A Dynamic Systems Approach to Risk Assessment in Megaprojects

By

Prince Boateng

A thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy

Royal Academy of Engineering Centre of Excellence in Sustainable Building Design,
School of Energy, Geoscience, Infrastructure and Society,
Heriot-Watt University,
Edinburgh, UK.

Supervisors
Dr George Zhen Chen
Prof Stephen O. Ogunlana

September 2014

ABSTRACT

Purpose- Megaprojects are large, complex, and expensive projects that often involve social, technical, economic, environmental and political (STEEP) challenges. Despite these challenges, project owners and financiers continue to invest large sums of money in megaprojects that run high risks of being over schedule and over budget. While some degree of cost, schedule and quality risks are considered during planning, the challenge of understanding how risk interactions and impacts on project performance can be modelled dynamically still remains. The consequences learnt from past experiences indicate that there was a lack of dynamic tools to manage such risks effectively in megaproject construction. In seeking to help address these problems, this research put forward an innovative dynamic systems approach called SDANP to risk assessment in megaprojects construction.

Design/methodology/approach – The research has developed an innovative SDANP method which involves an integrative use of system dynamics (SD) and analytic network process (ANP) for risk assessment. The SDANP model presented in the thesis has been testified by using data and information collected through a questionnaire survey and interviews from supply-side stakeholders involved in the Edinburgh Tram Network (ETN) project at the Phase One of its construction stage. The SDANP method is a case study risk assessment driven process and can be used against STEEP challenges in megaprojects.

Findings – The result of the case study project revealed that the SDANP method is an effective tool for risk assessment to support supply-side stakeholders in decision making in construction planning. The SDANP model has demonstrated its efficiency through case study, and has convinced construction practitioners in terms of its innovation and usefulness.

Research limitations/implications – Although the SDANP model has been developed for generic use in risk assessment, data and information used to run the simulation were based on the ETN project, which is in Edinburgh, Scotland. The use of the SDANP model in other megaprojects requires further data and information from local areas.

Practical implications – The SDANP method provides an innovative approach to a comprehensive dynamic risk assessment of STEEP issues at the construction planning stage of megaprojects for the first time. It provides an interactive quantitative way for developers to prioritise and simulate potential risks across the project supply network, to understand and predict in advance the consequences of STEEP risks on project performance at the construction stage.

Originality/value - The research made an original contribution in quantitative risk assessment with regard to the need for a methodological innovation in research and for a powerful sophisticated tool in practice. The SDANP has shown its advantages over existing tools such as the program evaluation and review technique (PERT) and the risk assessment matrix (RAM).

DEDICATION

This Thesis is dedicated to the LORD JESUS CHRIST.

[Deuteronomy 8:18 and Roman 9:28] KJV

ACKNOWLEDGEMENTS

I wish to thank the School of the Built Environment at Heriot-Watt University for providing the scholarship funding for this research. Also, my greatest acknowledgement goes to Dr George Zhen Chen, my primary supervisor for the immense assistance provided in terms of guidance, suggestions and encouragements throughout the research process. The memory he has implanted in me will forever remain. I wish to also acknowledge my second supervisor, Professor Stephen O. Ogunlana for the various ways he contributed despite his busy schedule as Professor and Chair of Construction Project Management.

My appreciation goes to Mr John White (Assistant Engineering Manager) in Edinburgh Trams Gogar Depot, Brian Donnelly (BSC Section Manager), Carsten Mieves (BSC Senior Engineer) and Jackie Paton (T&T Site Supervisor) for their assistance in helping to collect the relevant data on the Edinburgh Tram Network Project. Subsequently, I must acknowledge individuals who took part in the research survey and interviews, without their help this research would not have been possible.

I also acknowledge my parents, Madam Mary Ajongba-Sik and Mr. Anthony Y. Adanyeguh and siblings Atsu, Etse and Selorm for their dedication and support at every step towards my studies. I sincerely thank my loving wife, Haggar Boateng and my children Mag-Tony and Prince and my mother-in-law, Victoria Gbati for their understanding, love and support during this long, tedious and on many occasions strenuous journey. I wish to further express my gratitude to my good friend, Dr. Godwin Ayetor and family for the generosity extended to my family during our stay in the UK.

Last but not least, I wish to thank Professor Naomi Brookes, the chair of the EU COST Action TU1003 Megaprojects, who has been giving me unique opportunities and inspiring advice on research into mega transport projects with leading academics from all over the Europe. The project focuses on the Effective Design and Delivery of Megaprojects in Europe, and is funded and supported by the European Commission through the EU RTD Framework Programme and the European Science Foundation Union.

ACADEMIC REGISTRY
Research Thesis Submission

Name:	Prince Boateng		
School/PGI:	EGIS / Royal Academy of Engineering Centre of Excellence in Sustainable Building Design		
Version: *(i.e. First, Resubmission, Final)*	Final	Degree Sought (Award **and** Subject area)	**PhD in Construction Project Management**

Declaration

In accordance with the appropriate regulations I hereby submit my thesis and I declare that:

1) The thesis embodies the results of my own work and has been composed by myself
2) Where appropriate, I have made acknowledgement of the work of others and have made reference to work carried out in collaboration with other persons
3) The thesis is the correct version of the thesis for submission and is the same version as any electronic versions submitted*.
4) My thesis for the award referred to, deposited in the Heriot-Watt University Library, should be made available for loan or photocopying and be available via the Institutional Repository, subject to such conditions as the Librarian may require
5) I understand that as a student of the University I am required to abide by the Regulations of the University and to conform to its discipline.

* *Please note that it is the responsibility of the candidate to ensure that the correct version of the thesis is submitted.*

Signature of Candidate:		Date:	

Submission

Submitted By *(name in capitals)*:	PRINCE BOATENG
Signature of Individual Submitting:	
Date Submitted:	

For Completion in the Student Service Centre (SSC)

Received in the SSC by *(name in capitals)*:			
Method of Submission *(Handed in to SSC; posted through internal/external mail)*:			
*E-thesis Submitted (**mandatory for final theses)***			
Signature:		Date:	

TABLE OF CONTENTS

CHAPTER NINE: MODEL VALIDATION..289

CHAPTER TEN: CONCLUSIONS AND RECOMMENDATIONS....................324

LIST OF TABLES

LIST OF FIGURES

LIST OF EXHIBITS

LIST OF ABBREVIATIONS

CDR	Cost of Dispute Resolution
CDUD	Cost of Delay in Utility Diversion
CLA	Cost of Legal Action
COD	Cost Of Delays
COR	Cost Of Rework
DEG	De-Escalation to Grievances
Disp.	Disputes
DOAF	Delay Of All Forms
DOC	Delay in Obtaining Consent
EC	Economic Certainties
E*c*RM	Economic Risks Model
EG	Escalation to Grievances
EnC	Environmental Certainties
EnR	Environmental Risks
EnRE	Environmental Regulation Enforcement
E*n*RM	Environmental Risks Model
EnU	Environmental Uncertainties
EP	Energy Price
EPCO	Escalation to Project Cost Overrun
EPTO	Escalation to Project Time Overrun
ER	Economic Risks
ErG	Error Generation
EU	Economic Uncertainties
FE	Foreign Exchange
GCP	Ground Conditions Problem at a given site
GFP	Government Funding Policy
LA	Legal Actions
LIR	Local Inflation Rate
LRC	Legislative & Regulation Changes
MLDMBI	Multi- Level Decision Making Bodies Involvement
MP	Material Price
MPDS	Modification to Project Design & Specification

MPH	Material Price Hike
PA	Social Acceptability
PC	Project Scope
PC	Political Certainties
PDP	Political Debates on the Project
PH	Political Harmony
PI	Political Indecision
PIP	Political Interferences in the Project
PMPS	Pressure to Modify Project Scope
P*o*RM	Political Risks Model
PQD	Project Quality Deficiency
PR	Political Risks
Proj.C	Project Complexity
PS	Political Support
PT	Project Termination
PU	Political Uncertainties
RPCO	Risks of Project Cost Overrun
RPTO	Risks of Project Time Overrun
Rwk	Rework
SC	Social Certainties
SG	Social Grievances
SI	Social Issues
S*o*RM	Social Risks Model
SR	Social Risks
SU	Social Uncertainties
Tax.	Taxation
TC	Technical Certainties
TDUU	Time to Divert Underground Utilities
T*e*RM	Technical Risks Model
TPAS	Threat to Personal & Asset Security
TR	Technical Risks
TU	Technical Uncertainties
WCP	Worksite Coordination Problems
WI	Wage Inflation

LIST OF PUBLICATIONS

Part of the outcome from this PhD research has been published in one international conference and two international journals. The rest has been prepared for publication in international journals in 2014.

Boateng, P., Chen, Z. and Ogunlana, S. (2012a) ‘A system dynamics model to describe the impacts of critical weather conditions in megaproject construction’, *Journal of Construction Project Management and Innovation,* 2 (1) 208 – 224.

Boateng, P., Chen, Z. and Ogunlana, S. (2012b) ‘A system dynamics approach to risks description in megaprojects development’, *International Journal of Organization, Technology and Management in Construction-Special issue on megaproject Management,* DOI 10.5592/otmcj.2012.3.3.

Boateng, P., Chen, Z. and Ogunlana, S. (2014), ‘A Dynamic Systems Approach to Risk Assessment in Megaprojects’ *International Journal of Project Management,* (under review).

Ikediashi, D.I; Ogunlana, S.; Boateng, P. and Okwashi, O. (2012) ‘Analysis of risks associated with facilities management outsourcing: A multivariate approach’, *Journal of Facilities Management*, 10 (4) 301-316.

Ikediashi, D.I; Ogunlana, S. and Boateng, P. (2014) “Determinants of outsourcing decision for facilities management (FM) services provision”, *Facilities,* Vol. 32 (9/10), pp.472 – 489.

Rajaa Alasad, R., Motawa, I., Ogunlana, S. and Boateng, P. (2014) ‘Prioritization of Demand Risk Factors in PPP Infrastructure Projects’. *Construction Research Congress 2014:* pp. 1359-1368. doi: 10.1061/9780784413517.139.

LIST OF PRESENTATIONS

The findings of this PhD research has been presented to peers at one international conference and two workshops

Boateng, P., Chen, Z. and Ogunlana, S. (2012), ‘A conceptual system dynamics model to describe the impacts of critical weather conditions in megaproject construction’ *1st International Conference on Infrastructure Development in Africa, March 2012 – Ghana, West Africa.*

Boateng, P., Chen, Z. and Ogunlana, S. (2012), ‘Risk Informatics for Megaprojects Development: A New Approach to Risk Management’, *COST Action TU1003 Megaproject WG workshop, Edinburgh – September 2012.*

Boateng, P., Chen, Z. and Ogunlana, S. (2014) ‘Applying System Dynamics to Manage Dynamic Complexities of Risks in Megaproject Construction’, *Innovation Methodology (INNOMET) workshop on Effective Delivery of Megaproject, Edinburgh, Scotland - March 2014.*

Boateng, P., Chen, Z. and Ogunlana, S. (2014) ‘A Dynamic Systems Approach to Risks Assessment in Megaproject’ *EU COST Action TU1003 Seminar on Megaproject Risk Assessment and Simulation, Edinburgh, Scotland – May 2014.*

Boateng, P., Chen, Z. and Ogunlana, S. (2014) ‘Time and Cost Overruns in the Edinburgh Tram Network (ETN) Project: Causes and Scientific Modelling’. *MEGAPROJECT Whole Action Workshop, MC and Joint Working Group Meetings, International Festival for Business (IFB). Liverpool, UK – July, 2014.*

CHAPTER ONE: INTRODUCTION

1.1: Introduction

This chapter introduces an overview of the doctoral research, giving why such research is done and placing the research in a context that demonstrates its importance. First, the background of the study and statement of the research problem are addressed. The research aim and objectives are also presented. Subsequently, the scope and boundaries of the study are presented followed by a summary of the research methodology adopted. Thereafter, a statement of the contribution to knowledge and the significance of the research findings are described**.** The chapter concludes with an explanation of the organisation of the thesis.

1.2: Problem Statement

Construction, like many other industries is a free-enterprise system, and has sizeable risks built into its structure (Ashley, 1977, Mohammad *et al.,* 1991). From the initiation to the closing stages, the construction process, especially that for megaproject development, is complex and characterized by a number of uncertainties, and, as such, involves many risks that influence the project from feasibility through to the commissioning stages (Flyvbjerg et al., 2003). For example, uncertainty about changes in weather conditions, subcontractor delays, and unpredictable site conditions are typical risk variables that exist in every construction project. As a result, many construction projects fail to achieve their time, cost and quality goals.

For large and complex projects, such as highways, bridges, and airport expansion projects, risk management during construction is paramount to successful project delivery. Project Managers who do not interact attentively with the environment of these projects are likely to face difficulties during planning and execution of their projects (Ali-Mohammed, 2010). Evidence suggests that such megaprojects are usually money pits where funds are simply ‘swallowed up’ without delivering sufficient returns as a result of unbalanced subjective beliefs and information in assessing risks and uncertainties, and not taking corrective actions to control and manage the identified risks. For example, in Poole (2011), the transportation infrastructure industry has been revealed to have a major credibility problem. Its track record on megaprojects development is terrible. Project costs are often grossly underestimated, and traffic, often overestimated. These problems are well documented in history for many recent rail projects across the globe.

A study carried out by Danish academics Bent Flyvbjerg and colleagues, on 258 highway and rail projects (USD90 billion worth) in 20 countries in a book called Megaprojects and Risk (Cambridge University Press, 2003), revealed that transportation infrastructure projects do not perform according to budgets as estimated. According to the study, nearly all (90%) suffered cost overruns, with the average rail project costing 45% more than projected, the average highway project 20% more. Traffic forecasts were also far from accurate, with rail projects generating an average of 39% less traffic than forecast (though highway projects averaged a 9% underestimate of traffic). Based on a continuous research, Bent Flyvbjerg emphasized that cost overrun has not decreased over the past 70 years and seems to be a global phenomenon.

Other high profile highway projects are Boston’s Central Artery/Tunnel, the “Big Dig” and Virginia’s Springfield Interchange. These projects have made practitioners in the construction industry, and public taxpayers acutely aware of the problems of project delay and cost overruns. For example, the Big Dig was estimated at a cost of USA 2.6 billion but was completed at a cost of USA 14.6 billion. Additionally completion was delayed from 2002 to 2005. This indicates clearly that construction cost estimating on major infrastructure projects has not increased in accuracy over the past 70 years. The underestimation of cost today is in the same order of magnitude that it was then. According to Flyvbjerg *et al.* (2002), there is need for new ideas and techniques to be developed to improve this area where no learning seems to have taken place. One of the main reasons of megaproject cost and time overruns in Flyvbjerg’s study is that “risk is simply disregarded in feasibility studies by assuming what the World Bank calls the EGAP principle: Everything Goes According to Plan.”

With regards to the increasingly complex dynamics of megaprojects coupled with new procurements methods, the tendency today is to use risk quantification and modelling more as vehicles to promote effective risk response planning amongst multi-disciplinary project team members. According to Leung and Chuah, (1998**)**, an effective risk management approach can provide such a framework for project managers to identify and assess potential risk factors and take response actions in order to achieve the desired objectives of a given project. However, many of the risk management approaches developed by contractors and their consultants to analyze and assess risk generally rely on the contractor's experience and intuition (AI-Bahar, 1988). Rarely do megaproject contractors and Project managers quantify uncertainty and systematically assess the risks involved in a project. As a result, communicating construction project risks becomes poor, incomplete, and inconsistent throughout the construction supply chain.

Consequently, project members do not have adequate shared understanding of issues facing the project in order to implement effectively early warning systems and contingency plans to deal with problems resulting from the project environment. In addition, the proliferation of techniques and software packages purporting to provide project risk management facilities, has also failed to meet the needs of project managers. Tah and Carr (2000) emphasized that these systems are primarily founded on principles and methodologies derived in the 50s from operational research.

According to Tar and Carr, the focus is on quantitative risk analysis based on estimating probabilities and probability distributions for time and cost risk analysis. As a result, the techniques do not encourage project participants to develop in-depth understanding of the underlying elements and structures which constitute megaproject risk systems and render explicit latent concepts and assumptions which are implicit to current risk assessments. The techniques do not allow for the risks and uncertainties, remedial measures and lessons learned from previous projects with similar environments to be captured and re-used when developing new projects, to facilitate continuous learning and improvement.

