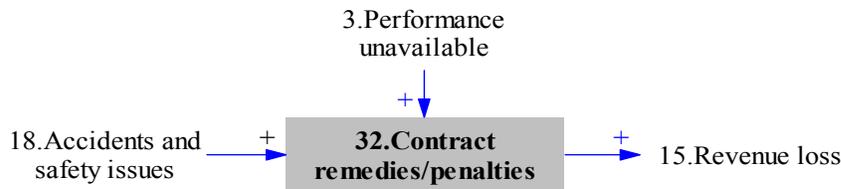
From the above statements, we can conclude that the ‘contract breach’ would be caused by ‘performance unavailable’ ‘failed commission tests’ ‘insolvency of contractor’ and ‘law/policy changes’, and would be likely to lead to ‘contractual disputes’ and ‘termination liabilities.’ Thus, the direct causes and consequences of ‘contract breach’ illustrated in Figure V31 are modified as Figure VI31 to fit the TSHR project.



**Figure VI31 The Modified Direct Cause and Consequence for ‘Contract Breach’**

**VI32. ‘Contract Remedies/Penalties’ on TSHR**

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 TSHR project.



**Figure VI32 The Modified Direct Cause and Consequence for ‘Contract Remedies/Penalties’**

**VI33. ‘Default of Subcontractors’ on TSHR**

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 TSHR project, the interview statement was below:

“The subcontractors are the core of PPP project supply chain, which take responsible to design, build, and operate TSHR project. There have ever been some defective design and facilities happened in TSHR 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 TSHR 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 this 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.”

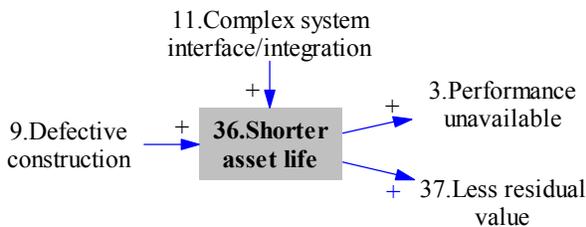
From the above interview statements, the direct causes and consequence of ‘latent defects’ illustrated in Figure V35 can basically fit the THSR project well.

**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.”

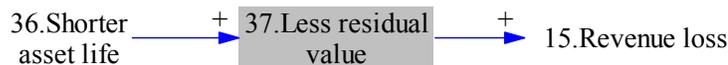
Thus, the direct cause and consequence of ‘shorter asset life’ illustrated in Figure V36 is modified as Figure VI36 to fit the THSR project.



**Figure VI36 The Modified Direct Cause and Consequence for ‘Shorter Asset Life’ Risk Event**

**VI37. ‘Less Residual Values’ on THSR**

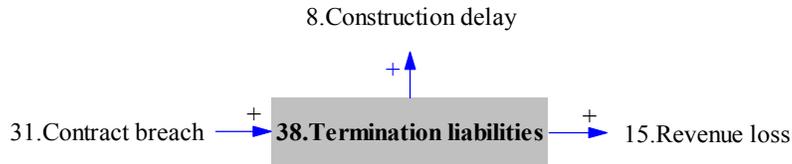
As discussed in Section VI26 and VI36, the ‘less residual value’ would be caused by ‘shorter asset life’; it would lead to ‘revenue losses.’ Thus, the direct cause and consequence of ‘shorter asset life’ illustrated in Figure V37 is modified as Figure VI37 to fit the THSR project.



**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’**

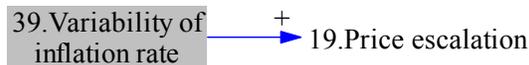
**VI39. ‘Variability of Inflation Rate’ on THSR**

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.



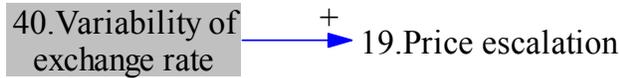
**Figure VI39 The Modified Direct Cause and Consequence for ‘Variability of Inflation Rate’**

**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 V140 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’**

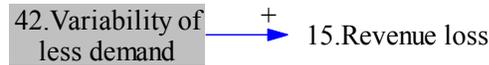
**VI42. ‘Variability of Less Demand’ on THSR**

As discussed in the Section V42 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<sub>2</sub> 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.



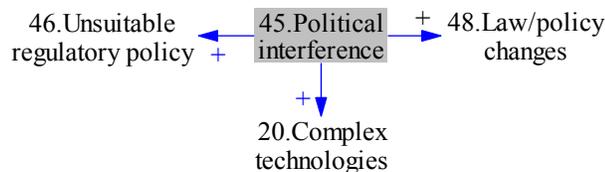
**Figure VI44 The Modified Direct Cause and Consequence for ‘Downside Economic Events’**

**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.



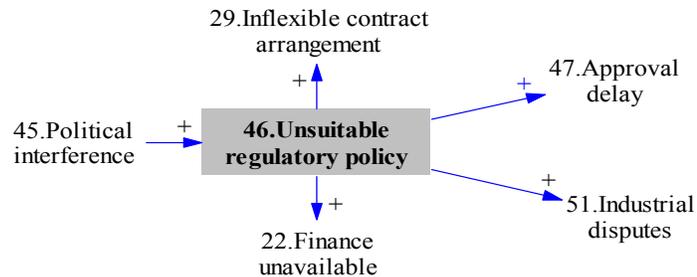
**Figure VI45 The Modified Direct Cause and Consequence for ‘Political Interference’ Risk Event**

**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.

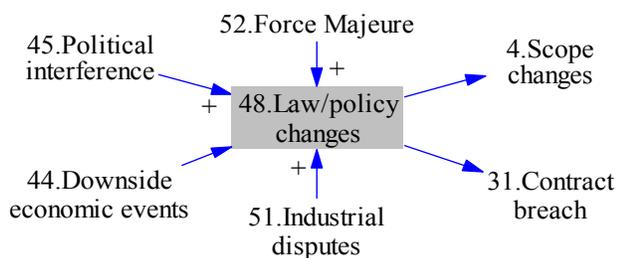


**Figure VI47 The Modified Direct Cause and Consequence for ‘Approval Delay’**

**VI48. ‘Law/Policy Changes’ on THSR**

As described in the Section V12, V14, V131, V144, V145, V151, and V152, 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.”

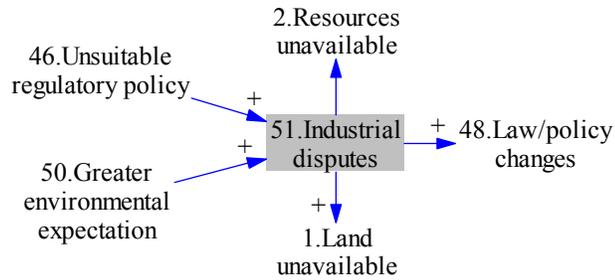
From the above statements, we can conclude that ‘greater environmental expectation’ would lead to ‘industrial disputes’ for THSR project. Thus, the direct cause and consequence of ‘greater environmental expectation’ illustrated in Figure V50 are modified as Figure VI50 to fit the THSR project.



**Figure VI50 The Modified Direct Cause and Consequence for ‘Greater Environmental Expectation’**

**VI51. ‘Industrial Disputes’ on THSR**

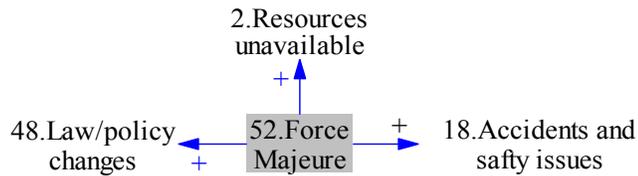
As described in the Section VII, VI2, VI4, VI46, VI48, and VI50, we conclude that the ‘unsuitable regulatory policy’ and ‘higher environmental protection expectation’ would cause ‘industrial disputes’ that would further lead to ‘land unavailable (for example, the negotiation argument on land acquisition 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

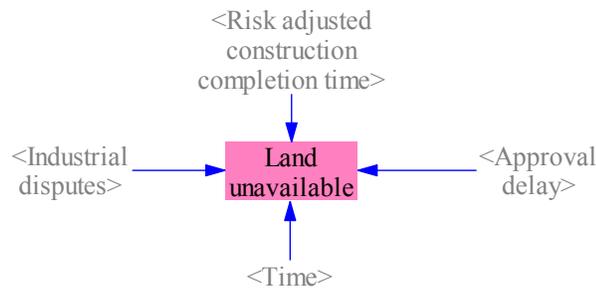
### VIII. RCN for 'Land Unavailable' on THSR

Based on the scenario statements described in Section VII and the Figure VII, 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 VIII:

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

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';  
 $\beta_{0k}$ : the constant term for the multiple regression model;  
 $\beta_{1k}, \beta_{2k}$ : the relational coefficients for the independent risk variables;  
 $\epsilon_k$ : the random error for the multiple regression model;



**Figure VIII The SD Model for 'Land Unavailable' Risk Effect**

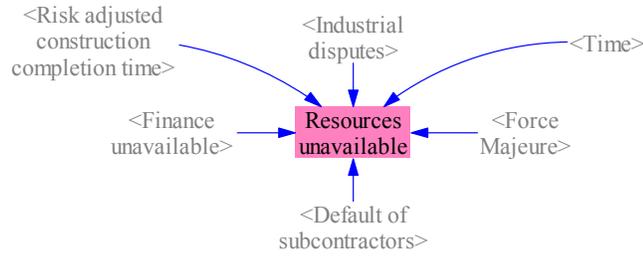
### VII2. RCN for 'Resource Unavailable' on THSR

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.

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

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';  
 $\beta_{0k}$ : the constant term for the multiple regression model;  
 $\beta_{1k}, \beta_{2k}, \beta_{3k}, \beta_{4k}$ : the relational coefficients for the independent risk variables;  
 $\epsilon_k$ : the random error for the multiple regression model;



**Figure VII2 The SD Model for 'Resources Unavailable' Risk Effect**

### 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';
- $\beta_{0k}$ : the constant term for the multiple regression model;
- $\beta_{1k}$ : the relational coefficients for the independent risk variables;
- $\varepsilon_k$ : 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, this 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;

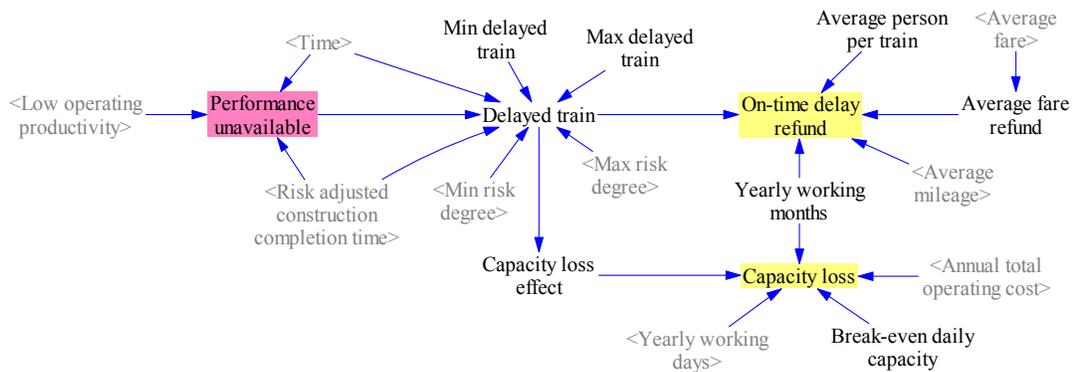
*DeT*: the number of trains that would likely delay on-time service;  
*AAF*: the annual average fare, as shown in Section 6.1.3;  
*Apt*: the average person per train = 350 person/train;  
*AM*: average mileage = 160 km;

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

$$\begin{aligned}
 CLE &= \text{Int}(DeT * 0.2) \\
 CL &= CLE * 12 / (BEDC * 2 * 365) * TOC
 \end{aligned}$$

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**

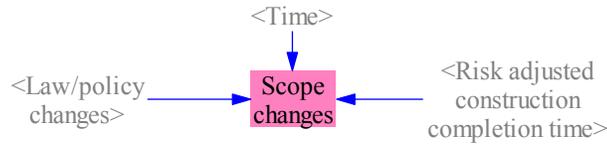
#### VII4. RCN for ‘Scope Changes’ on THSR

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:

$$RD_k(sc) = \beta_{0k} + \beta_{1k} * RD_k(lpc) + \varepsilon_k, \quad k = c, o$$

Where

*RD<sub>k</sub>*: 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’;  
 $\beta_{0k}$ : the constant term for the multiple regression model;  
 $\beta_{1k}$ : the relational coefficients for the independent risk variables;  
 $\varepsilon_k$ : the random error for the multiple regression model;



**Figure VII4 The SD Model for 'Scope Changes' Risk Effect**

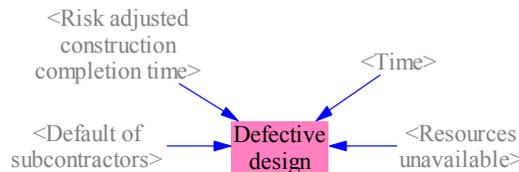
**VII5. RCN for 'Defective Design' on THSR**

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';
- $\beta_{0k}$ : the constant term for the multiple regression model;
- $\beta_{1k}, \beta_{2k}$ : the relational coefficients for the independent risk variables;
- $\varepsilon_k$ : the random error for the multiple regression model;



**Figure VII5 The SD Model for 'Defective Design' Risk Effect**

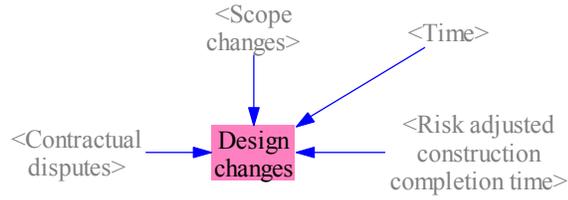
**VII6. RCN for 'Design Changes' on THSR**

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';
- $\beta_{0k}$ : the constant term for the multiple regression model;
- $\beta_{1k}, \beta_{2k}$ : the relational coefficients for the independent risk variables;
- $\varepsilon_k$ : 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:

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

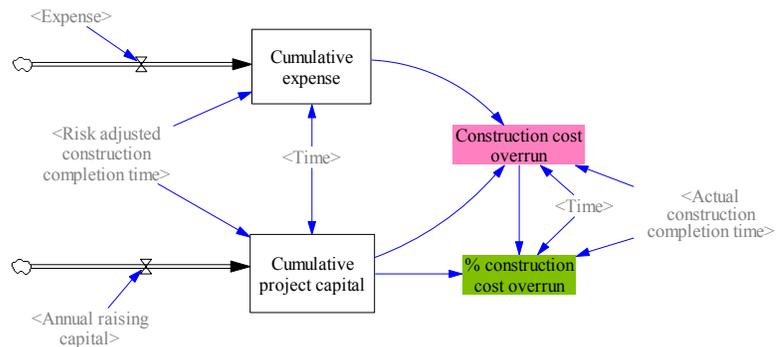
$$CE = \int_{RCST}^{RCCT} E$$

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

$$CCO = CE - CPC$$

where

- E*: annual expense;
- C<sub>radj</sub>*: risk adjusted annual construction cost;
- C<sub>ins</sub>*: annual insurance cost;
- C<sub>int</sub>*: 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:

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

where

- TD<sub>ij</sub>*: time delay effect for the risk event on a work package (in percentage);
- RD<sub>i</sub>*: random variable for the expected risk effect;
- TCMAX<sub>ij</sub>*: maximum time delay effect for a risk event on a work package (in percentage);
- TCMIN<sub>ij</sub>*: minimum time delay effect for a risk event on a work package (in percentage);
- RD<sub>max</sub>*: 25;
- RD<sub>min</sub>*: 1;
- i*: risk event index;
- j*: work package index

The variable increased completion time for work package was:

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

where

- ΔTD<sub>ik</sub>*: increased completion time for a work package caused by a risk event;
- TD<sub>ik</sub>*: time delay effect for a risk event in a work package (in percentage);
- SCT<sub>k</sub>*: scheduled completion time for a work package;
- SST<sub>k</sub>*: 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<sub>j</sub>*: the risk-adjusted construction completion time for a work package;
- SCT<sub>j</sub>*: 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<sub>j</sub>)*: the maximum value of the elements of an array *x<sub>j</sub>*;
- RCCT<sub>j</sub>*: the risk-adjusted construction completion time for a work package;
- SCT<sub>j</sub>*: 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:

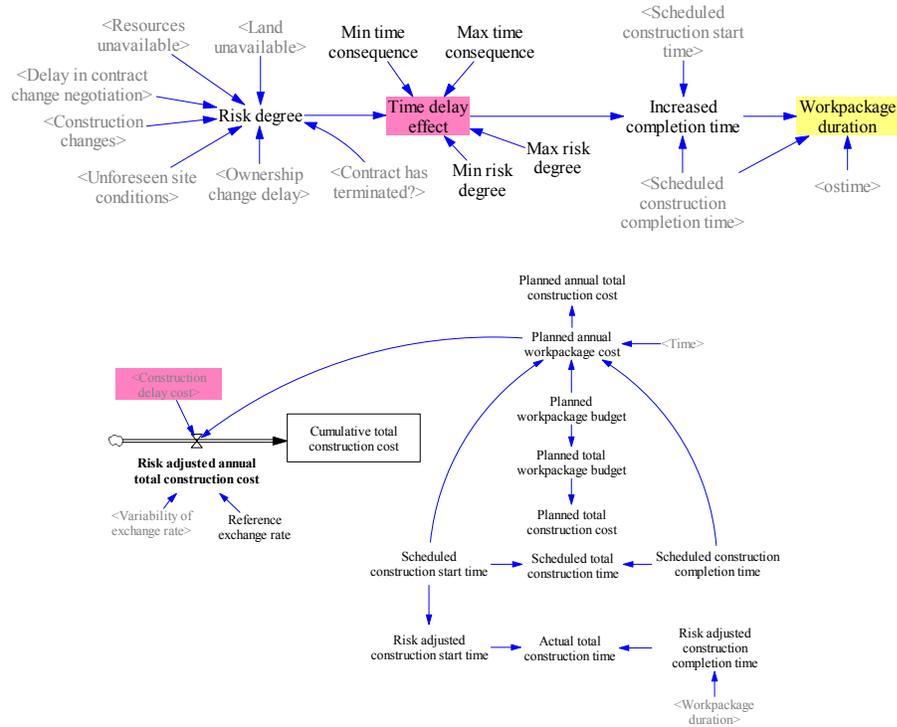
$$CDC = CD * ACDC$$

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’
- $\beta_{0k}$ : the constant term for the multiple regression model;
- $\beta_{1k}, \beta_{2k}, \beta_{3k}, \beta_{4k}$ : the relational coefficients for the independent risk variables;
- $\varepsilon_k$ : the random error for the multiple regression model;