For these reasons, the research aimed at developing a comprehensive new approach to risk management for megaproject development and construction. The interest of developing a new risk assessment tool for megaproject development is because the risk management assessment processes in construction project development implementation literature, while acknowledging adaptation as one phase in construction process and delivery, offers inadequate theory to address the problems faced during its implementation in megaproject delivery (Ali-Mohammed, 2010). Therefore, this research purposed to provide a risk management tool able to enhance the capabilities of the over 30 risk management techniques contained in the British Standards codes of practice (BS 31100:2011 Risk management- Code of practice; BS ISO 31000:2009 Risk management- Principles and guidelines and BS EN 31010:2010 Risk management-Risk assessment techniques) for risk management, and to lead the construction industry to establish a self-sustaining and grounded risk management procedure for megaproject development and construction.

To achieve the above purpose this research tends to dwell into a partial or entire set of social, technical, economic, environmental and political (STEEP) risks involved in transportation megaprojects during construction with a view to exploring the dynamics of the impact of such risks on the performance of megaprojects over time and adding to the understanding of their complex nature. This is by proposing a novel approach to policy makers capable of testing different strategies and interventions for reducing the risks of project cost and time overruns and quality deficiency in transportation megaprojects during construction.

It is on this basis that the research seeks to answer the following questions:

1. What are the generic risk events inherent in transportation megaprojects during construction?
2. How can the qualitative risk effects on project performance be quantified, prioritized and analyzed in transportation megaprojects?
3. How can risk interrelationships in transportation megaprojects be modelled?
4. How can project managers (PMs) assess the dynamics of risk effects in transportation megaprojects over time?

1.3: Aim and Objectives

The purpose of the research is to develop a new risk assessment model to enhance the decision-making process for megaproject development. The proposed risk decision-making model would be a useful tool to effectively and efficiently assist megaproject planners and managers to become more knowledgeable and effective in their decision-making with regard to risks in megaproject development. Eventually, the efficient use of the new model will benefit clients and the public by saving them time and money from construction delays. In order to achieve this purpose, the research has the following aim and objectives:

The study aims to develop a new risk assessment tool for megaproject construction through analytical and simulation models for comprehensive, integrated and proactive risk management in megaproject construction. The models, which comprise of the Analytical Network Process (ANP) and the System Dynamics (SD) methodology, will be useful to project managers for proactive measures in assessing risks effectively, efficiently and equitably during project lifecycles to avoid project delays and cost overruns. To achieve the aim, the study has the following objectives:

- To identify and describe the significant risks of a partial or entire set of social, technical, economic, ecological and political (STEEP) problems for megaprojects development and construction.
- To simulate and analyse the interactions among the risks.
- To assess major options against all risks and
- To develop a new methodology and tools for megaproject development.

1.4: Research Methodology Employed

In addressing the key research objectives, it was important to adopt an appropriate approach, which would enable appropriate data collection, analysis and interpretation of the findings for the benefit of practitioners and researchers. Consequently, as in all researches, the study commenced with an extensive literature review to help provide a thorough understanding of the recent developments in the methodologies used for assessing risks within the construction management discipline. The literature review provided profound opportunity to enable the author to understand related subjects of risks management in construction projects and to identify an appropriate theoretical framework for the study.

Following the literature review, a post positivism research paradigm was adopted to reflect the methodological (epistemological, ontological and axiological) approach involved. To this effect, qualitative and quantitative approaches were used to obtain relevant data from industrial stakeholders in the United Kingdom. Subsequently, interviews, case studies and a postal structured questionnaire survey were used in eliciting the main data (including piloting) and also in validating aspects of the findings relating to the potential relevance of the recommended application of the model. The research paradigm adopted also enabled pairwise comparison and a statistical tool such as a one-way analysis of variance (ANOVA) to be used in the analysis and interpretation of the data and discussion of the findings.

It must be noted that an underlying conception of this research was to help provide project managers, consultants, engineers and other industrial stakeholders involved in megaproject development the opportunity to have a clear understanding of the competencies expected of them to procreate excellent managerial practices during risk assessment. A detailed discussion of the research methodology including the rationale for eliciting the data from relevant respondents is presented in chapter three.

1. 5: Scope and Boundaries of the Study

The focus of this thesis is on risk management in megaproject development. The objective is to create a framework to identify and model the factors from the project’s external environment that contribute to risk in the development and construction of megaprojects. Just as solving an engineering or construction problem requires the definition of system boundaries, writing a dissertation requires the definition of the problem scope, as well as the boundaries of the systems and factors to be included in the tentative problem solution. These boundaries can also be arbitrary, but must be large enough to include the factors that contribute to the problem at hand, without being as large as to waste resources on unimportant factors.

Therefore, the risks considered in this research include the risks of a partial or entire set of social, technical, economic, environmental and political (STEEP) problems which result in cost and schedule overruns in megaproject construction. Following data obtained from literature and the administration of questionnaires, a case study from the UK was also incorporated into the study to develop and validate the proposed risk assessment models for illustrative decision making process on risk management.

Most of the techniques upon which this study is based were derived from the analytical network process (ANP) and system dynamics (SD) methodology. For the development of the new methodology, the STEEP risks were decoupled from programmatic risks that include budget, schedule and performance risks, and so these concerns were a critical part of modelling risk in the development of the new methodology. As part of the scope, the models of each STEEP risk when developed fulfilled two main conditions: (1) The models have a large number of risk components that the internal environment of the project has no influence on, and (2) exhibited social, technical, economic, environmental and political complexity. STEEP complexity is not a discrete characteristic, but can be defined along a continuum which ranges from very simple to extremely complex. Moreover, complexity is relative and a function of current intellectual manageability, which is evolving as new tools and techniques are developed (Leveson, 2000).

Consequently, it was extremely challenging to measure the level of complexity of different systems within the STEEP system. However, it should be obvious to readers that the examples used in this research belong to the set of complex STEEP systems for megaproject construction.

1.6: Research Significance

Every project faces a considerable amount of risk right from the initiation to the closing stages. A risk may or may not be unforeseen and can pose itself as an opportunity or a threat to the project. Risks may be business risks (with gains or losses) or pure risks (only losses) based on a scenario. In nature, they may be scope risks (with technical, performance or quality issues), external risks, organizational risks or exclusively project management risk.

In response to such growing uncertainty in modern projects, over the last decade the project management community has developed project specific standards for risk management. These include the British Standards Institution (2011), the Office of Government Commerce (2001), the UK Association for Project Management (2005) and the Project Management Institute (2009). The basic structure of all these models is similar and has a complete and acceptable framework. The 2000 edition of the Project Management Body of Knowledge (PMBOK); (PMI 2000) for example, consists of six risk management processes of planning, identification, qualitative analysis, quantitative analysis, response planning and monitoring and control.

While these risk management standards provide comprehensive approaches to decision making, their effectiveness relies on the ability to cope with the multidimensional uncertainty of risks: likelihood, impact and occurrence from the project’s external macro environment. The traditional tools and techniques used to manage risks are unable to address risks in megaproject construction. As a result, many megaprojects development fail to achieve their intended cost and schedule objectives during construction. Section 1.2 illustrated historical problems of many such megaprojects development. These problems and limitations identified, called for further development of tools and techniques in this research to model the dynamics and complexities of the factors that arise as risks during megaproject development.

1.7: Organisation of the Thesis

The thesis comprises ten chapters and these have been organised as follows:

Chapter One: This chapter deals with the background to the research including justification and the problem statement, aim and objectives and the associated contribution to knowledge emanating from the research.

Chapter two addresses generic risks relating to megaproject development and construction. Subsequently, an appropriate definition of the terms megaprojects, risks and risks management are provided. Another relevant issue discussed here is methods used for assessing risks in construction projects.

Chapter three addresses the research methodology adopted. The research paradigm is described including the design of the research instrument and method for collecting the relevant data. It also involves the systemic procedures upon which the research is based and against which the data collected is interpreted and the findings evaluated.

Chapter four presents the overview of the main case study for this research. The objective for selecting the case study is to deliver a critical review of the entire project and to identify, at the construction phase, mistakes and pitfalls which led to risks of project cost and time overruns and quality deficiency.

Chapter five introduces the first part of the data analysis. Having concluded the research introduction, the relevant literature review and the research methodology chapters, a preliminary analysis is undertaken as a prelude to the substantive analysis which led to the development of the dynamic simulation model for megaprojects (MegaDS model) for the assessment of risks in transportation megaprojects. This includes descriptive analysis of demographic data and the use of appropriate statistical methods on the dependent system variables.

Chapter six addresses the development of the substantive ANP models for the potential risks considered in this research. The chapter concluded with the Risk Priority Index

(RPI) calculation as a project ranking method for all risks and a summary of the relevancies of using the ANP for risk prioritization in the research.

Chapter seven is devoted exclusively to the development of the substantive causal loop diagrams for the identified STEEP risks.

Chapter eight is devoted to the development of the integrated ANP/SD stock and flow models including discussions of the findings. The application of the analysis of variance (ANOVA) is used to determine the extent to which STEEP risks affect the performance of the case study project.

Chapter nine describes the validation process and the methodology adopted in the validation procedure, namely empirical and rational validation for building confidence in the integrated ANP/SD models. The validation processes are discussed in terms of the literary, conceptual and substantive domains of the research. Results of both the empirical and rational validation process lend reasonable support to the reliability and robustness of the dynamic fit of the model and the literature search respectively.

Finally, in **chapter ten**, the fundamental objectives of the research are reviewed and highlighted. Conclusions drawn from the thesis are presented and recommendations are made.

1.8: Summary

The background of the study including the problem statement, aim and objectives, scope and research methodology have been presented. The significance of the findings, in particular, aspects relating to the potential contribution to knowledge has been illuminated. The next chapter, (i.e. chapter two) introduces a critical review of the generic risks in megaproject development, especially those relating to the underperformance in transportation megaproject at the construction phase.

CHAPTER TWO: LITERATURE REVIEW

2.1: Introduction

This section defines megaprojects, risk, and the risk management process related to the BS 31100:2011 and other risk management codes and standards. It also defines the approaches used to identify external risk such as STEEP and classify them for megaproject development and construction. The sections further provided extensive review into literature to formulate a comprehensive list of risks and to identify the impacts caused by such risks on megaproject construction.

As no references were found on risks related to the whole process of megaproject development management, literature focusing on the construction part of megaproject development was mainly investigated. Other complementary aspects of the relevant literature were also investigated in order to prepare a comprehensive list of risks that are related to the type of projects under discussion. The review was carried out in order to point out why there is the need for a new and more effective method of modelling and assessing risks in megaprojects at the construction stage.

2.2: Definitions

2.2.1: Megaprojects

For the purpose of this study, megaprojects are defined as being large infrastructure or major projects of over one billion (USD) in total installed cost, excluding development costs expended prior to the project being formally approved. Megaprojects are huge in magnitude and are characterized by a significant number of interfaces, interdependencies, complexity, and risks, some of which are strategic and must be managed at a level above the project team.

Britain’s Major Projects Association (MPA) defines major projects as “those which require knowledge, skills or resources that exceed what is readily or conventionally available to the key participants” (Major Projects Association, 2008). Flyvbjerg (2007) described a megaproject as “the most expensive infrastructure and investment projects that are carried out today, typically at costs per project from several hundred million to several billion dollars” (Flyvbjerg, 2007). A panel discussion at the 39th Engineering and Construction Contracting (ECC) Conference defined a megaproject as generally costing in excess of USD one billion (ECC 2007). It involves new technology development or an extension of existing technology. Megaprojects have significant interfaces, are complex and construction normally starts before engineering is complete.

By their nature, “Megaprojects tend to stretch available resources to the limit and sometimes beyond (Owen, 2004).” As a result, their developments are generally not decisions owners make today and execute tomorrow. Rather, each megaproject is a stream of highly complex decisions over a long time frame with increasing levels of commitment. Strategic decisions related to site selection, project financing and structuring, contracting, project scheduling, advance procurement and staffing and training will have a material impact on the economics of such projects. As such, large capital projects (megaprojects) face unique risks due to their complexity, resource requirements, long time horizons, and exposure to interrelated and pervasive drivers of risk. As a result, unique strategic application of decision analytic concepts, tools, and processes is needed to better manage the risks of these projects and lock in the full value of their investments.

2.2.2: Characteristics of Megaprojects

As discussed in section 2.2.1, megaprojects developments in the relevant body of literature are noted to be characterised by sizeable risks during construction. The common perception is that megaprojects often exhibit typical managerial problems that make them complex technologies when initiated and developed. At least nine features associated with megaprojects are notable**.** These are: 1. extreme complexity; 2. long project duration; 3. large amount of resources; 4. public entities involvement and public spending; 5. embedded in a network of public interest; 6. multiplicity of stakeholders; 7. technological challenges; 8. Uniqueness, 9. high impact on society and the general public.

- ***Extreme complexity:*** Technically, megaprojects are complex undertakings requiring cutting-edge engineering and construction techniques. Difficulty resulting from the lack of cooperation between stakeholders with conflicting interests and the changes occurring during the duration of the projects, such as changes in laws and regulations, increase the complexity (Capka, 2004). Complexity also implies risk and uncertainty in terms of funding and construction (Frick, 2008). Prominent examples are construction projects in the fields of transport infrastructure and resources extraction. Other types of technologies are described as 'high-tech' or scientific artefacts, such as particle accelerators (Stough & Haynes, 1997). Of these features, complexity emerges as a major challenge for managers of megaprojects. This challenge is brought about by a number of contributing factors such as tasks, components, personnel, and funding, as well as numerous sources of uncertainty and their interactions (Mihm, Loch, & Huchzermeier, 2003; Sommer & Loch, 2004). Research evidence suggests that the principal factors leading to complexity include: the large scale, long time span, multiplicity of technological disciplines, the number of participants, multi-nationality, the interests of stakeholders, sponsor interest, escalating costs over time, country risk, uncertainty, and high levels of public attention or political interest (Van Marrewijk et al., 2008).

- Also, the challenge of complexity of megaprojects can be studied under both technical and social complexity. While technical complexity is related to the size of the project, social complexity includes the interactions among the people involved in the project (Baccarini, 1996; Bruijn & Leijten, 2008; Cleland and King, 1983). As an example, the Channel Tunnel, which was opened in 1994 as an undersea rail tunnel linking England to northern France, presented both technical and social complexities. Technical complexities were encountered because the project entailed building the longest undersea portion of any tunnels worldwide. According to Anderson and Roskrow, (1994), the considerations for geology, design, engineering, and power supply aggravated the technical complexities of the Channel Tunnel. However, social complexities were mostly due to coordination among the large number of front-ended stakeholders and are similar to many other megaprojects across the world such as the ''Big Dig'' Central Artery/Tunnel Project in the U.S.A., Kuala Lumpur International Airport in Malaysia, Ultra Mega Power Plants in India; Port of Shanghai, the world's busiest container port, in China, and Burj

Khalifa, the world’s tallest building, in Dubai and the Hong Kong international airport (Davies, Gann, and Douglas, 2009).

- These examples illustrate the widespread nature of the dilemmas encountered by project management. According to Frick (2008), the reason for complexity is the large scale and scope of international megaprojects. This is enormous and highly visible in infrastructure projects such as tunnels, bridges, airports and rail systems. Capka (2004) argued that during the period of project initiation to final completion, changes occur in the economy, political landscape, and within the laws and regulations (Williams, 2000) which can take several years to come into force. In addition, is the existence of significant numbers of different, ambiguous, and interconnected tasks and activities to complete the project. Since the technology used in megaprojects is often new, developmental or cutting-edge, its behaviour and functionality are often hard to predict. In the case of an already complex product as the channel tunnel, the design phase took several years and witnessed countless adjustments during construction as the underlying technologies constantly evolved. Evidence shows that new developments and changes in technology increase uncertainty (Shenhar, 2001).

- Also, researches conducted by Merrow, (2011); Davies, Gann, and Douglas, (2009); Hertogh et al., (2008); Van Marrewijk et al., (2008); Merrow et al., (2008); Pryke and Smyth, (2006); Brady and Davies (2004); Flyvbjerg et al., (2003); Williams, (2002); Davies and Brady (2000); provided deeper understanding on how substantial number of project participants including contractors, sub-contractors, sponsors/governments, suppliers, investors, funding agencies, etc., can lead to further increase in complexity. Aligning a significant number of stakeholders is difficult and unpleasant if each stakeholder’s interests are to be maintained. Sponsors and stakeholders often have competing characteristics and goals. In addition to the difficulty of finding common ground for a large number of people, conflicts and misinterpretations can arise during the long life of project implementation. Undertakings with large amounts of resources may create controversy among stakeholders and over the management of resources. Moreover, the visibility of megaprojects and public attention increase the complexity (Capka, 2004; Kolltveit & Grønhaug, 2004; Vaaland & Håkansson, 2003).

- Further contributing to complexity is the work of Williams (2008). A review of Williams's book 'Complexity and its implications for megaproject research' revealed the complex causal chains that are in evidence in complex projects such as megaprojects. Williams argued that feedback loops in causal chains of complex projects leads to emergent, unpredictable and 'vicious' cycles of poor megaproject performance. He emphasized that the socio-political complexity in evidence in megaprojects exacerbate these cycles even further. Williams proposed that the emergent phenomenon of poor performance and its relationship to areas that traditionally lie outside concerns of formal project management means that new theory is required to design and deliver megaprojects effectively.

- ***Long project duration:*** Another characteristic typical to megaprojects is that they have *very long project duration*. For example, it can take up to several decades for the final product to be delivered (Haynes, 2002; Stough & Haynes, 1997; Merrow, 1988). This poses a challenge to project participants and planners as the long-time provides plenty of opportunities for changes to occur within the project or its environment. Essentially, these may cause a different project outcome than originally intended and planned (Merrow, 1988).

- ***Large amount of resources:*** Further to the above two characteristics is the *very large amount of resources (*physical supplies, funds and labour*)* needed to develop such projects. The total amount of funding that is regarded typical for a megaproject varies between authors, but figures of up to USD one billion are not considered unusual (Sewell, 1987). As Hall (1980) puts it, megaprojects typically require "a great deal of money by almost anyone's standard".

- ***Involvement of public entities and public spending:*** As the fourth characteristic, megaprojects exhibit the *involvement of public entities and public spending* – this serves as a possible explanation for why megaprojects are often an issue of public interest (Willians et al., 2009) and attract significant attention from public media outlets (Feldmann, 1985). What also follows from the involvement of public entities is that the reputation of the project participants involved, in particular that of public officials and the government, may be highly dependent on the success of these projects (Altshuler & Luberoff, 2003).

- ***Embedded in a network of public interest:*** The fifth characteristic is that megaprojects are usually *embedded in a network of public interests* where often complex has and interdependent goals oppose to each other. This is particularly challenging as these may change over time and because political decisions in various areas might be intertwined and impact on the project: For example, the revenue generation that follows from the construction of commercial buildings may depend on whether traffic policy facilitates easy access to the buildings (Flyvbjerg, Bruzelius & Rothengatter, 2003). In this sense, traffic policy can have a strong effect on the performance of the construction project. Next to policy conflicts, megaprojects may also depend on values and judgments of society: the public perception of a megaproject and its advantages and disadvantages along with the attitude towards the project can change with changes in the political climate or after elections (Hall, 1980). When the attitude becomes negative, this can, in turn, lead to a change in public policies causing sudden megaproject abandonment or hold-up (Hall, 1980).

- ***Multiplicity of stakeholders:*** This can be seen as a consequence of the potential for creating large-scale impacts. As a consequence, it may be difficult to fulfil each stakeholder’s requirements, and a large number of stakeholders may be difficult to manage (Altshuler & Luberoff, 2003; Kumaraswamy & Morris, 2002; Miller & Lessard, 2001; Feldmann, 1985). Diverging interests among public vs. private stakeholders are only one example for this type of challenge (e.g. public administrations might aim to increase security while private companies look for increased economic return). Even in homogeneous looking groups, e.g. the public administration, goals might diverge (according for example to local or temporal political initiatives). Moreover, large impact and long project duration often act as a kind of multiplier for this inherent complexity.

- ***Technological challenges:*** As the seventh characteristic, *technological challenges* are often mentioned as a typical megaprojects issue. First, the technology applied in the project is often very complex or even novel and innovative – in this case, the behaviour and functioning of the technology can be very hard to predict, and past experiences are typically not applicable (Hall, 1980). Secondly, the megaproject might be dependent on technological trends outside of the project itself (Feldmann, 1985). This poses management challenges since trends are often subject to change and hard to predict and may force the project to adapt (Feldmann, 1985).

- ***Uniqueness:*** Eighth, in conjunction with being technologically challenging, *uniqueness* is a constituent characteristic of megaprojects as they aim at developing “unique, dedicated, and usually one-off products” (Miller & Lessard, 2001), for which past experiences do not necessarily apply or not exist. Hence, megaprojects are considered an “engineering craft business” (Miller & Lessard, 2001).

- ***High impact on society and the general public:*** The ninth characteristic is concerned with the *high impact on society and the general public* (also related to the public spending) that mega projects can have on the world around them and the reactions they provoke (Goemans & Visser, 1987). Some research on mega projects has even been devoted exclusively to this topic, e.g. by Stough and Haynes who say that these impacts are usually “large-scale and complex” and “unevenly distributed in time and space”. Furthermore, the impacts may be trans-national, occur on a long-term basis affecting multiple generations (Stough & Haynes, 1997), and affect the economy, the civil society, and the natural environment (Flyvbjerg, Bruzelius and Rothengatter, 2003; Sewell, 1987). Because megaprojects are “embedded in contexts that are complex and adaptive” (Stough & Haynes, 1997), they usually have unforeseen and unintended consequences that are difficult to forecast or to plan. Consequently, possible responses to megaprojects comprise the rejection by the public or the protests of special-interest groups, e.g. environmental protectionists. These are often cited in literature as common problems in megaprojects with sabotage being the extreme case (Altshuler & Luberoff, 2003; Flyvbjerg, Bruzelius and Rothengatter, 2003; Sewell, 1987; Feldmann, 1985; Hall, 1980). Derived from the former characteristic but also related to other attributes, like spending of large amounts of public funds, we identify the *public awareness* that is devoted to megaprojects (e.g. in mass media) as the final characteristic.

2.2.3: Typical Problems Associated with Transportation Megaprojects

Constructing a megaproject facility takes a long time and usually involves a large capital investment. Megaprojects are often portrayed in literature to experience typical problems such as cost overrun, schedule slippage and the failure to meet stakeholders’ requirements or to deliver the intended outcome (Gould, 2002). In addition, revenue generation of completed megaprojects is often seen to be below expectations and that the project becomes unviable from an economic point of view. According to Kaliba et al., (2009), if project costs or schedules exceed their planned targets, client satisfaction would be compromised. The funding profile no longer matches the budget requirement and further slippage in the schedule could result. Ahmed et al., (2002), emphasised that delays on construction projects are a universal phenomenon and are usually accompanied by cost overruns. These have a debilitating effect on contractors and consultants in terms of growth in adversarial relationships, mistrust, litigation, arbitration, cash-flow problems, and a general feeling of trepidation towards other stakeholders.

Several studies have been undertaken on factors causing project time overruns (delay), cost overruns, quality deficiency, etc. and other specific risks in different types of megaproject development. Empirical evidence and studies show that these major instances of risks in megaprojects usually take place in the construction phase (Frimpong *et al.*, 2003). These studies usually focus on specific aspects of project performance.

2.2.3.1: Review of Delays in Megaproject Construction

In construction, the word “delay’’ refers to something happening at a later time than planned, expected, specified in a contract or beyond the date that the parties agreed upon for the delivery of a project (Pickavance, 2005). Delay can lead to many negative effects such as disputes and legal actions between megaproject owners and contractors, project cost overruns, loss of productivity and revenue, and contract termination. Although schedule delays seem to be embedded in all projects, identifying the main causes and preventing these problems from occurring are better than resolving subsequent delay-related disputes. Increasingly, realistic ‘construction time’ has become important because it often serves as a crucial benchmark for assessing the performance of a project and the efficiency of the contractor (Chan and Kumaraswamy, 2002). In this study, research literature from all around the world has been collated and consolidated for the better understanding of the overall picture of the issues.

According to the World Bank (2009), for many projects completed worldwide between 1999 -2005, the overrun varied between 50% - 80%. In the past few years, the number of claims submitted to the American Arbitration Association (AAA) reached almost 25% of the 1.7 million claims submitted over the past 74 years. In the United Kingdom (U.K), report by the National Audit Office entitled “Modernizing Construction”, published in January 2001, revealed that 70% of government construction projects were delivered late. Similarly, a research conducted by the Building Cost Information Service (BCIS, 2012) found that nearly 40% of all studied project had overrun the contract period. Safer *et al.*, (2012) point out in a study that the most common factors of these delays are related to financial and payment problems, improper planning, poor site management, insufficient experience, and shortage of materials and equipment. The study also acknowledged others which are: natural disaster such as flood and earthquake. In Ali Mohammed (2010), a study conducted on Highway and Bridge megaprojects at Bahrain revealed that, predominant factors (risks) such as traffic congestion, utility diversion, consultant’s supervision fees, land acquisition, environmental considerations and accuracy of existing services locations among the rest contributed to delays and disruptions in the project development.

Tommy *et al.*, (2006) revealed that natural ground conditions, poor communication, manpower problem, insufficient knowledge on work are the delay related risks in construction project in Hong Kong region. Jyh-Bin *et al.*, (2010) evaluated delays in construction and concluded that the phenomena are universal and are almost always accompanied by cost and time overruns. Therefore, it is essential to identify the actual causes of delay in order to minimize and avoid the delays and their corresponding expenses.

2.2.3.2: Review of Cost Overrun in Megaproject Construction

Cost overrun is common in megaproject construction. The sad truth about cost overrun is that they have been a fact of life since Biblical times *“For which of you, intending to build a tower, does not sit down first and count the cost, whether he has enough to finish it?”* (Luke, 14:28-NKJ). The problem of cost overrun, especially in the construction industry, is a worldwide phenomenon. Its forms are normally a source of conflict among clients, consultants and contractors on the issue of project cost variation. Project cost overruns create a significant financial risk to clients. However, in spite of the risks involved, the history of the construction industry is full of projects that were completed with significant cost overruns (Garry, 2005). For example, studies conducted by Flyvbjerg and others (2002, 2006 and 2009) on a sample of 258 transport projects indicated that, cost overruns in transport projects revealed that 9 out of 10 projects have cost overruns. Across 20 nations and 5 continents, the average overrun is found to be 45%, 34% and 20% for rail projects, bridges and tunnels, and road projects, respectively. This cost overrun is constant over a 70-year period and cost estimates have not improved over time.

The next example is a research conducted by Flyvbjerg, (2009) on the Danish Great Belt rail tunnel. This tunnel was opened in 1998 and happened to be the second-longest underwater rail tunnel in Europe. However, before it was opened, the cost of construction was about 120% over budget and proved nonviable. Only by cross-subsidizing the tunnel with revenues from a nearby motorway bridge made it possible to pay for the tunnel (Flyvbjerg, 2009).

Another example is the Boston's "Big Dig" (a/k/a "Central Artery/Tunnel Project"). This project has been a thorn in the side of the city and its commuters for over twenty years. The project's purpose was to build a 2 mile stretch of underground highway through the heart of Boston, replace the existing above-ground highway with green space, and to build a tunnel from Boston beneath the Boston Harbour to Logan International Airport in East Boston. At its height the project employed over 5,000 workers. The "Big Dig" has been troubled from the start by shoddy workmanship, as evidenced by problems with sub-standard materials, paving fraud, grout heaves, leaking tunnels and defective anchor bolts in the Ted William and I-90 tunnels. Originally proposed at $2.2 Billion, the project cost was estimated in 1985 at US$6.0 billion but was adjusted for inflation as of 2006. By 2006, the project costs have risen to US$15 Billion (143% cost escalation), with 73% of the cost being subsidized by Massachusetts taxpayers (Murphy 2008).

The last example is the case study adopted for this research (Edinburgh Tram Network Project). It is a tramway system which is currently under construction in Edinburgh, Scotland. With an original budget at a cost of £375 million in 2003, the cost of this tram system was revised by the City of Edinburgh Council (Project owners) to £776 million in 2011. It was originally scheduled to enter service in February 2011 but had to be postponed to summer 2014 due to budget problems. In February 2011, Edinburgh Evening News published that the German engineering contractors responsible for the delivery of the project have revealed 72% of the construction work remaining with just 38% of the budget left.

Other example cost overruns revealed in literature is a study conducted by the UK National Audit Office in 2007 to examine how the costs of building and improving roads were estimated and monitored from early forecasts through to the final cost of schemes. The UK Department for Transport had approved expenditure of over £11 billion between 1998 and 2021 for the development of new and existing trunk roads and motorways in the UK by the Highways Agency and under £1.7 billion on major road schemes which were proposed and developed by the local authorities. By 2006, the 36 schemes by the Highways Agency had been completed and had cost 6% more than estimated. By 2006 the 20 schemes by the local authorities completed had also cost 18% more than initially estimated.

Deviations in cost for some selected projects from Europe are presented in Table 2.1. Among these projects are six high-speed rail links: ICE Frankfurt-Cologne, Eurotunnel, Madrid-Seville AVE, Paris-Lille TGV, Lyon-Marseille TGV, and the Oeresund Fixed Link. Costs overruns lay between 8% (Lyon-Marseille TGV) and 116% (ICE Frankfurt-Cologne) adopted from the European Commission’s EVA-TREN project (EVA-TREN, 2008). Others include Edinburgh Tram Network Project (ETNP).

Many types of risks in literature were also identified to account for under performance of megaproject construction. In Zou et al., (2007), 25 key risks factors were identified to influence project objectives in large construction projects in China. Zou and his colleagues compared their findings with a parallel survey carried out in the Australian construction industry to highlight the unique risks associated with construction projects in China. The result concluded that, clients, designers and government bodies should take the responsibility to manage their relevant risks and work cooperatively from the feasibility phase onwards to address potential risks in time; contractors and subcontractors with robust construction and management knowledge should be employed to minimize construction risks and carry out safe, efficient and quality construction activities.

Table 2.1: Deviations in Total Construction Cost for Selected Megaprojects in Europe

Projects	Forecast	Actual	Overrun (%)	Source
ICE Frankfurt -Cologne	€2784 million	€6015 million	116	Adapted from EVA-TREN(2008), p. 45
Eurotunnel	€2702 million	€4568 million	69	
Oeresund Fixed Link	€1795 million	€2924 million	63	
Paris - Lille TGV	€2666 million	€3334 million	25	
Madrid - Seville AVE	€3263 million	€4029 million	23	
Lyon – Marseilles TGV	€4015 million	€4338 million	8	
Seville-Madrid HSR	€1575 million	€2693 million	71	Adapted from E-COST Action (TU1003), Megaproject portfolio of case studies (2012)
Madrid-Barcelona HSR	€6 billion	€9 billion	50	
Edinburgh Trams	£545 million	£776 million	42	

Notes: ICE stands for "*InterCityExpress*", the German HSR; TGV stands for "*Train Grande Vitesse*", the French HSR; AVE stands for "*Alta Velocidad Española*" (with "*ave*" meaning "bird"), the Spanish HSR.

Chen et al., (2004) conducted a case study research on the West Rail Project of Hong Kong and identified 15 risks concerned with the project cost. The risks revealed, were classified into three groups of resources factors, management factors and parent factors. The results concluded that "price escalation of material" pertaining to resource factors, "inaccurate cost budget" and "supplier or subcontractors' default" pertaining to management factors, and "excessive interface on project management" pertaining to parent factors are the most significant risks in the West Rail Project.

In Shen (1997), eight major risks accounting for project delay were identified and ranked based on a questionnaire survey with industry practitioners. Shen, in conclusion, proposed risk management actions to deal with the risks identified through individual interview surveys. In addition, other research works were identified to investigate into classifying the diverse risks influences on the project objectives in terms of cost and time risks and in different other phases. Levitt *et al.*, (1998) in a research "Impact of Owner-Engineer Risk Sharing on Design Conservatism," classified construction project risks as 1) Socioeconomic factors (environmental protection, public safety regulation, economic instability, exchange rate fluctuation); 2) Organizational relationships (contractual relations, attitudes of participants, communication) and 3) technological problems (design assumptions, site conditions, construction procedures, construction occupational safety). The result of the research concluded that, the combination of the above risk factors causes out of control uncertainties for all parties involved in the project stages.

Abdou (1996) identified and classified construction risks into three groups (construction finance, construction time and construction design). The study of Abdou further addressed the classified risks in detail and highlighted the different contractual relationships that existed among the functional entities involved in the design, development and construction of a project.