**Figure VII9 The SD Model for 'Defective Construction' Risk Effect**

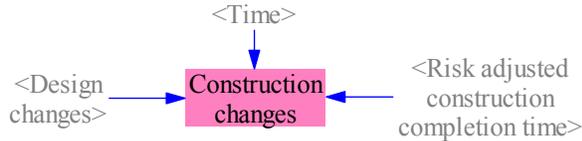
**VIII0. RCN for 'Construction Changes' on THSR**

Based on the scenario statements described in Section VII0 and the Figure VII0, 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 VII0 was:

$$RD_k(cc) = \beta_{0k} + \beta_{1k} * RD_k(dch) + \epsilon_k, k = c, o$$

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';
- $\beta_{0k}$ : the constant term for the multiple regression model;
- $\beta_{1k}$ : the relational coefficients for the independent risk variables;
- $\epsilon_k$ : the random error for the multiple regression model;



**Figure VII10 The SD Model for 'Construction Changes' Risk Effect**

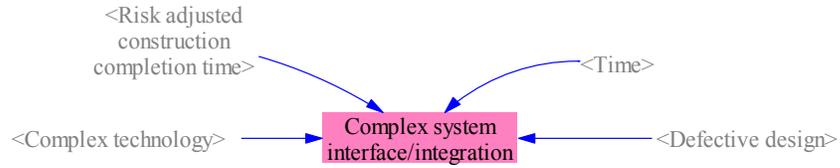
**VIII1. RCN for 'Complex System Interface/Integration' on THSR**

Based on the scenario statements described in Section VII1 and the Figure VII1, 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 relationship in the SD model illustrated in Figure VII11 was:

$$RD_k(csi) = \beta_{0k} + \beta_{1k} * RD_k(ct) + \beta_{2k} * RD_k(dd) + \epsilon_k, k = c, o$$

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';
- $\beta_{0k}$ : the constant term for the multiple regression model;
- $\beta_{1k}, \beta_{2k}$ : the relational coefficients for the independent risk variables;
- $\epsilon_k$ : the random error for the multiple regression model;



**Figure VII11 The SD Model for 'Complex System Interface/Integration' Risk Effect**

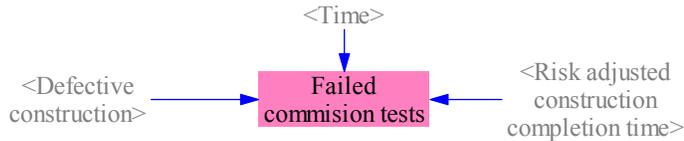
**VIII2. RCN for 'Failed Commissioning Tests' on THSR**

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:

$$RD_k(fct) = \beta_{0k} + \beta_{1k} * RD_k(dc) + \epsilon_k, k = c$$

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';
- $\beta_{0k}$ : the constant term for the multiple regression model;
- $\beta_{1k}$ : the relational coefficients for the independent risk variables;
- $\epsilon_k$ : the random error for the multiple regression model;



**Figure VII12 The SD Model for 'Failed Commissioning Tests' Risk Effect**

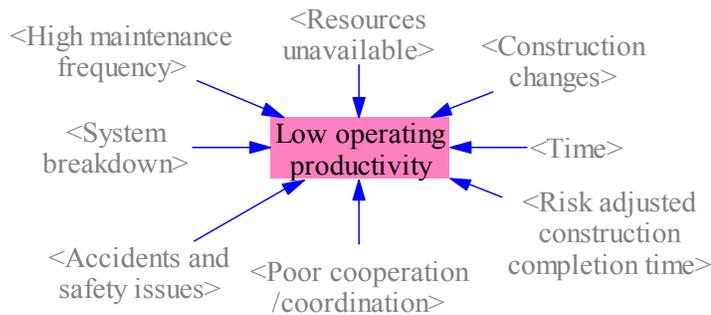
**VIII3. RCN for 'Low Operating Productivity' on THSR**

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:

$$RD_k(lop) = \beta_{0k} + \beta_{1k} * RD_k(ru) + \beta_{2k} * RD_k(cc) + \beta_{3k} * RD_k(hmf) + \beta_{4k} * RD_k(sb) + \beta_{5k} * RD_k(asi) + \beta_{6k} * RD_k(pcc) + \epsilon_k, k = o$$

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';
- $\beta_{0k}$ : 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;
- $\epsilon_k$ : the random error for the multiple regression model;



**Figure VII13 The SD Model for ‘Low Operating Productivity’ Risk Effect**

**VIII4. 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:

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

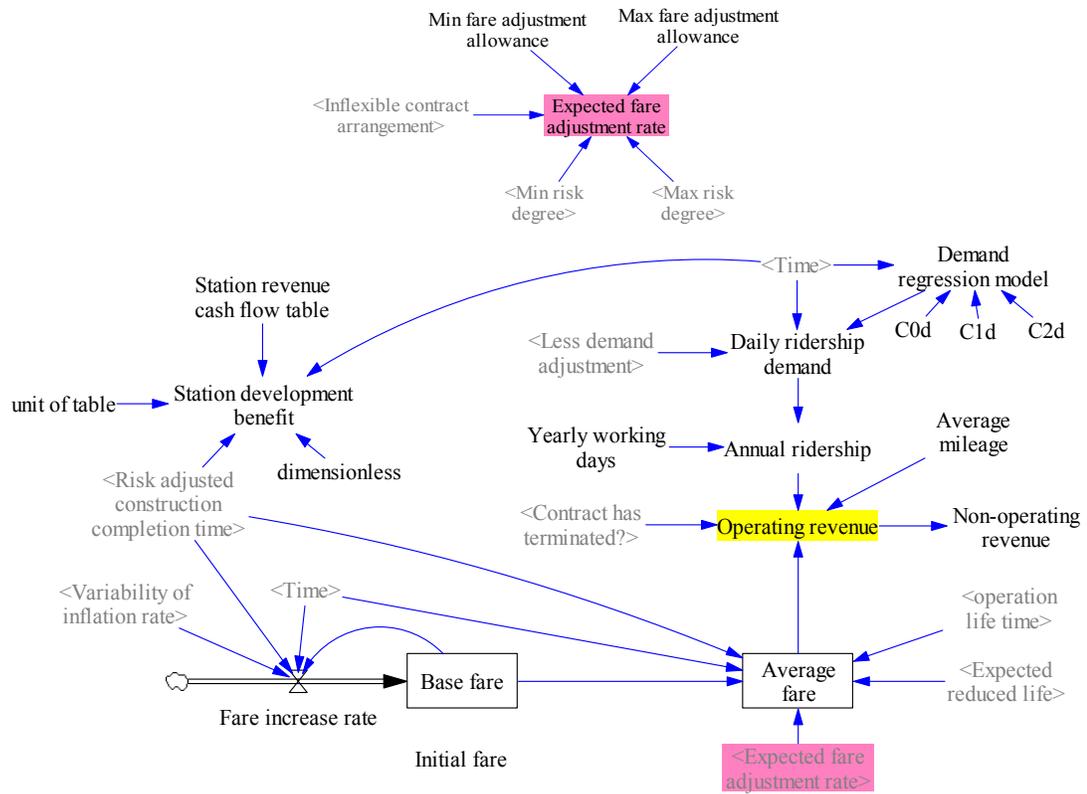
where

- EFA*: the ‘expected fare adjustment rate’
- FA<sub>max</sub>*: maximum fare adjustment allowance = 0.2;
- FA<sub>min</sub>*: minimum fare adjustment allowance = 0;
- RD*: random variable for the expected effect;
- Ica*: risk event ‘inflexible contract arrangement’;
- RD<sub>max</sub>*: 25;
- RD<sub>min</sub>*: 1

**VIII5. 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**

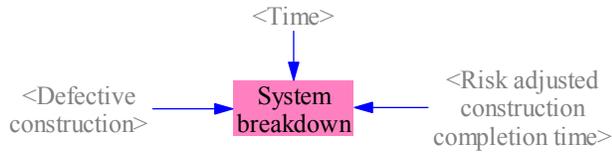
**VIII.6. RCN for 'System Breakdown' on THSR**

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:

$$RD_k(sb) = \beta_{0k} + \beta_{1k} * RD_k(dc) + \beta_{2k} * RD_k(csi) + \epsilon_k, k = o$$

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';
- $\beta_{0k}$ : the constant term for the multiple regression model;
- $\beta_{1k}, \beta_{2k}$ : the relational coefficients for the independent risk variables;
- $\epsilon_k$ : the random error for the multiple regression model;



**Figure VII16 The SD Model for 'System Breakdown' Risk Effect**

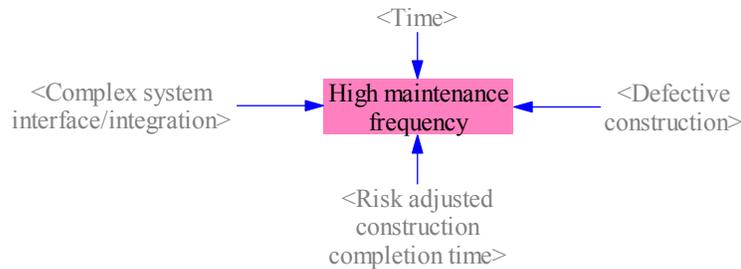
**VIII7. RCN for 'High Maintenance Frequency' on THSR**

Based on the scenario statements described in Section VII7 and the Figure VII7, 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:

$$RD_k(hmf) = \beta_{0k} + \beta_{1k} * RD_k(dc) + \beta_{2k} * RD_k(csi) + \varepsilon_k, k = 0$$