Scholten (2006) estimated that problems of external factors have had a strong impact on about 17% of projects supported by European Cohesion Funds and a small to negligible impact on 41% only. The main external factors identified by Scholten were: Public protest, Archaeological factors / habitats, Weather conditions, Economic growth (faster/slower than expected) and Land purchase.

2.3: Generic Risks in Megaproject Development

Based on the objective one of this research which seeks to identify and describe all significant risks of the partial or entire set of social, technical, economic, environmental and political (STEEP) problems for megaprojects construction and development and the historic problems relating project performance in literature, the next sections of this report tried to investigate the sources of STEEP risks that impact on megaproject performance during construction. At the end, a summary of the identified risks in the relevant body of literature is presented in Table 2.6 of this report

2.3.1: The Social Risks

It is often the case that during the construction phase of megaprojects, local socio-economic impacts are at their highest, with nearby communities potentially affected by the acquisition of land and assets, disturbance to lifestyle and cultural values, various forms of noise, air and water pollution, and in some cases, potential for the transmission of disease (e.g. from worker camps). As a result, social risks may arise when civil societies and stakeholders take up issues concerning environmental standards, labour standards, human rights, sustainability and apply pressure on the project developer, so that the company can change policies and approaches to operations. These impacts can pose a risk to the efficient management of a project.

In addition to the project team, there is also a wide range of people and organisations that have an interest in a particular project and become involved, to varying degrees, in decision-making. These are known collectively as stakeholders. They may have a professional interest in the project, they may be potential users of a scheme, or their environment or livelihood may be affected in some way by the implementation of the scheme; their opposition may make it very difficult to proceed with the project.

Given the broad range of stakeholders involved, they are likely to have conflicting interests; which need to be recognised and carefully managed as part of the engagement process. Stakeholders can be grouped under three broad categories: government/authorities, businesses/operators and communities/local neighbourhoods. Examples of each are shown in Table 2.2. Furthermore, increasing degrees of social risks interaction with other STEEP factors would in turn generate collateral effects via spreading and cascading failures within project interrelated subsystems (Boateng et al., 2012). The results will then be catastrophic scenarios and crippling losses of public invested funds and valuable time that were previously thought to be uncorrelated and unforeseeable (Boateng et al., 2012).

Table 2.2: Typical Stakeholders involved in Transport Projects

Government/Authorities	Businesses/Operators	Communities/Local Neighbourhoods
European Union	National Business Associations	National Environmental NGOs
Ministry of Transport	Major Employers	Motorist Associations
Other National Ministries	Regional and National Businesses	Trade Unions
Regional Government	Private Financiers	Media
Local Authorities	Local Business Associations	Local Authority Forums
Neighbouring Cities	Town Centre Retailers	Local Community Organisations
Local Transport Authority	Small Businesses	Local Interest Groups
Other Local Transport Bodies	Transport Operators/providers	Cycle/Walking Groups
Other Local Authority Bodies	Transport Consultants	Public Transport User Groups
Politicians		Transport Users
Other Decision-Makers		Citizens
Partnership bodies		Visitors
Project Managers		Citizens in Neighbouring Cities
Professional Staff		Disabled People
		Landowners
		Transport Staff

Source: European Commission Directorate-General for Energy and Transport

As illustrated in Figure 2.1, the involvement of project investors to resolute changes to company policies, the change requests from customers and suppliers, and grievances from employees and other external stakeholders from the civil society, NGOs, local business owners and others may result to social risk (Kytle and Ruggie, 2005). The entry of these social risks into a company’s divisions can cause many megaprojects to fail to achieve their intended cost and schedule objectives during construction.

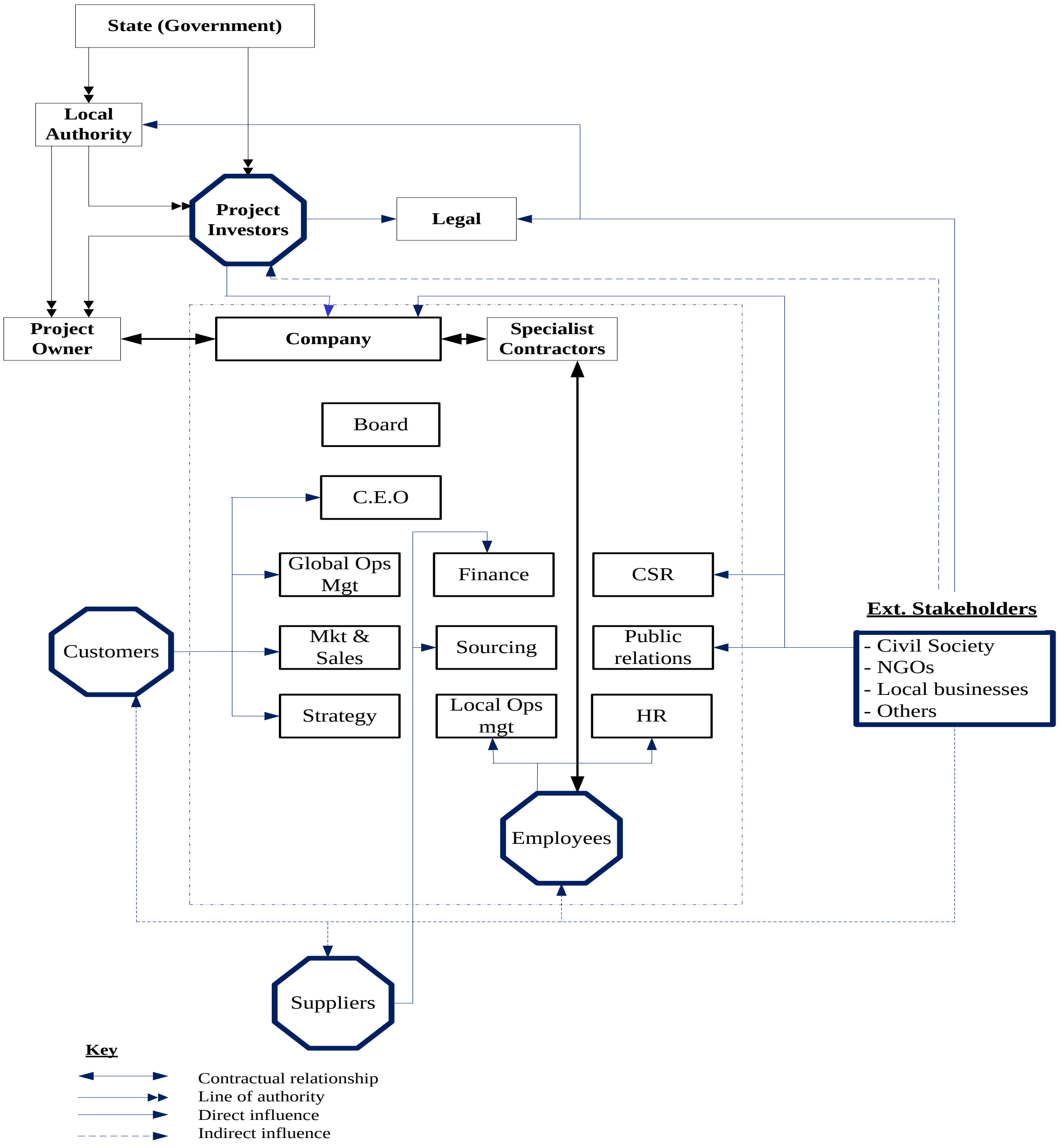


Figure 2.1: Social Risk Entry Points during Megaproject Construction

Source: Kytle and Ruggie (2005) (modified)

Conversely, the construction period (as well as the operations phase) offers opportunities for communities and local businesses to secure employment or procure contracts. Fully realised, these opportunities can be of benefit not only in terms of promoting local economic development, but in making a positive contribution to the commercial and reputational objectives of both the main engineering contractors and the project proponent or client. However, there is a challenge in managing the risks emanating from the social environment effectively in order to realise the opportunities and benefits of such projects. These challenges lie not only with the project proponent (ie. client), be that a public agency or private entity, but also with the large engineering service companies contracted to develop or manage the project, and with the engineering consultants advising the client in the formulation and review of tender documents and in the task of construction management.

2.3.1.1: Effects of Megaproject during Construction

Megaproject constructions are complex and have relatively large effects on people and environment compared to other construction projects. Due to the capital intensity of such projects, they often require diversion of traffic, and even in some cases to divert rivers. This, in turn, affects existing user rights and access to some parts of roads, and therefore has significant impact on livelihoods as well as the environment. Evidence in literature proved that the effects of such large developmental projects on socioeconomic activities and the archaeological historical sites of every nation are enormous. Table 2.3 indicates the various issues and their associated effects that generate social risks in transportation megaprojects during construction.

Table 2.3: Social Effects and Issues of Transportation Megaproject during construction

Effects	Issues
Social Effects	– Community Cohesion – Pedestrian and Bicycle Safety – Accessibility to Family, Friends, and Community Resources – Construction Disruptions – Need to Relocate – Choice of Travel Modes
Economic Effects	– Changes in Traveler Costs – Land and Property Value – Effects on the Competitiveness of Businesses – Linkages Between Residences and Jobs
Aesthetics and Livability	– Air and Water Quality – Traffic Noise – Availability of and Access to Public Space – Lighting – Signage and Visual Changes

Drawing on the typology set out in Table 2.3, it is important to note at this point that the extent to which a given effect and issue is studied and/or appears within the literature does not denote the level or extent of its impact across different vulnerable social groups within society. We further recognise that whilst many of the social issues identified in this section are similar to those found in the environmental literature, these are often presented with a view towards overall impact levels, as opposed to more detailed discussions of how they impact differentially upon various segments of society and businesses. We attempt to identify each of these issues to a certain extent. Extracts of summaries of the individual risk issues indicated in Table 2.3 were taken from the National Cooperative Highway Research Program (2001); Contractor's Final Report, NCHRP Web Document 31 (Project B25-19) and are presented below**.**

- **Social Effects**

According to Sinha and Labi, S., (2011), Geurs *et al.*, (2009, p.71) and FHWA (1982), the social effects of transportation megaprojects under construction can take many forms and can be very difficult to estimate with precision. Perceptions as to the relative importance of different sorts of social effects also vary quite widely.

- **Community Cohesion**

As Geurs *et al.*, (2009, p.71) and FHWA (1982) indicated, community cohesion stems from the social interaction among members of a community. Such interaction can involve regular participation in community social events or neighbourly exchanges on the street. Cohesion also is likely to involve a sense of closeness among residents, and a sense of being safe in one's neighbourhood. While it is easy to define in general terms what community cohesion is, expressing it analytically is difficult because it is the product of myriad interacting factors that are difficult to quantify.

- **Pedestrian and Bicycle Safety**

Changes in transportation systems may affect the safety of persons as they go about their daily lives in their neighbourhoods or places of work. Increased traffic or changes in traffic patterns may transform a pedestrian-friendly environment into one in which residents are at greater risk of injury. It also may make it more difficult and unsafe to walk or travel by bicycle. Such changes necessitate a consideration of pedestrian and bicycle traveling patterns and of possible alternative routes for pedestrians and cyclists.

- **Accessibility to Family, Friends, and Community Resources**

Few would disagree that an important element in quality of life is easy access to family, friends, and community. Transportation system changes can significantly limit or enhance people’s opportunities for interaction in their community by altering routes of access.

- **Construction Disruptions**

Transportation projects inevitably create disruptions in normal vehicle operations during the construction phase, creating delays for motorists or forcing them to take alternative routes. Construction delays may last from a few days to many months, and often require people to allow more time for travel. Much of the literature on estimating the disruptions caused by the construction of a project prior to its initiation takes the form of estimating motorist delay for specific road types. Most of this research focuses on traffic diversion and lane or road closures, rather than on the impact construction may have on neighbourhood quality or business viability.

- **Need to Relocate**

Some transportation projects necessitate the relocation of residents of a particular area. This raises strong concerns among planners and residents regarding the quality of the area to which residents will relocate, and the ability of residents to adjust to their new surroundings, form social relationships, and travel to work, school, or other important destinations.

The majority of relocation research takes the form of neighbourhood/community surveys and is based on displacement events, typically from the perspective of how poorly the displaced residents fared after they were relocated. Research also exists on factors that influence the ability of residents to adjust to a new location, regardless of their motivation for moving. Very little research has attempted to estimate impacts, but some has looked at the displaced population before, as well as after, the displacement, and considers the emotional impact on residents who expect to be displaced sometime in the future.

- **Choice of Travel Modes**

New transportation projects have the potential to provide individuals with the opportunity to choose travel modes that were previously not a viable option. Occasionally, such projects may also remove options for some individuals. It is important to consider how a transportation change may affect individuals' mode choice and the compatibility of modes.

According to World Commission for Dams (2000), these issues are not confined to the design, construction and operation of transportation megaprojects. However, they are also about social, environmental and political choices which aspire towards the development and improvement of the well-being of people. The relocation of people to make way for the construction of the routes of such projects can create conflict. Farmers and business owners along the project's routes may also suffer from the allotment of different but poor agricultural land and business areas with inadequate facilities and substandard housing and infrastructure.

Kytle and Ruggie (2005) indicated that social risk will occur when stakeholders identify a company's vulnerability on a social issue, such as a potentially inflammatory policy, ethic, or practice, and pressure the organization to change its approach. According to Kytle and Ruggie (2005), social risk often involves human rights, labour, or environmental sustainability, and can destroy a company's reputation if left unchecked. Kytle and Ruggie further viewed social risk as a measure of the gap between the boundary of responsibility which the project organization acknowledges and that perceived by its stakeholders. This gap is obviously widened if the project organization takes a "legal minimum" approach to their responsibilities, without acknowledging the broader dimensions of social licence to operate.

To minimise social issues and militate against social grievances, conflicts and disputes, legal actions, and treats to persons and asset security, Ofori (1992) suggested that environmental issues should be considered as the fourth objective of every construction project besides time, cost, and quality. It should be considered even before embarking upon project feasibility studies. Table 2.4 presents a list of risks that can be generated through a project's interactions with its local stakeholders at the construction phase.

Table 2.4: Risks Generated Through a Project's Interactions with Stakeholders

Risks	**Reference(s)**
- Inability to obtain land/access rights	Hilber, and Robert-Nicoud (2013); Turner *et al.,* (2011); Funderburg *et al.,* (2010), Glaeser and Ward. (2006).
- Compensation costs higher than expected	Hilber and Robert-Nicoud, (2013), Turner *et al.,* (2011), Funderburg *et al.,* (2010), Glaeser and Ward (2006), Fraser, (1990), McTague and Jergeas, (2002).
- Delays due to community/legal action	Funderburg *et al.,* (2010)
- Delays due to local labour disputes	Alinaitwe, Mwakali and Hansson, (2007), Al-Momani (2000), McTague and Jergeas, (2002).
- Threats to personal or asset security	Alinaitwe, Mwakali and Hansson, (2007), Jones and Brinkert, (2008).
- Vandalism & damage	Alinaitwe, Mwakali and Hansson, B. (2007), Al-Momani (2000). Jones and Brinkert, (2008).
- Cost overruns	Bruzelius, Flyvbjerg and Rothengatter, (2002), Altshuler and Luberoff. (2003), Lee (2008), Fraser (1990).
- Third part claims	Galloway, (2009)
- Costs due to community action	Alinaitwe, Mwakali and Hansson, (2007), Al-Momani (2000), Jones and Brinkert, (2008), Funderburg *et al.,* (2010)
- Delays dues to local labour disputes	Fraser (1990) Al-Momani, (2000).

- **Economic Effects**

Transportation megaprojects under construction can have dual effects: they improve the public's access to many forms of opportunity when completed, but they can also result in problems related to disruptions, pollution and greater traffic levels within or near a corridor area when delays occur during construction. In this section, we try to explain four major areas of risks evolved from such projects on society in the following sub headings.

- **Changes in Traveller Costs**

Transportation megaprojects under construction may significantly affect travellers, often by increasing or decreasing the amount of time these travellers may require to reach their destination. Project delays, disputes and legal actions relating to the project will also further increase delays and congestion and often provide a significant time increase for motorists. In addition, construction delays of such projects may increase time en route for some travellers, while creating longer journeys for others. However, when such projects go as planned, they may often improve the safety of users and reduce the safety of particular groups, such as pedestrians. Vehicle operating costs may also be reduced by smoother, more direct facilities involving fewer stops and starts, but higher speeds may actually increase the per-mile cost of operating a vehicle.

- **Land and Property Value**

Transportation megaprojects may serve as catalysts for comprehensive urban reinvestment projects with the expectation that they will improve economic development. They may affect property values in a number of ways. Construction of such projects may provide improved access to an area and thereby increasing property values. On the other hand, properties adjacent to and along the routes of the projects may decline in value as a function of their proximity to the facility, or as a result of a new undesirable visual feature in the environment.

- **Effects on the Competitiveness of Businesses**

Major construction works involved in transportation megaprojects may disrupt routine business activity along the project routes. Business owners may suffer customer losses as access to their business becomes restricted, which in turn will affect the number of employees the business requires. Customers who find alternative businesses during the construction period may not necessarily return once construction is completed.

Likewise, businesses may lose parking spaces during construction and not be able to serve as many customers.

- Linkages between Residences and Jobs

The way in which transportation megaprojects are structured and constructed often has significant effects on the ability of persons to travel from their homes to their jobs. Evidence from Edinburgh Tram Network (ETN) Project revealed that inner-city residents of the main City Centre and Haymarket frequently face transportation disadvantages when trying to reach jobs located in the suburbs. Evidence suggests that if affordable housing were located near their jobs, many would have relocated rather than commute long distances to work or use alternative transport.

• Aesthetics and Livability

Effects on the aesthetics and livability of neighbourhoods and communities in which the megaproject is executed, are certainly closely related to social and economic effects. Construction of transportation megaprojects can substantially affect an area’s aesthetics and other aspects of quality of life, either positively or negatively. Livability such as air quality (especially localized pollution, such as that near streets upgraded to handle greater traffic volumes), changes in noise levels and accessibility to public buildings and spaces, the psychological effects of excessive glare from lighting on roadways and signage are among the livability issues that affect people when transportation megaprojects are undertaken. Further explanations of these factors are presented below.

- Air and Water Quality

The activities of transportation megaproject construction have the potential to impact water quality and contribute to area emissions of air pollutants. The largest sources of anticipated pollutants would be dust generated by excavation, grading, and other ground-disturbing activities and exhaust emissions from equipment. All construction-related emissions would be temporary and vary from day to day, depending on the type of work being done. Construction-related emissions would also be experienced at different locations during the construction process, depending on the area(s) under construction at any one time and the distance to likely receptors. Because of the changing nature of these conditions (i.e., construction activity, construction location, and distance to receptors), an estimate of total construction emissions is not possible.

Also, the project could have potential adverse impacts on water quality related to construction activities. These include, but are not limited to: exposure of soils potentially resulting in erosion impacts to receiving waters; footing excavations for pier foundation resulting in possible groundwater contamination; potential surface water impacts from dredging and dewatering operations, concrete pouring, and washout activities, management and application of chemical products; construction activities performed on barges; and the potential for accidental spills from construction equipment and materials. Additional construction-related impacts may include discharges of waste material, accidental spills, and suspension of bottom sediments. Measures similar to those taken during construction will be taken to address these impacts. However, preventing these impacts may be difficult due to the complex site conditions, with limited space and several constraints.

- **Traffic Noise during Construction**

Megaproject construction would result in intermittent and varying levels of construction noise. Construction noise is unavoidable and could adversely affect some nearby residents during construction activity periods. Noise effects are often the most significant impact on the livability of an area because they are not confined to the outside environment but intrude into people's homes. For example, pile driving during construction would generate noise that is unique in terms of noise level. Noise may result from a number of sources, including increased traffic or a new rail line, and may affect residents in a variety of ways, including creating sleep disturbances and heightening stress levels. However, the impact would be temporary and limited to the time of the construction in any one location. Because of vehicle technology improvements and more strict noise regulations, Noise levels generated by construction equipment will be minimised.

- **Availability of and Accessibility to Public Space**

Availability of/and accessibility to public space serves significant social and recreational functions. Construction period may diminish or cause the removal of residents’ access to public space, which may in turn have repercussions on levels of social interaction and cohesiveness within a neighbourhood. It is therefore useful to consider the importance of public spaces to residents of an area when developing a transportation project.

- **Lighting**

Construction activities may increase lighting in a neighbourhood or community in the form of roadway or signage lighting. Also, night time construction activities which involve the use of lighting equipment could cause glare, potentially affecting residents in the immediate vicinity. Therefore, it is useful for planners to have a basic understanding of light trespass and glare, and how to minimize their intrusion into residents’ homes. It is important for planners to consider the overall increases in lighting in an area that may result from increased signage.

- **Signage and Visual Changes**

All construction activities would involve the use of barges, heavy equipment, stockpiles of soils and materials, removal of trees and other structures on the project routes to provide staging areas and clearances for heavy equipment and other visual signs of construction. Increases in signage, as a result of construction activities, may have a significant effect on the visual quality of a neighbourhood. During construction periods, residents would experience the most noticeable visual changes. It is advisable to consider residents’ preferences for types of signs; such preferences can be assessed through neighbourhood surveys and photomontage techniques.

2.3.2: Technical Risks

Essentially, technical risk is the most common and well understood form of risk. Technical risk is the subject of close surveillance. To minimize the technical risk, the contractor’s project manager is responsible to evaluate the risk in detail to ensure that the project will be constructed in accordance to the design specification and host government’s requirements and function well. Thus, a well reputed and established consultant together with an experience contractor should be hired to implement the project without any tolerance to the standard codes and practice.

Tatum, (1987) defined construction technical risks as risks associated to the combination of construction methods, construction resources, work tasks, and project influences that define the manner of performing a construction operation to “unaccomplished desired aim necessary for human sustenance and comfort” (Shin, Watanabe, and Kunishima, 1989). Also, these risks are related to technological problems that are familiar to the design/construct professions which have some degree of control over this category. However, because of rapid advances in new technologies which present new problems to designers and constructors, technological risk has become greater in many instances (Dvir, 2005). Certain design assumptions which have served the professions well in the past may become obsolete in present time. Site conditions, particularly subsurface conditions which always present some degree of uncertainty, can create an even greater degree of uncertainty during construction. Klein and Cork, (1998) concluded that the designs may have to be modified after construction has begun because construction procedures may not have been fully anticipated. An example of facilities which have encountered design change uncertainty is the Edinburgh Trams Network project (ETNP). Owners, designers and contractors of ETNP have suffered site technological problems such as site conditions and design changes for undertaking such projects.

Further to the site conditions problems and design changes are requirements or scope ambiguity in megaproject construction projects. Complexity, uncertainty and ambiguity associated with megaproject requirements influence the difficulty of managing such large infrastructure projects. Project complexity refers to the number of different activities that must be performed to complete the project (Pich et al., 2002). On the other hand, ambiguity exists when relationships between project decision variables and even the variables themselves are unknown. It can also be referred to as a lack of awareness of the project management team about certain states of the real world or causal relationships due to information inadequacy that arise from both project ambiguity and project complexity. This implies that many different actions and states of the real world parameters interact to make it difficult for the effect of actions to be assessed. This usually makes tasks become ambiguous since the full range of tasks required to complete the project is likely to be unknown at the outset, and the full range of decision variables that must be specified to satisfy the completion of each task is also unknown. Because of the interdependencies that may exist among decision variables associated with project tasks, communication and coordination are needed so that detailed product and process specifications and task requirement can be determined (Moenaert et al., 1995).

The risk of technical difficulties including latent defects in operation of project plant, equipment during construction is another factor and other unforeseen situations. Unforeseen uncertainty makes contingency planning more difficult because not all influencing factors in the project can be anticipated, and prevented. While unforeseen events are, by definition, unforeseen, the project manager is not completely at the mercy of unpredictable events. Therefore, the megaproject manager has to be an opportunistic manager who can detect the new threats very quickly and control them. Project financiers may usually try to minimize this risk by preferring tried and tested technologies to new unproven technologies. However, as Flyvbjerg (2009) put it in a research, project promoters appear to be particularly prone to cost underestimation. But as Klein and Cork (1998) indicated, lending can only take place if such risks are minimised earlier through expert report as to the proposed technology to be adopted. Also, Shin, Watanabe, and Kunishima, (1989) emphasised the need to manage technical risks during the loan period by requiring a maintenance retention account to be maintained so that a proportion of cash-flows to cover future maintenance expenditure can be received. That means there is a need of technological advancement to overcome this type of risk.

Another key area of technical risks is supply chain breakdown. Analysis carried out for BIS by Harris (2013) has shown that for large project the main contractor may be directly managing around 70 and more sub-contracts of which a large proportion are small or less. For example, projects where 70% of sub-contracts are below certain contract price (£50,000 or less). Notwithstanding the structure of the industry, insufficient material or not supply in time, material type mismatch or quantity mistake of material and equipment will demonstrate supply chain problems and cause fragmentation in the main contracting organisation.

Other technical risks that can impact megaproject performance include: scheme design risk such as difficulty of engineering, defective design, inefficient optimized construction scheme, large percentage of new technology adopted; too advanced scheme, unqualified technology, insufficient estimation, over-evaluation of one's own strength, underestimate rivals, risk of construction quality, poor time management during project control, the confused financial administration and many others.

2.3.3: Economic Risks

Economic risks for megaproject development are mostly risks of project finance that evolve during the project delivery (Baloi and Price, 2003). For example, inadequate sources of project funds by an owner or funding agent may create time delays and financing problems. Capital costs of projects are also influenced by fluctuations in the exchange rates of foreign currencies against the dollar, inflation, and many other financial and economic factors such as tariffs and fiscal policies (Chen et al., 2004; Leung et al., 2004, Ling and Lim, 2007). The term Project Financing refers to a wide range of financing structures where the provision of funds is not primarily dependent upon the credit support of the sponsors or the value of the project’s physical assets but on project’s capacity to service the debt and provide an equity return to the sponsors through its cash flows (Wang *et al.,* 2000). Project finance involves the setting up of an “ad hoc” project company (called Special Purpose Vehicle - SPV) to carry out the venture (Opler *et al.*, 1997). According to Opler, the SPV is capitalised through equity and debt funding which is used to cover project capital expenditures and pre-operational costs; once the project is completed, the SPV can start its commercial activities thus generating the necessary cash flows to repay the financing.

Risk management is essential to ensure the project is completed on time, to budgeted cost and the delivery of service in line with expected standards. As cash flow generation depends on all these variables, financiers are closely concerned with the feasibility of the project as a whole and with the way to manage the impact of potentially adverse factors (Xenidis and Angelides, 2005 and Molenaar, 2005). A successful financing structure for megaprojects entails a balanced allocation of project risks among the various interested parties (Kapila and Hendrickson, 2001). These risks must be fully understood by all involved parties and must be properly mitigated.

In transportation megaproject such as Tram network construction, financing the nature and level of risks vary during the life cycle of the project and fall into two broad areas of completion and market (Opler *et al.*, 1997). Completion risks may arise during investment phase, while market risk is associated with the operational one.

2.3.3.1: Completion Risks

Completion risk is the risk that the mega transportation system will not be completed within the established performance, schedule and cost objectives (Poole and Peter, 2011). This type of risk basically evolves from three sources such as the adoption of unproven technologies or innovative technical solutions; the involvement of inexperienced project managers; and an inadequate definition of contractual structure. For most megaprojects, the government or the major project financiers will examine carefully the contractual obligations of the contractor vs. the SPV and will require that certain provisions be contained in the relevant contracts. The most common structure of project finance construction contract is the Engineering, Procurement and Construction (EPC) Contract. An EPC contract generally provides for the obligation of the contractor to build and deliver the project facilities on a turnkey or fixed price basis, that is, at a certain pre-determined fixed price, by a certain date, in accordance with certain specifications, and with certain performance warranties. EPC contract is quite complicated in terms of legal issues therefore the project company the EPC contractor should have enough experience and knowledge about the nature of the project in order to avoid their faults and minimize risks during the contract execution. Other alternative forms of construction contract are project management approach and alliance contracting. Basic contents of an EPC contract are description of the project; contract price; payment; completion date; completion guarantee and Liquidated Damages (LDs); performance guarantee and LDs and Cap under LDs.

Since vendors will be willing to enter into such a contract only if the system's requirements are well developed this will give the lenders a high degree of confidence that the system can successfully be completed. In addition, the contract will be structured around an incentive payment scheme which involves the contractor placing a portion of the contract price at risk (i.e. the contractor is paid a part of the contract only if the system meets performance criteria during its nominal in-orbit life). Clearly, the greater is the portion "at risk" and the level of performance required, the greater is the contractor's commitment to the new system and, consequently, financiers' confidence in the venture.

2.3.3.2: Market Risk

Market risk is the risk the target market will not materialise. In project finance this risk must be carefully assessed and mitigated; the most usual way of doing this is through an agreement between the project company and the operator. The project company delegates the operation, maintenance and often performance management of the project to a reputable operator with expertise in the industry under the terms of the Operations and Maintenance (O&M) agreement. The operator can be one of the sponsors of the project company or third party operator. In other cases the project company may carry out the operation and maintenance of the project by itself and may eventually arrange for the technical assistance of an experienced company under a technical assistance agreement. Basic contents of an O&M contract are Definition of the service; Operator responsibility; Provision regarding the services rendered; Liquidated damages and Fee provisions.

As indicated in section 2.4.3, not only the nature but also the level of project risks varies over the life cycle of megaproject development. The investment phase comprises all the activities associated with the construction of project assets, under a turn-key contract, that is the capital expenditure relating to the ground infrastructure. The investment phase starts with the so called “Financial closure” when the financing contracts are finalised and the SPV is entitled to draw down the funds and ends when the project’s assets are completed and the SPV starts commercial operations to generate revenues.

2.3.4: Environmental Risks

‘Environmental risks are risks to the natural health and productivity of environmental systems and risks to human health stemming from alteration and/or degradation of environmental systems’ (Lerche and Glaesser, 2006 as cited in Chen, Z., et al., 2011). These risks include extreme natural disasters (Storms, flood, landslides, snow, hailstorm, earthquake, tsunami, etc.) and socioeconomic consequences (Chen, Z., et al., 2011). Failure to mitigate these risks can result in serious impacts such as erosion, permanent loss of wild life, community severances, increased accidents, and destruction of indigenous lifestyles.

For construction projects, several aspects of environmental issues have been identified by academic researchers in the literature. According to Chen et al. (2000), dust, harmful gases, noise, solid and liquid wastes, fallen objects, and ground movements are types of pollution and/or hazards sources from construction activities which impact on the environment. Chen et al., (2005) considered construction impacts on the natural and social environments under eight categories: soil and ground contamination, ground and underground water, construction and demolition waste, noise and vibration, dust, hazardous emissions and odours, wildlife and natural features impacts and archaeology impacts. Cole (2000) emphasised that resource use, ecological loading and human health issues are the major impacts of construction process on the environment.

In Shen and Tam (2002) construction environmental impacts were classified as environmental resources extraction (fossil fuels and minerals); the extension of generic resources consumption (land, water, air, and energy); the production of waste that require the consumption of land for disposal; and pollution of the living environment with noise, odours, dust, vibrations, chemical and particulate emissions, and solid and sanitary waste.

The study by March (1992) categorised environmental impacts by the construction industry under ecology, landscape, traffic, water, energy, timber consumption, noise, dust, sewage, and health and safety hazards. These impacts by construction activities typically cause negative effects which include waste production, mud, dust, soil and water contamination and damage to public drainage systems, destruction of plants, visual impact, noise, traffic increase and parking space shortage and damage to public space Cardoso (2005). Failure to mitigate these risks can result in further potential occupational health and safety risks, primarily in the areas of erosion, permanent loss of wild life, community severances, increased accidents, and destruction of indigenous lifestyles (Chau, 1995). For example, exposure to dust particles, toxic fumes from chemicals used in material testing and many other hazardous materials can damage both the natural and human health. Figure 2.2 indicates the major effects of the construction industry on the natural environment.