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';
- $\beta_{0k}$ : the constant term for the multiple regression model;
- $\beta_{1k}, \beta_{2k}$ : the relational coefficients for the independent risk variables;
- $\varepsilon_k$ : the random error for the multiple regression model;



**Figure VII17 The SD Model for 'High Maintenance Frequency' Risk Effect**

**VIII8. RCN for 'Accidents and Safety Issues' on THSR**

Based statements in Section VII8 and the Figure VII8, 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:

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

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';

$f_m$ : risk event 'Force Majeure'  
 $\beta_{0k}$ : the constant term for the multiple regression model;  
 $\beta_{1k}, \beta_{2k}, \beta_{3k}, \beta_{4k}$ : the relational coefficients for the independent risk variables;  
 $\epsilon_k$ : the random error for the multiple regression model;

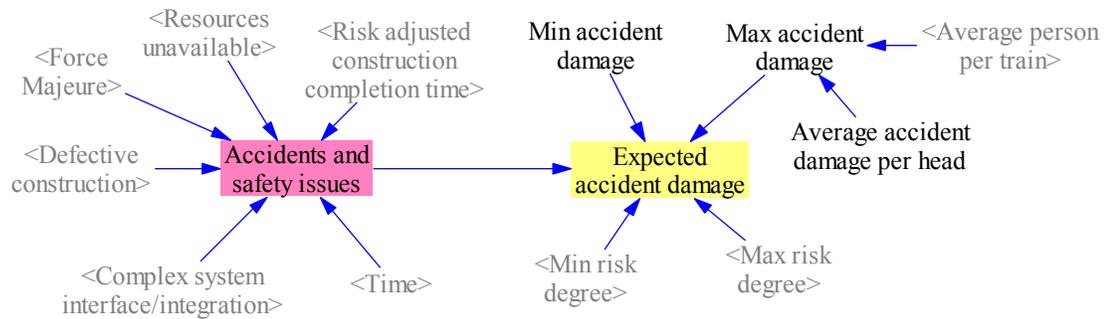
As for the direct consequence of contract remedies/penalties, according to the interview statements, the maximum accident and safety loss for death penalty and system damage due to human factor and national disaster is NT\$0.174 billion. This researcher assumes the expected accident and safety loss is 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**

### VIII19. 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 VIII19 (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

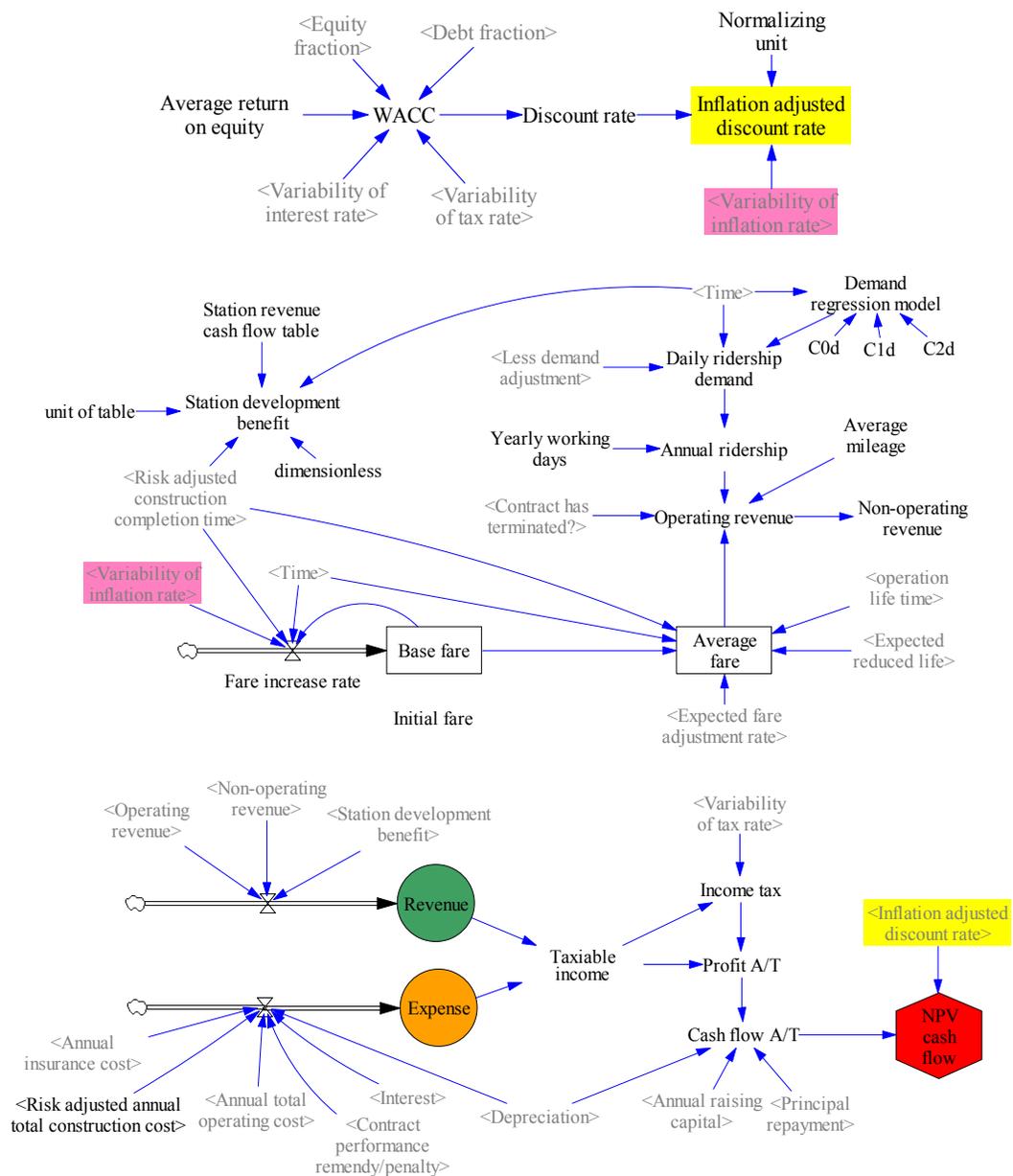
$AFIR'$  = risk adjusted annual fare increase rate;  
 $F_b$ : base fare;  
 $r_{inf}$ : variability of inflation rate

Furthermore, based on the scenario statements described in Section VII19, 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:

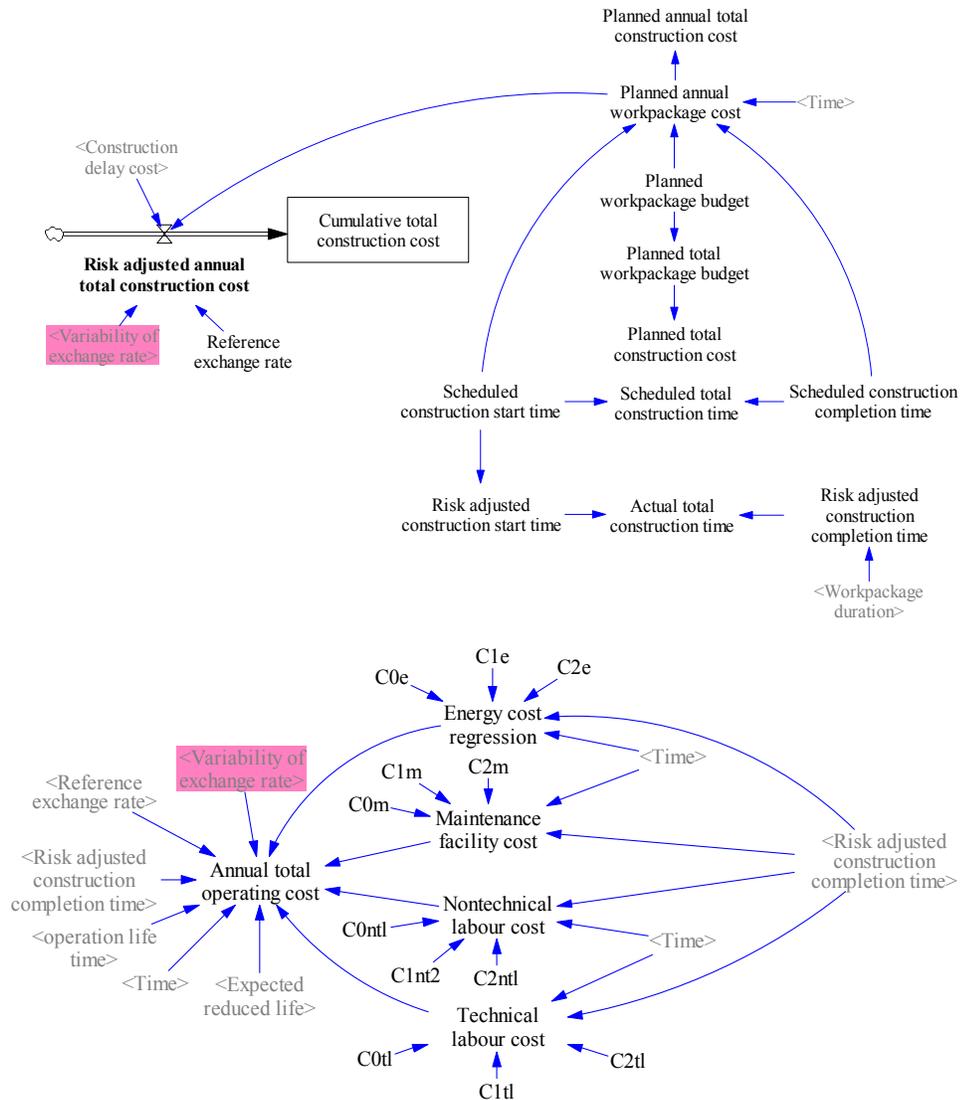
$$CC_{adj} = (PATCC + CDC) * r'_{ex} / r_{rex}$$