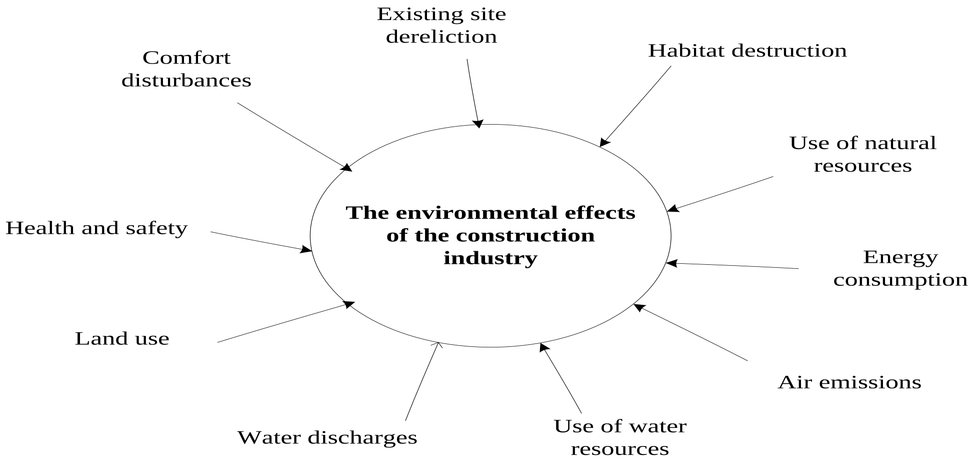


Figure 2.2: The Main Environmental Effects of Construction Activities. Source: Griffith, (1994)

2.3.5: Political Risks

Political risks may arise from the interactions between the government and the surrounding environment or society. Typically, they prevail from politically motivated events that adversely affect investments, contracts, or other businesses, be it national or international. In megaproject development and construction, the exercise of political power is the root cause of political risks in its delivery. For example, changes in laws and regulations permit requirements and government approvals, changes in pollution laws, and public consultation.

According to Kettis (2004) political risk is difficult to clarify due to the fact that it is a phenomenon present in the interface between an organization and a political environment and involves the concepts of risk and uncertainty, political sources and political environments. At a general level political risk is 'an implicitly unwanted political activity' (De-Mortanges and Aller, 1996) and has been classified under two categories (See Table 2.5); risks arising from government action and risks arising from government and societal events, also known as instability risks.

Table 2.5: Political Risks Classification and Categories in Project Development

Risks Classification	**Category**	
	Government Risks	Instability Risks
Firm-Specific	– Discriminatory regulations – "Creeping" expropriation – Breach of contract	– Sabotage – Kidnappings – Firm-specific boycotts
Country-Level	– Mass nationalizations – Regulatory changes – Currency inconvertibility	– Mass labour strikes – Urban rioting – Civil unrests – politically motivated violence

The first distinction that must be made is between firm-specific political risks and country-specific political risks (Murray, 2007). Firm-specific political risks are risks directed at a particular company and are, by nature, discriminatory. For instance, the risk that a government will nullify its contract with a given firm or that a terrorist group will target the firm's physical operations are firm-specific. By contrast, country-specific political risks are not directed at a firm, but are countrywide, and may affect firm performance. Examples include a government's decision to forbid currency transfers or the outbreak of a civil war within the host country (Reinersten and Reinersten, 2000). Firms may be able to reduce both the likelihood and impact of firm-specific risks by incorporating strong arbitration language into a contract or by enhancing on-site security to protect against terrorist attacks. By contrast, firms usually have little control over the impact of country-level political risks on their operations.

There is a second distinction to be made between types of political risk: government risks and instability risks (Murray, 2007). Government risks are those that arise from the actions of a governmental authority, whether that authority is used legally or not. A legitimately enacted tax hike or an extortion ring that is allowed to operate and is led by a local police chief may both be considered government risks. Indeed, many government risks, particularly those that are firm-specific, contain an ambiguous mixture of legal and illegal elements. Instability risks, on the other hand, arise from political power struggles. These conflicts could be between members of a government fighting over succession, or mass riots in response to deteriorating social conditions.

With regard to megaprojects development, political risks are frequently classified into two categories: project risks and general risks (Loosemore et al., 2006). Project risks are those specific to the project’s micro-environment and include such risks arising from the technical, contractual, management and site conditions. General risks are those arising from the project’s macro-environment. General risks have a significant impact on the outcome of the project and include legal, political, economic, social or technological risks. It is recognized by project sponsors that the most significant general risk to a project is political risk. Whereas project risk is identified, quantified and assessed to form part of the business cases (value for money) for decision making, it is the general risks such as political risk that are not (Gannon, 2007). Some project sponsors have experienced problems in identifying and representing political information that is political support for a project, within a project’s business case and using this information to make decisions on the political risk associated with a project. In many instances there is a tendency for project sponsors to focus on the quantifiable aspects for the business case for decision making and keep the qualitative political information for decision making outside of the business case. Fundamentally, a project’s business case is used as a tool to support project decision making and planning.

Table 2.6: Summary of Types and Sources of Risks in Megaproject Construction

No	**Risk Type**	**Risk Source**	**Reference(s)**
1	**Social**	Inability to obtain land and access rights	Hilber and Robert-Nicoud, (2013), Turner *et al*., (2011), Funderburg *et al.*, (2010), Glaeser and Ward, (2006).
		Compensation costs higher than expected	Hilber and Robert-Nicoud, (2013), Turner *et al*., (2011), Funderburg *et al.*, (2010), Glaeser and Fraser, (1990), McTague and Jergeas, (2002).
		Community and legal actions	Funderburg *et al.*, (2010)
		Delays dues to Local labour disputes	Alinaitwe, Mwakali and Hansson, (2007), Al-Momani, (2000). McTagueand, (2002), Fraser, (1990), Al-Momani, (2000). Case: the Vasco da Gama Bridge (EC, 2003), the Thailand Underground Rail Project (Ghosh & Jintanapakanont, 2004).
		Threats to personal or asset security	Alinaitwe, Mwakali and Hansson, (2007), Jones and Brinkert, (2008).
		Vandalism & damage	Alinaitwe, Mwakali and Hansson, (2007), Al-Momani, (2000). Jones and Brinkert, (2008).
		Cost overruns	Bruzelius, Flyvbjerg and Rothengatter, (2002), Altshuler and Luberoff, (2003), Lee, (2008), Fraser, (1990), Singh, (2009).
		Third party claims	Galloway, (2009)
		Costs due to disputes, community and legal action	Alinaitwe, Mwakali and Hansson, (2007), Al-Momani, (2000). Jones and Brinkert, (2008). Funderburg *et al.*, (2010)
		Involvement of too many Multi-level decision making bodies	Winch, (2000), Olander and Landin, (2005), Bourne and Walker, (2006), Miller and Lessard, (2001), Jafaari, (2004).
		Social issues and grievances	Soderholm, (2008), Cole, (2000), Chen *et al.*, (2005), March, (1992), Cardoso, (2005).

Table 2.6: Summary of Types and Sources of Risks in Megaproject Construction (Continued)

No	Risk Type	Risk Source	Reference(s)
2	**Technical**	Ambiguity of project scope/ Scope change	Miller & Lessard, (2008), HS2 Ltd (2009), Case: the Channel Tunnel Rail Link(PAC, 2006a), the Thailand Underground Rail Project (Ghosh & Jintanapakanont, 2004), Edinburgh Trams (Audict Scotland, 2011)
		Ground conditions on given project sites	Tommy *et al.*, (2006), Case: the Thailand Underground Rail Project (Ghosh & Jintanapakanont, 2004).
		Inadequate project complexity analysis	Audit Scotland, (2011); Brockmann, (2007); HS2 Ltd (2009), Yasemin (2013),
		Unforeseen modification to project	Audit Scotland (2011), HS2 Ltd (2009). Case: the Thailand Underground Rail Project (Ghosh & Jintanapakanont, 2004).
		Inaccurate project cost estimate	Audit Scotland (2011)., HS2 Ltd (2009), Yasemin (2013),
		Failure to meet specified standards	Audit Scotland (2011). HS2 Ltd (2009), Yasemin (2013).
		Technical difficulties in utilities diversions	HS2 Ltd (2009), Audit Scotland (2011), Yasemin (2013),
		Engineering and design change	Austin (2000), Choo *et al.*, (2004), Ross,Cartwright and Novakovic (2006). Case: the BBC's White City 2 Development (PAC, 2006b), the Melbourne City Link (Hodge, 2004), The Thailand Underground Rail Project (Ghosh & Jintanapakanont, 2004).
		Supply chain breakdown	Haynes, (2002), Eglin (2003), Norrman and Jansson (2004), Kane (2001), CIOB (2010), Wolstenhome, (2009), 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).
		Project time overruns	Jyh-Bin Yang *et al.*, (2010), Fugar (2010), Yasemin (2013), Chidambaram, *et al.*, (2012), Shaikh and Muree (2010), Kang, (2010), Kikwasi,(2012), Safer ali *et al.*, (2012), Mohd (2010),
		Project cost overruns	Jyh-Bin Yang *et al.*, (2010), 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).
		Project delays of all forms	Jyh-Bin *et al.*, (2010), Fugar (2010), Yasemin *et al.*, (2013), Chidambaram, *et al.*, (2012), Shaikh and Muree, (2010), Kang, (2010), Kikwasi, (2012), Safer ali *et al.*, (2012), Mohd (2010).

Table 2.6: Summary of Types and Sources of Risks in Megaproject Construction (Continued)

No	Risk Type	Risk Source	Reference(s)
3	**Economic**	Change in government funding policy;	Haynes, (2002). Case: the Melbourne City Link (Hodge, 2004), the London Underground (EC, 2002)
		Taxation changes	the London Underground (EC, 2002)
		Change in government	Hertogh *et al.*, (2008)
		Wage inflation;	Frimpong *et al.*, (2003); Denini, (2009). Case: the Channel Tunnel Rail Link (PAC, 2006a), the Thailand Underground Rail Project (Ghosh & Jintanapakanont, 2004)
		Local inflation change;	Frimpong *et al.*, (2003). Case: the Channel Tunnel Rail Link (PAC, 2006a), the Thailand Underground Rail Project (Ghosh & Jintanapakanont, 2004)
		Foreign exchange rate;	Case: the North-South Expres sway (NSE) and the Kuala Lumpur-Karak Highway(The Work Bank, 1999), the Water Conservancy and Hydropower Project in Southern China (Lu, 2004), the Thailand Underground Rail Project (Ghosh &Jintanapakanont, 2004).
		Material price changes;	Audit Scotland (2004), Haynes (2002)
		Economic recession;	Audit Scotland (2004), Haynes (2002).
		Energy price change/interest rate	Case: the North-South Expressway (NSE) and the Kuala Lumpur-Karak Highway (The Work Bank, 1999), the Harnaschpolder Wastewater Treatment Project (Smith, 2006).
		Catastrophic environmental effects;	Case: the Great Belt and Oresund Links/Demark (Flyvbjerg et al., 2003), the London Underground (EC, 2002), the Channel Tunnel Rail Link (PAC, 2002b), the Melbourne City Link (Hodge, 2004), the Labin B-Power Plant (Lu, 2004), the Thailand Underground Rail Project (Ghosh & Jintanapakanont, 2004).
		Project technical difficulties	Audit Scotland (2004)
		Project delays of all forms	Jyh-Bin *et al.*, (2010), Fugar (2010), Yasemin *et al.*, (2013), Case: the Melbourne City Link (Hodge, 2004), the Thailand Underground Rail Project (Ghosh & Jintanapakanont, 2004).

Table 2.6: Summary of Types and Sources of Risks in Megaproject Construction (Continued)

No	**Risk Type**	**Risk Source**	**Reference(s)**
4	Environ - mental	Environmental issues from works (Pollution)	Tommy (2006), Case: the Great Belt and Oresund Links/Demark (Flyvbjerg *et al.*, 2003).
		Unfavourable climate conditions (Snow, rain, etc.)	Case: the Great Belt and Oresund Links/Demark (Flyvbjerg *et al.*, 2003), the London Underground (EC, 2002), the Channel Tunnel Rail Link (PAC, 2002b), the Melbourne City Link (Hodge, 2004), the Labin B Power Plant (Lu, 2004), the Thailand Underground Rail Project (Ghosh & Jintanapakanont, 2004).

Table 2.6: Summary of Types and Sources of Risks in Megaproject Construction (Continued)

No	**Risk Type**	**Risk Source**	**Reference(s)**
5	Political	Change in government funding policy	Haynes, (2002). Case: National Air Traffic Services (NAO, 2004b; PAC, 2003), the Melbourne City Link (Hodge, 2004), the London Underground (EC, 2002), the London Underground (EC, 2002)
		Political opposition/interferences	Case: the Bangkok Elevated Road and Track System (The Work Bank, 1999), the Constanta Water Project (EC, 2004b), the Prescom in Targoviste. (EC, 2004b).
		Government discontinuity	Flyvbjerg *et al.*, (2003).
		Lack of political support	Flyvbjerg, *et al.*, (2003). Case: the Bangkok Elevated Road and Track System (The Work Bank, 1999), the Constanta Water Project (EC, 2004b), the Prescom in Targoviste. (EC, 2004b),
		Political indecision	Ruuska *et al.*, (2009). Haynes, (2002).
		Project termination	Case: the North-South Expressway (NSE) and the Kuala Lumpur-Karak Highway (The Work Bank, 1999).
		Delay in obtaining consent/Approval;	Case: National Air Traffic Services (NAO, 2004b; PAC, 2003), the Water Infrastructure in Southern China (Lu, 2004).
		Legislative/regulatory changes	Case: National Air Traffic Services (NAO, 2004b; PAC, 2003), the Melbourne City Link (Hodge, 2004), the London Underground (EC,2002),
		Protectionism	Perminova *et al.*, (2008)
		Delay in obtaining temporary Traffic Regulation Orders (TROs)	Audit Scotland (2011)

2.4: Risk Management Process

ISO 31000 defined risk management as the central part of the strategic management of any organisation. It is the process whereby organisations methodically address the risks attached to their activities. The focus of risk management is to assess significant risks so that suitable risk responses can be implemented to achieve maximum but sustainable value from all the activities of the organisation. Risk management enhances the understanding of the potential factors that affect an organisation. It increases the probability of success and reduces both the probability of failure and the level of uncertainty associated with achieving the objectives of the organisation.

According to Arrow (2008), the practice of risk management began to evolve many decades ago in the insurance and financial sectors and has only become an integral part of the construction industry over the last few decades. Arrow emphasized that project risk management was recognized as a separate management function not until the 1950s. This specialized methodology for risk management developed rapidly and has become a global standard of practice in a shorter frame of time due to rapid advancement of technology.

Despite the coming of age of risk management as a profession, Baker et al., (1999) established that “there is no global (project risk management) industrial standard”. This implies that there is also a wide range of risk definitions (see Table 2.7), and risk management standards have been discussed in the literature and within the domain of project management since the mid-1990s. Some of these standards (See Table 2.8) include the BS 31100:2011; BS ISO 31000:2009; BS EN 31010:2010; BS 6079 3:2000, BS IEC 73:2002 and the risk management standards published jointly by the Association of Insurance and Risk Managers (AIRMIC), the National Forum of Risk Management in the Public Sector (ALARM), the Institute of Risk management (IRM) (AIRMIC et al, 2002) and CIRIA guide to the systematic risk management for construction (Godfrey, 1996).

The BS 31100:2011 recognizes the risk management process as “an essential part of good management” and defines it as the “effect of uncertainty upon objectives”. Risk management is the “coordinated activities to direct and control an organization with regard to risk”.

Table 2.7: Definitions of Risk

Reference	Year	Definition
BSI.	2011	The effect of uncertainty upon objectives
HM Treasury	2004	The uncertainty of outcome, whether positive opportunity or negative threat of actions and events
AIRMIC et al.	2002	The combination of the probability of an event and its consequences
BSI,	2002	Uncertainty inherent in plans and the possibility of something happening (i.e., a contingency) that can affect the prospect of achieving business or project goals.
BSI	2000	The combination of the probability of an event occurring and its consequences for project objectives
Godfrey	1996	The chance of an adverse event
ISO/IEC Guide 73		The combination of the probability of an event and its consequences.

Royer (2000) emphasized that risk management for a megaproject must be of critical concern to project managers, as unmanaged or unmitigated risks can be disastrous and cause chronic project failure. According to Schaufelberger (2005), “the current level of risk management is often driven by the capabilities of the available tools and techniques. Schaufelberger emphasized that the depth of analysis could be improved by the use of advanced information technology capabilities to enable effective knowledge management and learning from experience, for example using artificial intelligence, expert systems or knowledge-based systems to permit new types of analysis”.

In 2002, Del Cano and de-La Cruz established that the UK Ministry of Defence, British Standards Institution (BSI), US National Aeronautics and Space Administration (NASA), US Department of Defence and US Department of Transport have adopted five iterative phases of risk management processes. The five phases which include initiation, identification, analysis, response planning and control, were also recognised by leading project risk management guides such as the Project Risks Analysis and

Management Guide (PRAM) and the Project Management Body of Knowledge (PMBOK).