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



**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**



**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**

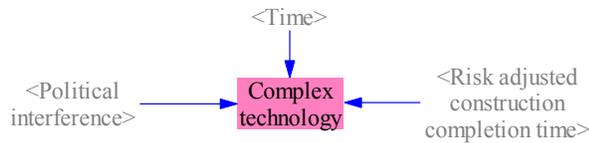
Based on the scenario statements described in the Section VI20 and Figure VI20, the direct cause for ‘complex technologies’ is ‘political interference’ and the direct consequence is ‘complex system interface/integration’. Therefore, the linear multiple-regression model used to address the direct cause relationship in the SD model illustrated in Figure VII20 was:

$$RD_k(ct) = \beta_{0k} + \beta_{1k} * RD_k(pi) + \epsilon_k, k = c, o$$

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’;
- $\beta_{0k}$ : the constant term for the multiple regression model;

$\beta_{1k}$ : the relational coefficients for the independent risk variables;  
 $\varepsilon_k$ : the random error for the multiple regression model;



**Figure VII20 The SD Model for 'Complex Technologies' Risk Effect**

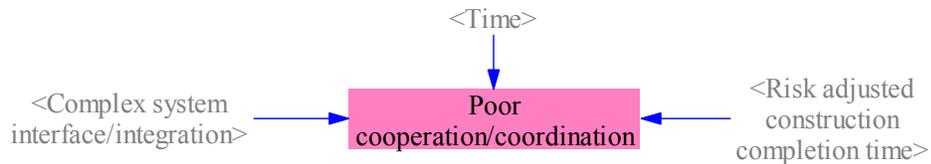
**VII21. RCN for 'Poor Cooperation/Coordination' on THSR**

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';
- $\beta_{0k}$ : the constant term for the multiple regression model;
- $\beta_{1k}$ : the relational coefficients for the independent risk variables;
- $\varepsilon_k$ : 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:

$$RD_k(fu) = \bar{\pi} + \varepsilon_k, k=c;$$

$$= \bar{D}_{sc} + \varepsilon_k, k=o;$$

Where

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

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

$$\pi = (EXP-APC)/APC*100\%$$

$$\bar{\pi} = \int_{t_{sc}}^t \frac{\pi - \bar{\pi}}{t - t_{cs}}$$

where

*EXP*: annual total expense;  
*APC*: annual project raising capital;  
*t*: time at construction stage  
*t<sub>cs</sub>*: construction start time

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

$$RD_k(fu) = 1 + \varepsilon_k, \bar{\pi} \leq -100\%;$$

$$= (\bar{\pi} + 1)(RD_{max} - RD_{min}) + 1 + \varepsilon_k, -100\% < \bar{\pi} < 0\%;$$

$$= 25 + \varepsilon_k, \bar{\pi} \geq 0\%$$

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:

$$D_{sc} = Eb / (I + (Pr / (1 - Tm)))$$

$$\bar{D}_{sc} = \int_{t_{os}}^t \frac{D_{sc} - \bar{D}_{sc}}{t - t_{os}}$$

where

*E<sub>b</sub>*: 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  $\bar{D}_{sc}$  when  $0 < \bar{D}_{sc} < D_{sc}^*$  (desired DSC level) :

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

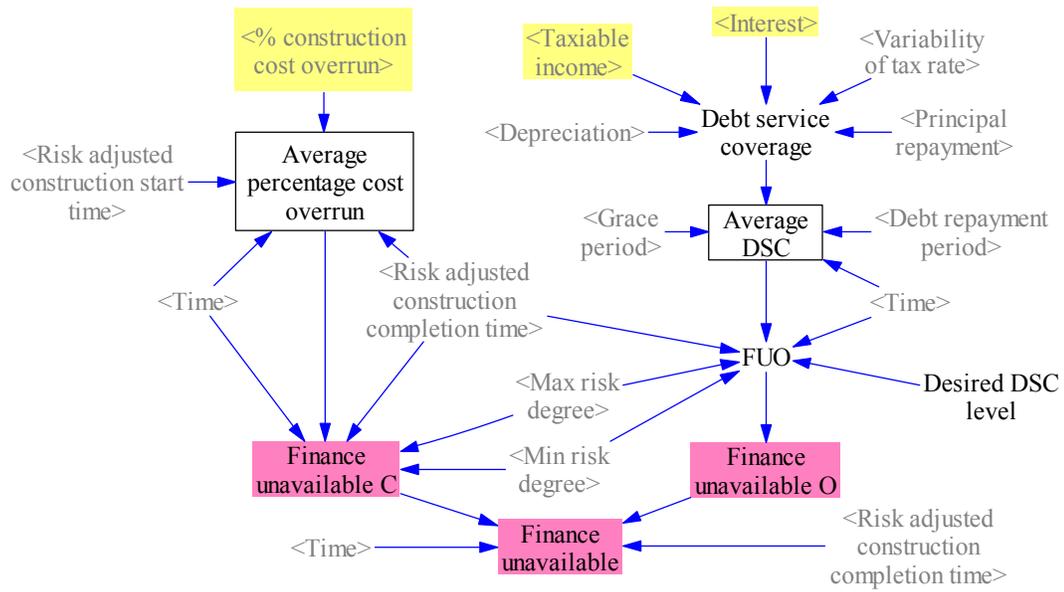
$$= RD_{max} - \bar{D}_{sc} (RD_{max} - RD_{min}) / D_{sc}^* + \varepsilon_k, \bar{D}_{sc} < D_{sc}^*$$

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**

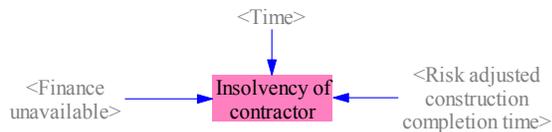
**VII24. RCN for 'Insolvency of Contractor' on THSR**

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:

$$RD_k(ioc) = \beta_{0k} + \beta_{1k} * RD_k(fu) + \epsilon_k, k = c, o$$

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';
- $\beta_{0k}$ : the constant term for the multiple regression model;
- $\beta_{1k}$ : the relational coefficients for the independent risk variables;
- $\epsilon_k$ : the random error for the multiple regression model;



**Figure VII24 The SD Model for 'Insolvency of Contractor' Risk Effect**

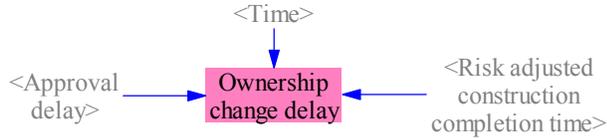
**VII25. RCN for 'Ownership Changes Delay' on THSR**

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';
- $\beta_{0k}$ : the constant term for the multiple regression model;
- $\beta_{1k}$ : the relational coefficients for the independent risk variables;
- $\varepsilon_k$ : the random error for the multiple regression model;



**Figure VII25 The SD Model for 'Ownership Change Delay' Risk Effect**

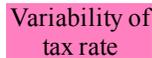
**VII26. RCN for 'Variability of Tax Rate' on THSR**

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:

$$t'_m = \text{RANDOM TRIANGULAR}(a, m, b)$$

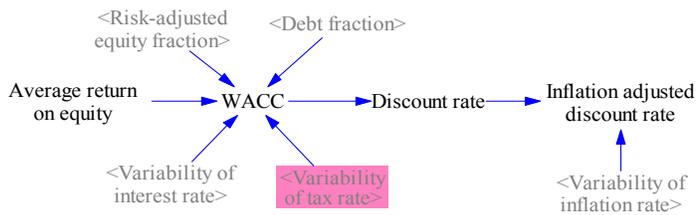
where

- $t'_m$ : 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



**Figure VII26 (a) The SD Model for 'Variability of Tax Rate' Risk Effect**

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**

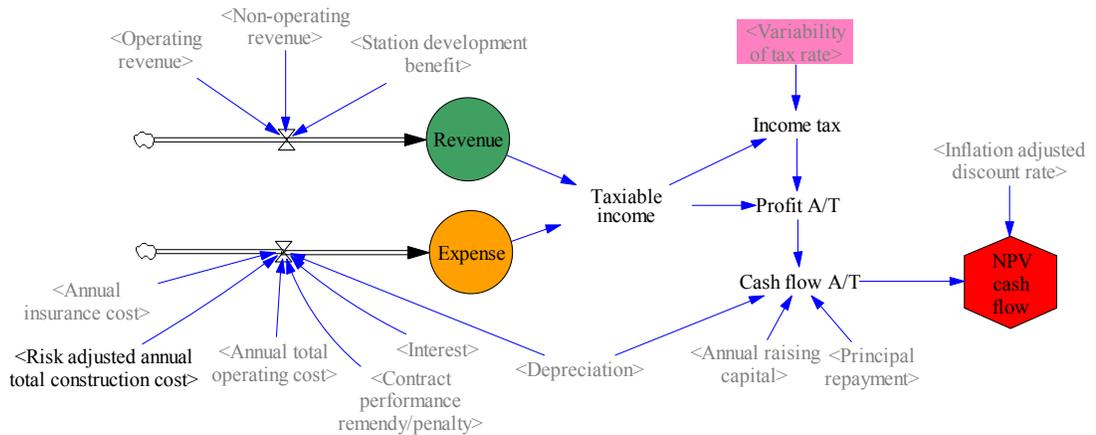
According to the interview statements described in Section VI27, the variable 'annual insurance cost' shown in Figure VII27 was below:

$$AIC = CPB/CP$$

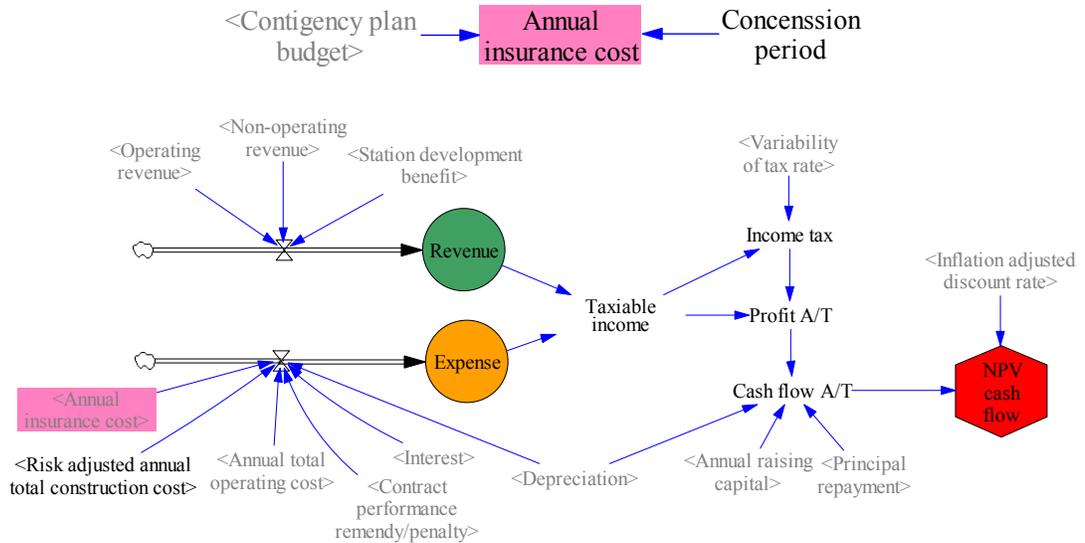
where

*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**

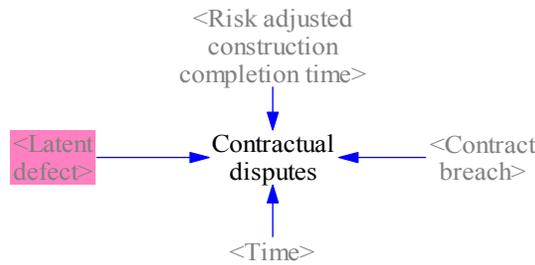
**VII28. RCN for ‘Contractual Disputes’ on THSR**

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’.
- $\beta_{0k}$ : the constant term for the multiple regression model;
- $\beta_{1k}, \beta_{2k}$ : the relational coefficients for the independent risk variables;
- $\varepsilon_k$ : the random error for the multiple regression model;



**Figure VII28 The SD Model for ‘Contractual Disputes’ Risk Effect**

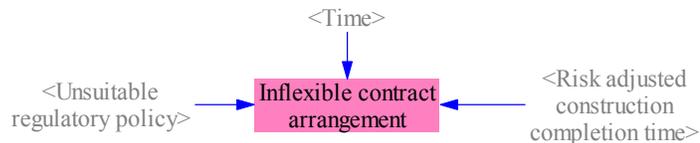
**VII29. RCN for ‘Inflexible Contract Arrangements’ on THSR**

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’;
- $\beta_{0k}$ : the constant term for the multiple regression model;
- $\beta_{1k}$ : the relational coefficients for the independent risk variables;
- $\varepsilon_k$ : 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 relationship 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’;
- $\beta_{0k}$ : the constant term for the multiple regression model;
- $\beta_{1k}, \beta_{2k}$ : the relational coefficients for the independent risk variables;
- $\varepsilon_k$ : 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**

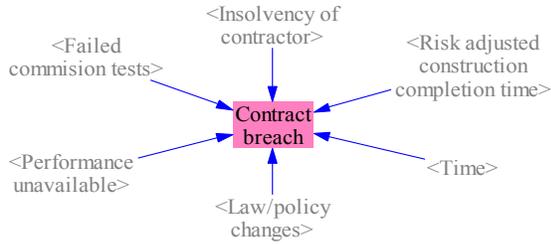
Based on the scenario statements described in Section VI31 and the Figure VI31, the direct causes for ‘contract breach’ are ‘performance unavailable’ ‘failed commission tests’ ‘insolvency of contractor’ and ‘law/policy changes’; the direct consequences are ‘contractual disputes’ and ‘termination liabilities.’ 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’;
- $\beta_{0k}$ : the constant term for the multiple regression model;
- $\beta_{1k}, \beta_{2k}, \beta_{3k}$ : the relational coefficients for the independent risk variables;
- $\varepsilon_k$ : 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

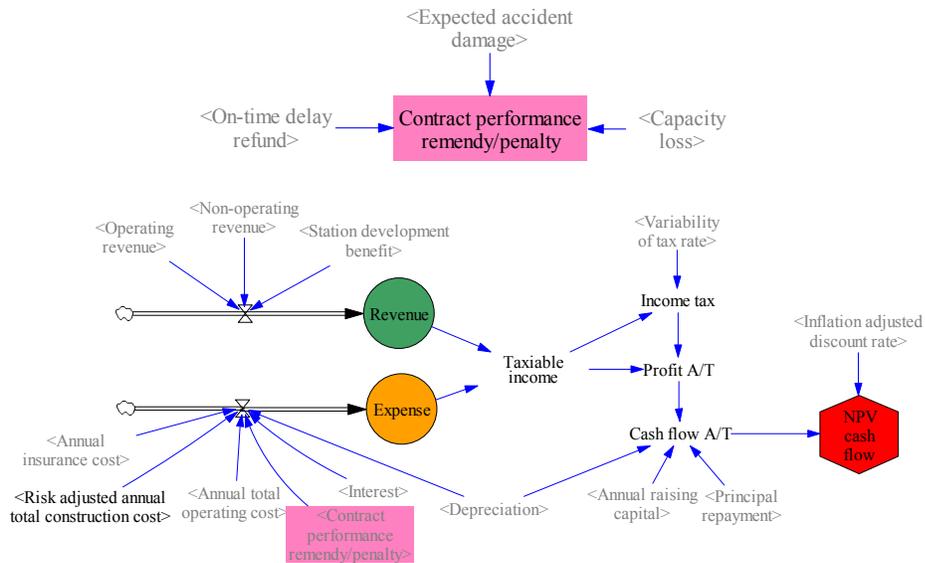
*CPP: contract performance remedy/penalty;*

*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**

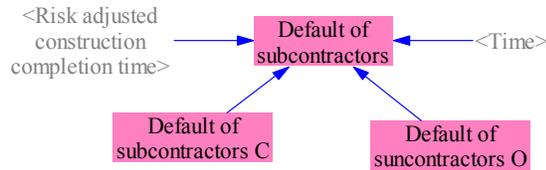
**VII33. RCN for ‘Default of Subcontractors’ on THSR**

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:

Where

$$RD_k(ds), k=c, o$$

$RD_k$ : 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 modeling.

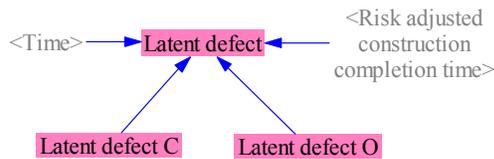
**VII35. RCN for ‘Latent Defect’ on THSR**

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:

where

$$RD_k(ld), k=c, o$$

$RD_k$ : 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**

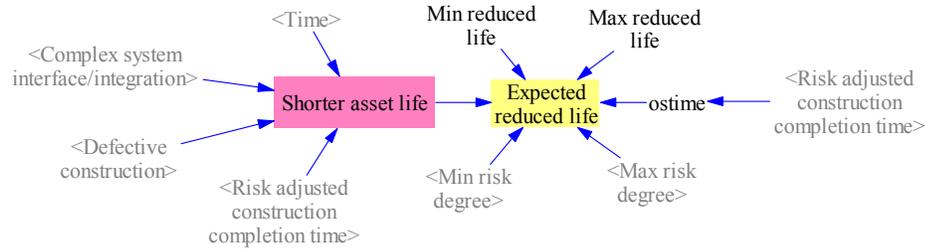
**VII36. RCN for ‘Shorter Asset Life’ on THSR**

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:

$$RD_k(sal) = \beta_{0k} + \beta_{1k} * RD_k(dc) + \beta_{2k} * RD_k(cii) + \varepsilon_k, k=0$$

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';
- $\beta_{0k}$ : the constant term of for the multiple regression model;
- $\beta_{1k}, \beta_{2k}$ : the relational coefficients for the independent risk variables;
- $\varepsilon_k$ : 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  $\alpha$  would be changed to  $\alpha'$ :