Table 2.8: Definitions of Risk Management

Reference	Definition
BSI, 2011	The coordinated activities to direct and control an organization with regard to risk
AIRMIC et al, 2002	The process whereby organizations methodically address the risks attaching to their activities with the goal of achieving sustained benefit within each activity and across the portfolio of all activities.
BSI, 2002	Systematic applications of policies, procedures, methods and practices to the task of identifying, analyzing, evaluating, treating and monitoring risk.
PMI, 2004	The processes involved in identifying, analyzing and responding to risk. It includes maximizing the results of positive events and minimizing the consequences of adverse events
HM Treasury, 2004	The structured approach to identifying, assessing and controlling risks that emerges during the course of the policy, programme or project life cycle.
BSI, 2000	The systematic application of management policies, procedures and practices to the task of establishing the context, identifying, analyzing, evaluating, treating, monitoring and communicating risk.

More recently, researchers consider risk management from a broader perspective (Baldry, 1998; Chapman, 1997 and Williams, 1994) that incorporates opportunity management (Hillson, 2002; Olsson, 2007) and uncertainty management (Ward and Chapman, 2003; Perminova et al., 2008) to have better management and stakeholder buy-ins. Klein and Cork, 1998; Ward, 1999; Hendrickson, 1998; Baccarini and Archer, 2001; Raz and Micheal, 2001; Dvir et al., 2003; Chapman and Ward, 2004; and Barber, 2005 believed that these will provide effective relationships between project planning and project success.

Uher and Toakley (1999) as cited in Zou et al., (2007), also investigated various structural and cultural factors concerned with the implementation of risk management in the conceptual phase of a project life cycle and found that while most industry practitioners were familiar with risk management, its application in the conceptual phase was relatively low; qualitative rather than quantitative analysis methods were generally used; widespread adoption of risk management was impeded by a low knowledge and skill base, resulting from a lack of commitment to training and professional development. Figure 2.3 indicates a simplified version of a systematic risk management process obtained from ISO 31000.

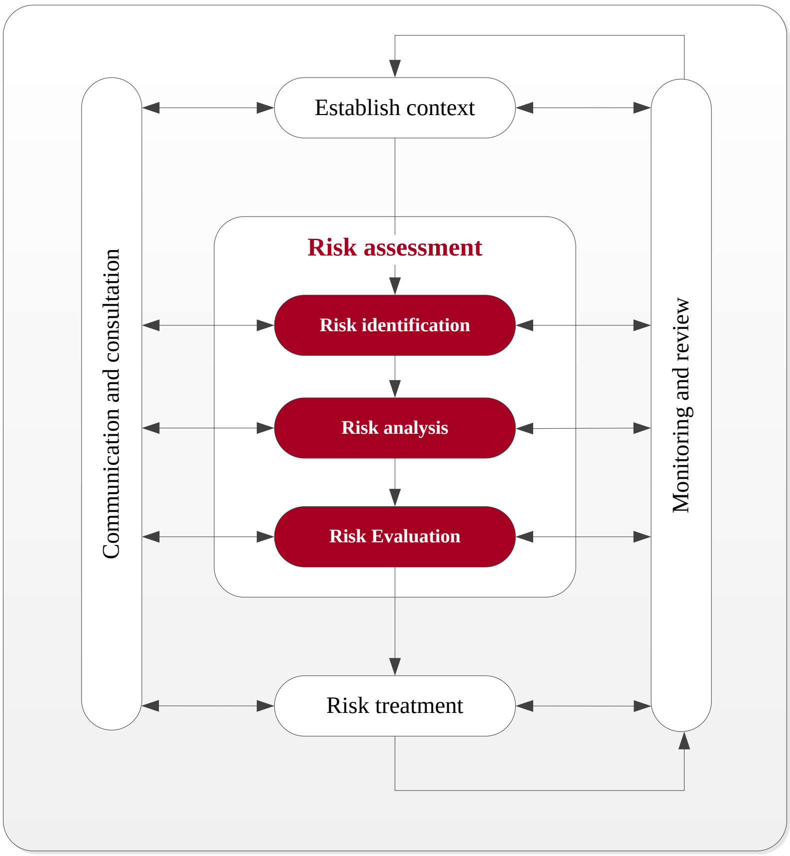


Figure 2.3: Risk Management Process (ISO 31000, 2009)

2.4.1: Establishement of Context

Risk management context is a management process at the strategic level within organisations that follows specific context of project management processes and the internal and external environment of the organisations. Within the context, Project managers must:

- Ensure that the risk management strategy has been developed in accordance with best practice, including establishing criteria for risk evaluation.
- Define proposal/project scope and objectives including key performance indicators
- Develop the risk management methodology to be used for assessing the proposal or project
- Define the objectives and expected benefits of the risk management process
- Consult with key stakeholders (internal and external) to agree appropriate levels of materiality.

2.4.2: Risk Assessment

Risk assessment is the initial process before setting priorities and deciding on cost-effective measures to control risks. To assess major risks effectively, the megaproject risk analyst must evaluate STEEP risks in two fundamental dimensions: (1) the magnitude of the potential critical outcomes, and (2) the probabilities attached to them. Risk assessment is not only limited to the analysis of a single worst case scenario. It can provide a global picture and may therefore be presented as a set of probability distributions over a full range of possibilities. The following is an overview of the approaches involved in risk assessment.

2.4.2.1: Risk Identification

The process of risk identification creates understanding of risks and their categories for an effective risk management system. BS 31100:2011 defines risk identification as the: "process of finding, recognising and describing risks" and recommends a systematic approach to risk identification as do other recognised standards (BSI, 2000, AIRMIC et al, 2002, Godfrey, 1996) such as risks that influence progress, health and safety, the natural environment, budget, schedule and quality of projects under development. The advantages and disadvantages demonstrated by these methods should always be taken into account when using them in corporate practice. These and other techniques have been used by academic researchers to identify various projects risks in the construction project management domain.

Due to the fact that these techniques are well-known and thoroughly-discussed in the scientific literature, this report does not provide detailed descriptions about them. Rather, the strengths and weaknesses of some of them are sourced from the Practice Standard for Project Risk Management and represented in Table 2.9. The advantages and disadvantages of these and other specific methods and techniques should always be taken into account, when managing megaprojects. Since every project is different, a decision on which a method is chosen and applied will depend on a situation and its specific needs and has to be made on a case-by-case basis. The methods listed in Table 2.9 are just a few examples out of the many more comprehensive methods and techniques described in the literature (Marcinek et al., 2010).

Additionally, there are other risk management methods that include consideration of risks to the natural environmental, social values, and as well as other factors such as the performance history of the development proponent. Within the risk management framework, Environmental Risk Assessment provides such assessment for determining the environmental and social risk aspects of the project under development. The assessment process, which is also called the Environmental and Social Impact Assessment (ESIA), is the process of identifying, estimating and evaluating the environmental and social consequences of current or proposed project. For construction projects, it is carried out to enable project planners to forecast and prevent negative environmental impacts, and to establish management mechanisms that will ensure compliance with regulatory standards and minimize the negative impacts on the natural and social environment (Ingold, 2000). Increasingly, there is a tendency to integrate the assessment of social impacts and benefits into EIAs to produce Environmental and Social Impact Assessment (ESIAs) (Windsor and McVey, 2005). In some cases, Social Impact Assessments (SIAs) may be prepared separately from the EIA where a more detailed analysis of social impacts than can be achieved within an ESIA is required.

Changes in the practice of Environmental Impact Assessment (EIA) and advances in information technology have greatly expanded the range of tools available to the EIA practitioner (See Table 2.10). For example, map overlay methods, originally pioneered by McHarg (1971), have evolved into sophisticated Geographic Information Systems (GIS). Expert systems, a branch of artificial intelligence, have been developed to help in screening, scoping, developing terms of reference (TOR), and conducting preliminary assessments. These systems use comprehensive checklists, matrices, and networks in combination with hundreds of impact rules developed by EIA experts. The global embrace of sustainable development has made the analysis of costs and benefits an integral part of EIA. This has forced the expansion of factors to be considered in traditional cost benefit analysis.

From a company's perspective, an ESIA with an appropriate socio-economic focus, based on State government decisions should not only satisfy regulatory requirements (Pearce, 1998), but also contribute to the improvement of its internal project design, construction and implementation activities as a means of minimizing negative impacts on both the society and the natural environment. As indicated in Table 10, many of the ESIA processes of the risk management standards provide comprehensive approaches to decision making. However, their effectiveness in dealing with risks relies on the ability to cope with the multidimensional uncertainty of risks: likelihood, impact and occurrence from the projects external macro environment.

Traditional tools are unable to address risks in megaproject construction. As a result, many megaproject developments fall short in achieving their intended cost and schedule objectives during construction. The problems and limitations identified call for further approaches supported by specialized tools and techniques as strategies for managing risks during megaproject development and construction. This is important not only in terms of the democratic process, but helps to identify what stakeholders perceive to be potential negative socio-economic impacts of a megaproject under development on them and the natural environment.

Table 2.9: Risk Identification Tools and Techniques

Technique	Strengths	Weaknesses	CSFs for Effective Application
Analytic Hierarchy Process	− Assists in developing a relative weighting for project objectives that reflects the organization's priorities for time, cost, scope and quality for the project − Assists the creation of an overall project priority list of risks created from the risks' priority with respect to individual objectives	− Organisational decisions are often made by committees, and individuals may not agree on relative priority among objectives − Difficult to gather the information about pair-wise comparison of the objectives from high-level management	− Expert facilitator in the process − Agreement by management that it is useful to develop a consistent set of priorities among objectives − Use of proper method or available AHP software
Assumptions & Constraints Analysis	− Simple structured approach − Can be based on assumptions & constraints already listed in project charter − Generates project specific risks	− Implicit/hidden assumptions or constraints are often missed	− Requires a comprehensive list of assumptions & constraints
Brainstorming	− Allows project participants contribute to the discussion − Can sometimes involve all key stakeholders − Generates creative ideas	− Requires attendance of key stakeholders at a workshop, therefore can be difficult to arrange and expensive − Prone to Groupthink and other group dynamics − May produce biased results if dominated by a strong person (often management) − Often not well facilitated − Generates non-risks and duplicates, requires filtering	− Attendance of representative group of stakeholders − Requires commitment, honesty & Preparation − Good facilitation − Use of structure (e.g. RBS)
Cause and Effect Diagrams	− Visual representation of project promotes structured thinking	− Diagram can quickly become over-complex	− Effective selection of critical impacts (e.g. by use of sensitivity analysis)

Source: Based on: Practice Standard for Project Risk Management (2009). Project Management Institute, Inc., Newtown Square, pp.72-76.

Table 2.9: Risk Identification Tools and Techniques (Continued)

Technique	Strengths	Weaknesses	CSFs for Effective Application
Check lists	− Captures previous experience − Present detailed list of risks	− Check list can grow to become unwieldy − Risks not on the list will be missed − Often only includes threats, misses opportunities	− Regular maintenance is required − Use of structure can assist (e.g. RBS)
Delphi technique	− Captures input from technical experts − Removes sources of bias	− Limited to technical risks − Dependent on actual expertise of experts − May take longer time than available due to iterations of the experts' inputs	− Effective facilitation − Careful selection of experts − Clear definition of scope
Document review	− Exposes detailed projects specific risks − Requires no specialist tools	− Limited to risks contained in project documentation	− Understanding of relevance of prior experience
FMEA/Fault Tree Analysis	− Structured approach, well understood by engineers − Produces an estimate of overall reliability using quantitative tools − Good tool support	− Focuses on threats not so useful for opportunities − Requires expert tool not generally available to those except experts	− Detailed description of the area being assessed − Statistically accurate data on fault probabilities for many events
Force Field Analysis	− Creates deep understanding of factors that affect project objectives	− Time-consuming and complex technique − Usually only applied to a single objective, so does not provide whole-project view	- Prioritized objectives
Industry knowledge base	− Captures previous experience − Allows benchmarking against external organizations	− Limited to what has previously happened − Excludes project-specific risks	- Access to relevant information
Influence diagrams	− Exposes key risk drivers − Can generate counterintuitive insights not available through other techniques	− Requires disciplined thinking − Not always easy to determine appropriate structure	- Identify key areas to address

Source: Based on: Practice Standard for Project Risk Management (2009). Project Management Institute, Inc., Newtown Square, pp.72-76.

Table 2.9: Risk Identification Tools and Techniques (Continued)

Technique	Strengths	Weaknesses	CSFs for Effective Application
Interviews	− Addresses risks in detail − Generates engagement of stakeholders	− Time consuming − Raises non-risks, concerns, issues, worries etc., so requires filtering	- Good interviewing and questioning skills − Environment of trust, openness, confidentiality − Preparation − Open relationship between interviewer and interviewee
Nominal Group Technique	− Encourages and allows all participants to contribute − Allows for different levels of competence in common language − To a large extent, auto documenting − Provides ideal base for affinity diagramming (grouping by risk categories for use in the Risk Breakdown Structure and Root Cause Analysis)	− Can lead to frustration in dominant members who feel it is moving slowly	− Good briefing of all participant in the technique − Strict facilitation
Post-project reviews/Lessons learned/Historical Information	− Leverages previous experience − Prevents making the same mistakes or missing the same opportunities twice − Enhances the Organizational Process Assets	− Limited to those risks that have occurred previously − Information is frequently incomplete: details of past risks may not include details of successful resolution; ineffective strategies are rarely documented − Creative generation of ideas	− Well-structured project lessons learned database − Participation of previous project team members (ideally including the project manager)
Prompt Lists	− Ensures coverage of all types of risk − Stimulates creativity	− Topic can be too high level	− Choice of list relevant to the project and its environment

Source: Based on: Practice Standard for Project Risk Management (2009). Project Management Institute, Inc., Newtown Square, pp.72-76.

Table 2.9: Risk Identification Tools and Techniques (Continued)

Technique	Strengths	Weaknesses	CSFs for Effective Application
Probability and Impact Matrix (P-I Matrix)	− Allows the organisation to prioritise the project risks for further analysis (e.g., quantitative) or risk response − Reflects the organisation's level of risk tolerance	− Does not explicitly handle other factors such as urgency or manageability that may partly determine a risk's ranking − The range of uncertainty in the assessment of a risk's probability or impact may overlap a boundary	− P×I matrix requires that the input data are clear and unambiguous in assigning levels of probability and impact − Effective estimation of impact and likelihood as outlined previously − Organizations should be careful to assess the combinations of probability and impact that qualify a risk as low, moderate or high risk so that the method used reflects the organisation's risk attitude − Definitions used to designate the levels of impact (L,M,H) for each objective should represent the same level of impact as perceived by the organization's management or project stakeholders as reflecting the organisation's utility function
Questionnaire	− Encourages broad thinking to identify risks	− Success depends on the quality of the questions − Limited to the topics covered by the questions − Can be a simple reformatting of a checklist	− Clear and unambiguous questions − Detailed briefing of respondents
Risk Breakdown structure (RBS)	− Offers a framework for other risk identification techniques such as brainstorming − Ensures coverage of all types of risk − Test for blind spots or omissions	− None	− Requires a comprehensive RBS, often tailored to the project

Source: Based on: Practice Standard for Project Risk Management (2009). Project Management Institute, Inc., Newtown Square, pp.72-76.

Table 2.9: Risk Identification Tools and Techniques (Continued)

Technique	**Strengths**	**Weaknesses**	**CSFs for Effective Application**
Root-Cause Analysis	− Allows identification of additional, dependent risks − Allows the organization to identify risks that may be related because of their common root causes − Basis for development of pre-emptive and comprehensive responses − Can serve to reduce apparent complexity	− Most risk management techniques are organized by individual risk. This organization is not conducive to identifying the root causes − Can oversimplify and hide existence of other potential causes − There may be no valid strategy available for addressing the root cause once it has been identified	− Ability to identify if a risk is an outcome of a more fundamental cause − Willingness by management to accept and address the root cause rather than adopting partial workarounds
SWOT Analysis	− Ensures equal focus on both threats and opportunities − Offers a structured approach to identify threats and opportunities − Focus on internal (organizational strengths and weaknesses) and external (opportunities and threats)	− Focuses on internally generated risks arising from organizational strengths and weaknesses, excludes external risks − Tends to produce high level generic risks, not project-specific	− Good facilitation − Strict adherence to the technique, to avoid confusing the four SWOT perspectives (i.e. between Strengths and Opportunities, or between Weaknesses and Threats)
System Dynamics	− Exposes unexpected interrelations between project elements (feedback and feed-forward loops) − Can generate counterintuitive through other techniques − Produces overall impacts of all included events and risks	− Requires specialized software and expertise to build models − Focuses on impacts but difficult to include the concept of probability	− Understanding of feedback − Competence in applying tools and understanding their output − Quality of the system model − Accuracy of input data collected for the specific project

Source: Based on: Practice Standard for Project Risk Management (2009). Project Management Institute, Inc., Newtown Square, pp.72-76.