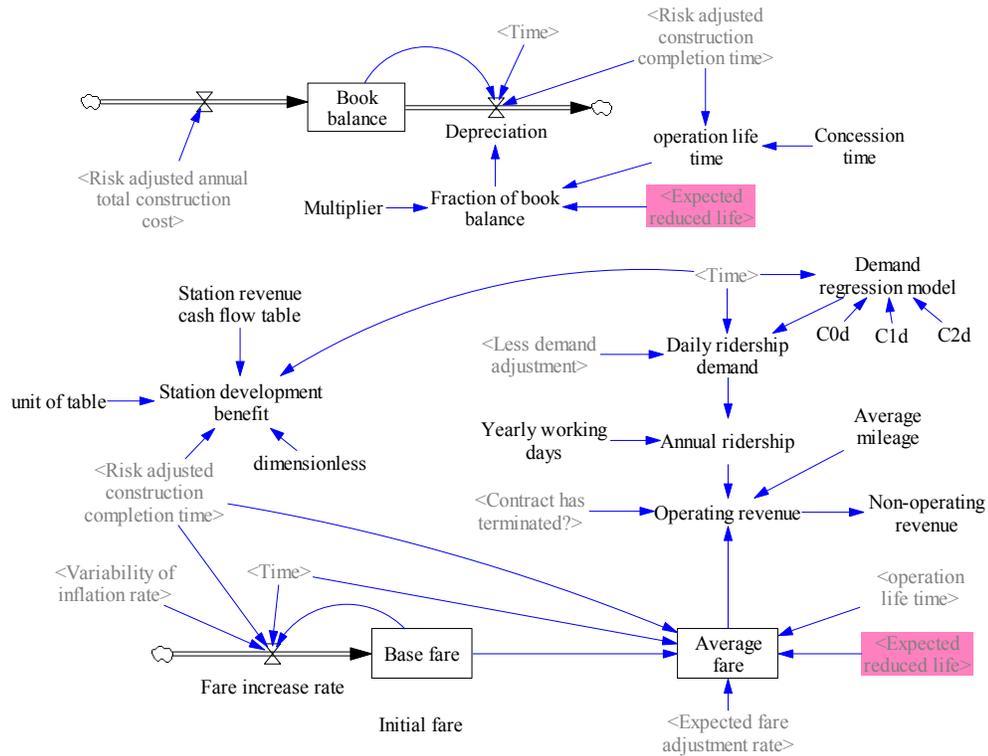
$$\alpha' = \lambda(100\% / (L - ERL))$$

$$D'_n = \alpha BB_{n-1} = \alpha C_{asset} (1 - \alpha)^{n-1}$$

$$BB'_n = C_{asset} (1 - \alpha)^n, n=1, \dots, L-ERL$$

Where

- $\alpha'$ : the new fraction of the book balance;
- $\lambda$ : 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:

$$AAF = 0, RACCT < t < RACCT + L - ERL$$

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

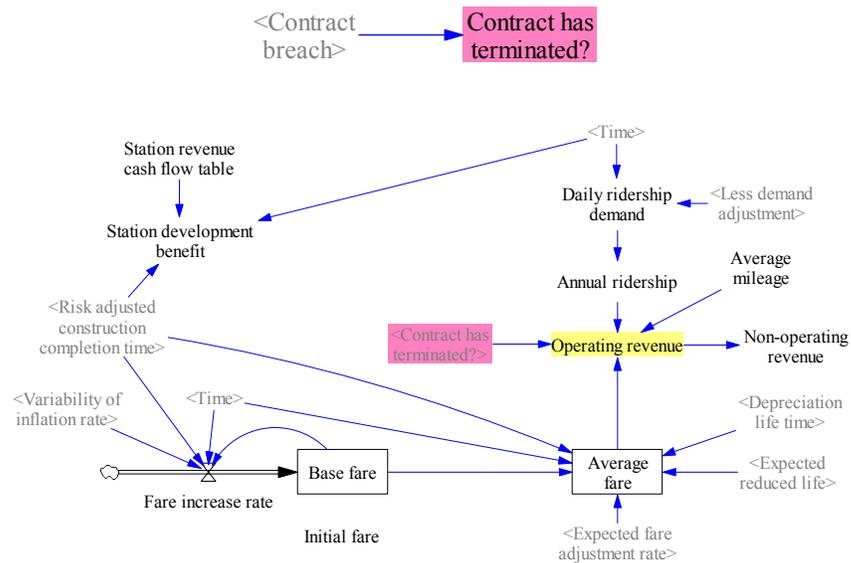
*Cht*: risk variable 'contract has terminated?';  
*RD*: random variable for the expected risk effect;  
*cb*: risk event 'contract breach'

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<sub>inf</sub>*: 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

## Variability of inflation rate

### 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:

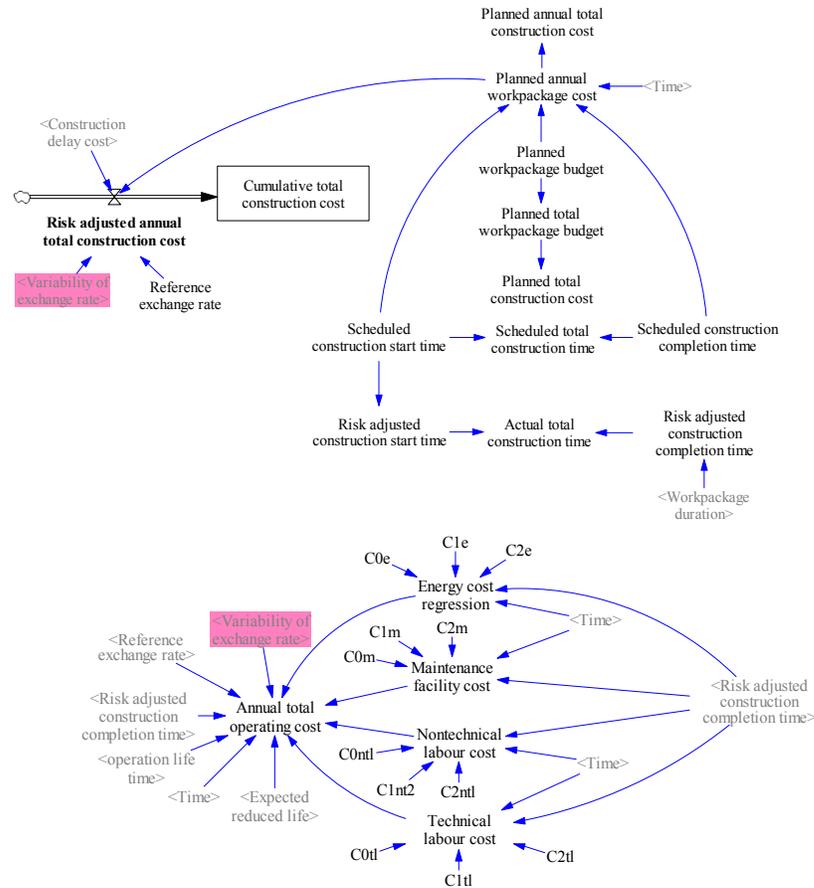
## Variability of exchange rate

$$r_{ex} = \text{RANDOM NORMAL}(\mu, \sigma)$$

where

$r_{ex}$ : random variable for 'variability of exchange rate';  
 $\mu$ : mean=30.73;  
 $\sigma$ : 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**

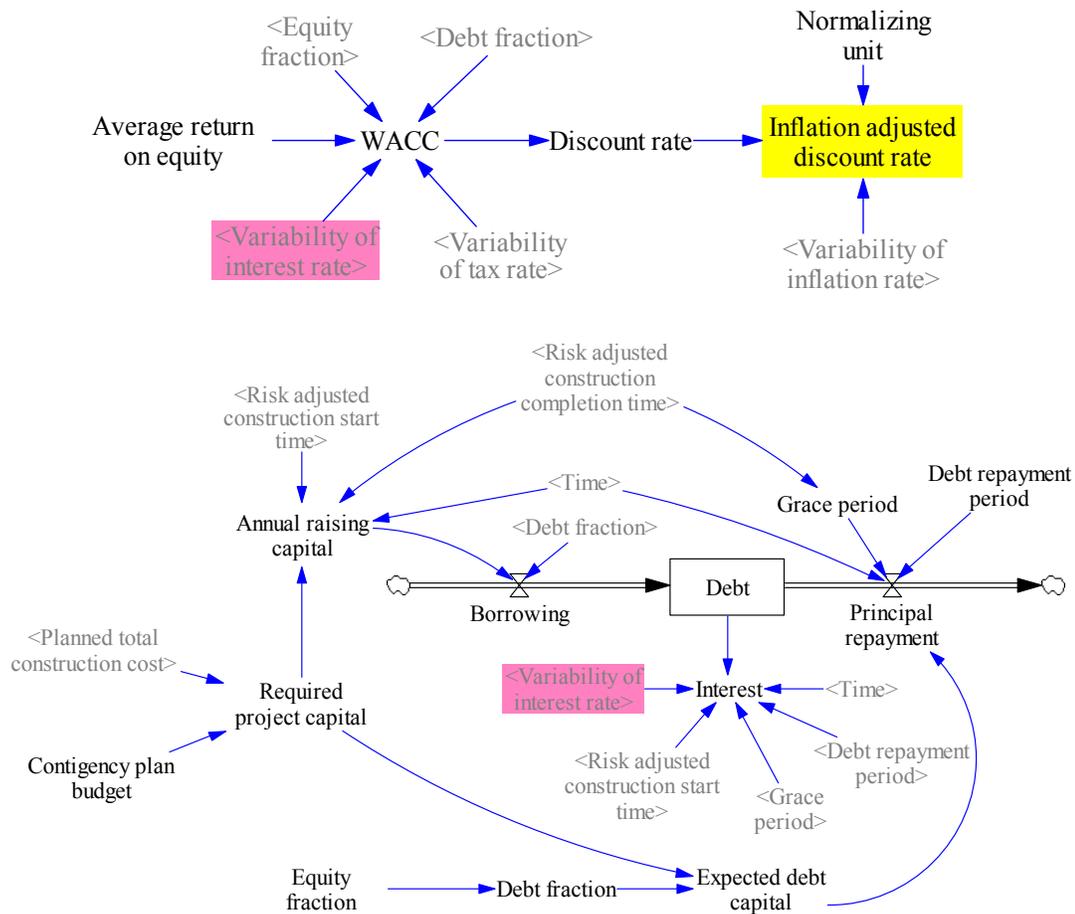
Based on the scenario statements described in Section VI41 and the Figure VI41, the 'variability of interest rate' shown in Figure VII41 is an independent risk variable that has no the direct causes, but has direct effects on construction expense and operation expense. According to Central Bank (2005)'s 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:

$$r_{int} = \text{RANDOM TRIANGULAR}(a, m, b)$$

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, this 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, this 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 Sofrerrail (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 Flyvbjerg 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 from 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:

$$LDA = VarLd + OptBias;$$

$$VarLd = \text{RANDOM NORMAL}(a_1, b_1, \mu_1, \sigma_1);$$

$$OptBias = \text{RANDOM NORMAL}(a_2, b_2, \mu_2, \sigma_2)$$

Where

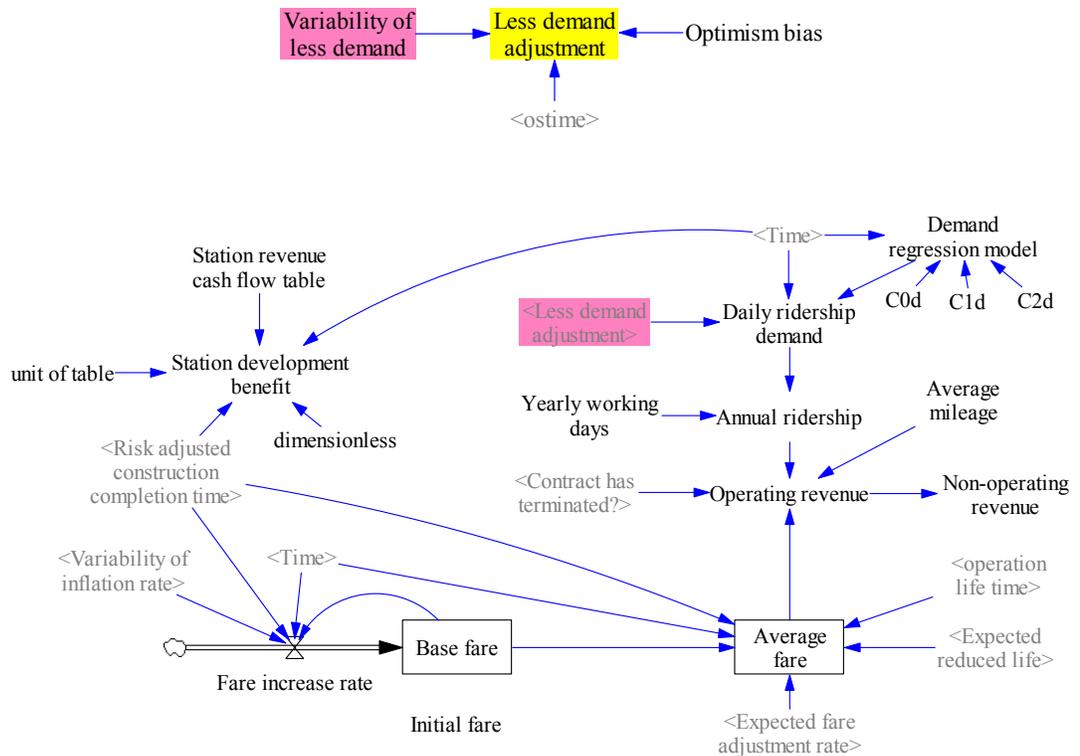
- LDA: random variable for 'less demand adjustment';
- VarLd: random variable for 'variability of less demand';
- OptBias: random variable for 'optimism bias';
- $a_1$ : minimum value of 'variability of less demand' = -0.13;
- $b_1$ : maximum value of 'variability of less demand' = 0.71;
- $\mu_1$ : mean value of 'variability of less demand' = 0.166;
- $\sigma_1$ : 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;
- $\mu_2$ : mean value of 'optimism bias' = -0.39;
- $\sigma_2$ : 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.

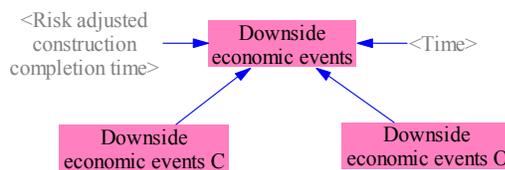
**VII44. RCN for ‘Downside Economic Events’ on THSR**

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**

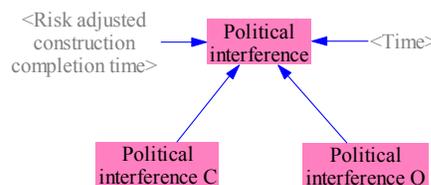
**VII45. RCN for ‘Political Interference’ on THSR**

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**

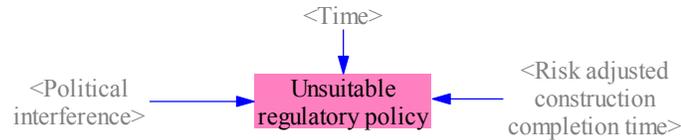
**VII46. RCN for ‘Unsuitable Regulatory Policy’ on THSR**

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';  
 $\beta_{0k}$ : the constant term for the multiple regression model;  
 $\beta_{1k}$ : the relational coefficients for the independent risk variables;  
 $\varepsilon_k$ : the random error for the multiple regression model;



**Figure VII46 The SD Model for 'Unsuitable Regulatory policy' Risk Effect**

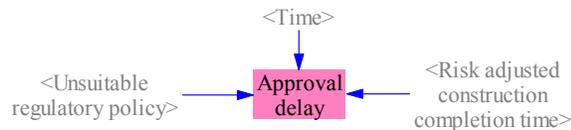
**VII47. RCN for 'Approval Delay' on THSR**

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';  
 $\beta_{0k}$ : the constant term for the multiple regression model;  
 $\beta_{1k}$ : the relational coefficients for the independent risk variables;  
 $\varepsilon_k$ : the random error for the multiple regression model;



**Figure VII47 The SD Model for 'Approval Delay' Risk Effect**

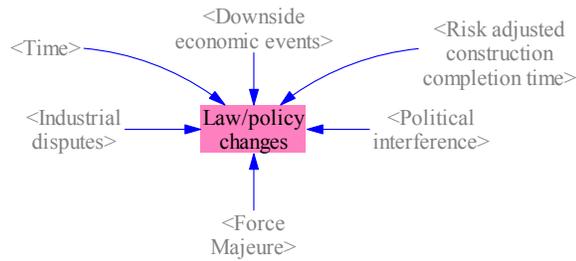
**VII48. RCN for 'Law/Policy' on THSR**

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';
- $\beta_{0k}$ : the constant term for the multiple regression model;
- $\beta_{1k}, \beta_{2k}, \beta_{3k}, \beta_{4k}$ : the relational coefficients for the independent risk variables;
- $\varepsilon_k$ : the random error for the multiple regression model;



**Figure VII48 The SD Model for 'Approval Delay' Risk Effect**

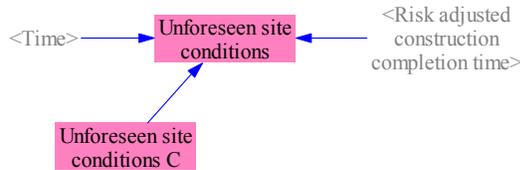
**VII49. RCN for 'Unforeseen Site Conditions' on THSR**

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**

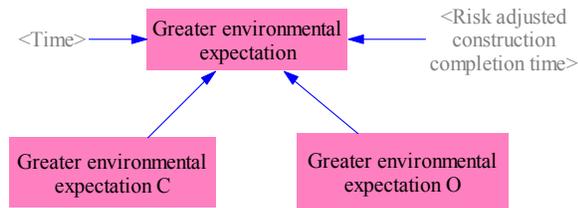
**VII50. RCN for 'Greater Environmental Expectation' on THSR**

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**

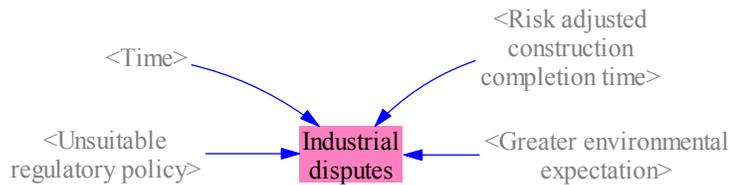
**VII51. RCN for 'Industrial Disputes' on THSR**

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';
- $\beta_{0k}$ : the constant term for the multiple regression model;
- $\beta_{1k}, \beta_{2k}$ : the relational coefficients for the independent risk variables;
- $\epsilon_k$ : the random error for the multiple regression model;



**Figure VII51 The SD Model for 'Industrial Disputes' Risk Effect**

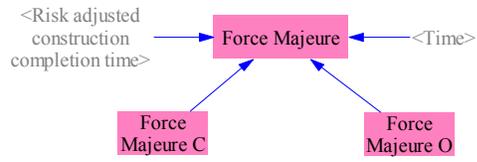
**VII52. RCN for 'Force Majeure' on THSR**

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'



**Figure VII52 The SD Model for 'Force Majeure' Risk Effect**

## Appendix VIII ANOVA List for 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 VIII 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