Table 2.10: Tools and Measures for Environmental Management

Tools and Measures	**Explanation, advantages and constraints**
Meteorological Forecast	– Based on data, geophysical and oceanic factors, statistical techniques, and climate variability. Meteorological forecast is possible on a seasonal, monthly, weekly and daily basis. – Forecast can be utilized for weather-related disaster prediction, which can provide warnings and information to prevent damage and permit escape during hazard events. – Accurate and timely warnings and forecasts are expected, but uncertainty should always be taken into account.
Geographic Information Systems (GIS)	– Computer systems capable of combining layers of digital data from different sources, including satellite images, to create maps and data sources. – Maps and data can support land-use planning, risk and vulnerability assessment, disaster forecasting, and hazard management. – Cost, specialized expertise, and commitment of updating data may be constraints in using this system.
Environmental Assessment (EA)	– EA is a framework of environmental analysis, and includes Strategic Assessment, Impact Assessment, Management Program, and Auditing. – At project level, EA helps in avoiding or mitigating negative impacts, or finding alternatives, and improving project design. – There are checklists and guidelines available for assessment, but evaluation is subjective, and predicting all negative impacts is difficult.
Social Assessment (SA)	– SA is a framework of social analysis, which investigates socio-cultural and social variables systematically. – Indigenous population, gender, and involuntary resettlement are key issues of Social Assessment
Institutional Building for Collaboration and Coordination	– Networking and coordination provides diversity of skills, knowledge, and resources, and collaboration between public, private, NGOs, International organizations, and local community to ensure maximum results of development efforts. – Each stakeholder has different needs and interests, and the bureaucratic organization has an inflexible and paternalistic nature, which makes it difficult to collaborate with other stakeholders.

Source: DAC/OECD Development Co-operation Report, (1993)

2.4.2.2: Risk Analysis and Evaluation

The key purpose of risk analysis is to establish the relationship between the likelihood of a given event and consequences of its occurrence. In practice, a highly significant stage within the risk analysis is the selection of an analysis method, i.e. when project managers or risk analysts choose a method, which allows the management team to analyse the predefined risk (Husnan, 2000). The main categories of risk analysis methods, which are used by companies, are presented in Table 2.11.

Table 2.11: Main Categories of Risk Analysis Methods

Main category	**Type of analysis**	**Description**
Simplified risk analysis	Qualitative	An informal procedure that establishes the risk picture using brainstorming sessions and group discussions. The risk might be presented on a coarse scale, e.g. low, moderate or high, making no use of formalised risk analysis methods.
Standard risk analysis	Qualitative or quantitative	This is a more formalised procedure in which recognized risk analysis methods are used, such as ANP/AHP where risk matrices are often used to present the results.
Model-based risk analysis	Primarily quantitative	This type of analysis makes use of techniques such as system dynamics, event tree analysis and fault tree analysis to calculate risk

Source: Aven, T. (2008): Risk analysis - Assessing uncertainties beyond expected values and probabilities, New Jersey: John Wiley & Sons Inc., p.4.

The result of the risk analysis can be used to produce a risk profile that gives a rating of significance to each risk and provides a tool for prioritising risk treatment efforts. This ranks the relative importance of each identified risk. This process permits the identified risks to be mapped to the project area affected, conveys an idea to how control mechanisms can be put in place and to demonstrate where the level of investment in controls might be increased, decreased or reapportioned (Frame, 2003).

The risk analysis activity assists the effective and efficient operation of the organisation by identifying those risks that require attention by management. This will facilitate the ability to prioritise risk control actions in terms of their potential to benefit the organisation. The ranges of available risk response treatments include tolerate, treat, transfer and terminate. An organisation may decide that there is also a need to improve the control environment (PMI, 2000 and 2009).

2.4.3: Risk Treatment

Risk treatment is presented in ISO 31000 as the activity of selecting and implementing appropriate control measures (Risk Action Plans) to modify the risk. Risk treatment includes as its major element, risk control (or mitigation), but extends further to, for example, risk avoidance, risk transfer and risk financing. Any system of risk treatment should provide efficient and effective internal controls. Effectiveness of internal control is the degree to which the risk will either be eliminated or reduced by the proposed control measures. The cost effectiveness of internal control relates to the cost of implementing the control compared to the risk reduction benefits achieved.

Compliance with laws and regulations is not an option. An organisation must understand the applicable laws and must implement a system of controls that achieves compliance. Risks responses in terms of broad risk management strategies like risk prevention (including risk avoidance), impact mitigation; risk sharing; insurance; and risk retention will be helpful in the response identification and assessment process to deal with risks. However, it should be recognised that some losses or elements of a loss may be uninsurable, such as uninsured costs and damage to employee morale and the reputation of the organisation.

2.5: Summary

This chapter has discussed some important generic issues regarding the significance of developing a new tool for assessing risks impact on megaproject performance during construction, especially, within the construction industry. While social, technical, economic, environmental and political (STEEP) risks were described as main contributors to project cost and time overruns and quality deficiency, it is observed that the dynamic assessment of such risks using a new risk assessment tool is yet to be reflected in construction management practice in the real world. Although, the construction of megaprojects provides a key contribution to wider economies and serves as underlying driver of employment in many local and regional communities, questions still remain about the potential STEEP risks impacts on these projects and also the debate about the negative effects of such large projects on local and regional communities where construction occurs.

As a result of the complex nature of these risks within global dimensions (Chen et al., 2011), megaprojects were described as being (1) extremely complex, consisting of multiple interdependent components, (2) highly dynamic, (3) involving multiple feedback process, (4) having nonlinear relationships and (5) require both “hard” and “soft” data (Sterman, 1992). There are innumerable other risks that can be associated with megaproject construction but are beyond the scope of this research.

Currently, in the construction management domain, potential risk impacts are assessed for megaprojects prior to commencement through many assessment procedures based on individual proposals. While these procedures remain important for the assessment of most new projects, they do not cover all impacts of megaprojects on regional communities. These and other unfavourable issues identified in current literature buttress the main motivation for much of the existing research and current studies on risks in megaprojects construction.

Using the Edinburgh Tram Network (ETN) Project as a case study, it is intended to address these risks appropriately by developing an integrated ANP and a SD methodology to assess the impact they have on project cost, time and quality during construction. It is contended that ETNP offers an appropriate foundation for this study because of its considerable significance and the huge socio-economic interest it attracts.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1: Introduction

This chapter discusses the methodology adopted for the research. It involves the systemic procedures upon which the research is based and against which the data collected is interpreted and the findings evaluated. To ensure a formal discourse on this research, the key research questions are first discussed followed by the research strategy and a commentary on the choice of the method including the research instrument design and the ethical consideration for the data collection. The data collection procedure is also described in this chapter. Subsequently, the relevant information on the respondents, the sampling frame and sample size are also presented. The chapter concluded on how data was collected and a summary of the methodology chapter.

3.2: The Research Questions

The key research questions in the introductory chapter 1, section 1.2 of this research and issues regarding risks in transportation megaproject discussed in the literature review (Chapter 2) are summarized in Table 3.1. *The Deductive reasoning* column explains the discussion about what issues have been resolved and remain unresolved. The *Research gaps* column indicates the unsolved issues and the corresponding research actions which are then converted into the research questions in order to arrive at a solution.

Table 3.1: The Issues Learned from the Literature and their Corresponding Deductive Reasoning, Research Gaps and Questions7

Issues learned from the literature	The Deductive reasoning	Research gaps	Research questions
1. Are risks in transportation megaprojects independent? How can the relationship of all risks be identified if they are not physically independent?	As discussed in the literature review, risks in transportation megaprojects may not be independent in reality.	There is a need to investigate which risks would have impact over project cost, time and quality during construction and how to model the dynamics of physical interaction effects of such risks on megaproject during construction stage for effective project delivery.	1. What are the generic risk events inherent in transportation megaprojects during construction? 3. How can risks interrelationships in transportation megaprojects be modelled?
2. Is there a general failure in estimating performance risks in transportation megaproject in the construction phase? Are the tools used to evaluate such risks appropriate?	As discussed in Chapter 2, the estimation for risk impacts on transportation megaprojects is not well dealt with in general. The available risks evaluation tools in literature have been identified to have their own advantages and limitations. For example, the cost effectiveness analysis (CEA) tool used for cost minimization is useful for project screening and ranking (Watson, 2005). However, the CEA coupled with multi-criteria decision making (MCDM) is subjective and causes failure in practice when members of risks evaluation board make rating for each criterion (Lebo & Schelling, 2001). Also, there is a wide belief that the implementation of transportation megaprojects are mainly for positive economic impacts (Mackie et al., 2003). However, the challenge to develop appropriate tools to convert qualitative risk effects on project performance in the construction phase into quantitative effects is a new thing for researchers to consider.	There is a need to convert qualitative risk into quantitative effects on project performance.	2. How can the qualitative risk effects on project performance be quantified, prioritized and analyzed in transportation megaprojects?

Table 3.1: The Issues Learned from the Literature and their Corresponding Deductive Reasoning, Research Gaps and Questions (Continued)

Issues learned from the literature	The Deductive reasoning	Research gaps	Research questions
3. What are the criteria and tools that are useful to evaluate, compare and assess risks holistically in transportation megaprojects under the current risks assessment and evaluation approaches?	As discussed in the literature review (Chapter 2), the current risks assessment tools usually ignore outcomes of 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 current tool in terms of risk assessment is so subjective that it can be easily manipulated (Shaoul, 2005). As a result, it is necessary to move from these assessment approaches to a more dynamic approach for transportation mega projects. (Grimsey & Lewis, 2005; Reilly, 2005; Reilly& Brown, 2004).	There is a need to apply robust risk assessment methods that are able to deal with the dynamism of risk variables in transportation megaprojects during construction	4. How can Project Managers assess the dynamics of risk effects in transportation megaprojects over time?

3.3: Research Strategy

As indicated in Figure 3.1, researchers utilized multi-strategy research paradigms to combine with a single case study incorporated with quantitative and qualitative research strategies. The diagram indicates the relationship of comparative methodological choices to meta-theory for the overall research strategy in this study.

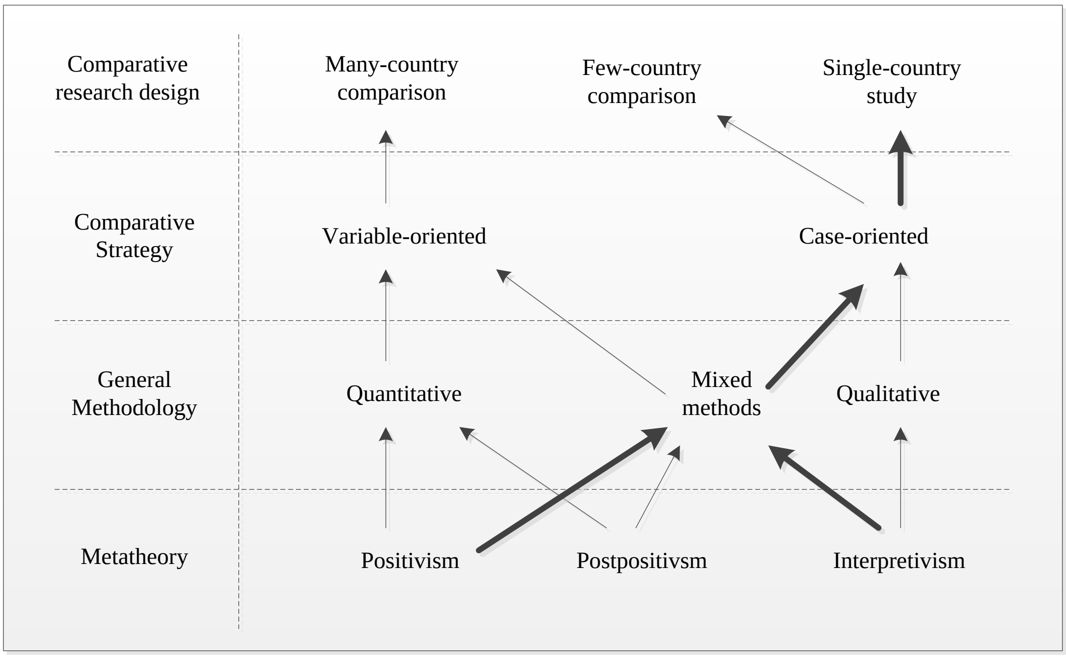


Figure 3.1: Relationship of Comparative Methodological Choices to Meta-Theory

Source: Lor (2011), chapter 4. P.6

To remain within the iceberg metaphor, the diagram should be read from the bottom (the metatheoretical level) upwards. Roughly following the levels distinguished by Pickard (2007), the methodological level has been divided into three sublevels, those of general methodology, comparative strategy, and comparative research design. Section 3.3.1 further explains the fundamental differences between the general strategies (research paradigms) adopted for the study, followed by research strategies for each research question in section 3.2.2.

3.3.1 Research Paradigms

Investigating megaproject risks dynamism requires a consideration of the overall research paradigm within which the research is to be undertaken, and the research methods that are appropriate within this paradigm. According to Pollack (2007), the term paradigm generally refers to "*a commonly shared set of assumptions, values and concepts within a community, which constitutes a way of viewing reality.*" As represented in Figure 3.1, there are two major paradigms in research. These are the qualitative paradigm (phenomenological or interpretive) and the quantitative paradigm (positivist). The quantitative paradigm (positivism) assumes that a social phenomenon obeys natural laws and can be subjected to quantitative logic while the qualitative paradigm (interpretivism) argues that a social phenomenon does not obey natural laws but is interpreted based on peoples' conviction and/or understanding of the realism surrounding the phenomenon (Walliman, 2006).

Table 3.2: Fundamental Differences between Quantitative and Qualitative Research Strategies

Orientations	**Qualitative**	**Quantitative**
Principal orientation to the role of theory in relation to research	Inductive; Generation of theory	Deductive; Testing of theory
Epistemological orientation	Interpretivism	Positivism
Ontological orientation	Constructionism/constructivism	Objectivism

Source: Adopted from Bryman, (2004)

In practice, the fundamental difference between the two traditions (See Table 3.2) is influenced by the epistemological and ontological assumptions underlying the research (Keraminiyage et al, 2005). Epistemology is a theory of knowledge (Stacy and Miles, 2007). It is used to define the knowledge through which a research process is investigated and developed (Smyth and Morris, 2007). On the other hand, ontology is a theory of the nature of social entities (Bryman, 2004). Saunders et al., (2009) state that ontology is a theory concerning the nature of social phenomena as entities that are to be admitted to a knowledge system.

By adopting positivism as the paradigm underpinning this study, the epistemological and ontological assumptions dictated that case studies, surveys and experiments would be most ideal as the research method. However, experiments in this research will not be an appropriate choice because such methods are carried out usually in a laboratory setting where the investigator can manipulate behaviour directly, precisely and systematically (Yin, 2009). In view of the nature of investigation associated with this research, experiment was discounted as an appropriate option. In surveys, samples are examined through questionnaires while case studies involve an empirical enquiry that investigates a contemporary occurrence within a real life context (Yin, 2009).

3.3.2. Research Strategies for Each Research Question

Based on section 3.3.1, research strategies and methods for each key research question were produced in Table 3.3.

Table 3.3: Cross-categorisation and matching of research question type and research strategy

Strategy	**Form of Research Question**	**Is Control of behaviour required?**	**Is there focus on contemporary events?**
Experiment	How, Why?	No	Yes
Survey	Who, What, Where. How many, How much?	No	Yes
Archival Analysis	Who, What, Where, How many, How much?	No	Yes/No
History	How, Why?	No	No
Case study	What, How, Why?	No	Yes

Source: adopted from Yin (2009)

The Table 3.3 indicates five major research strategies (experiments, surveys, archival analysis, histories and case studies) developed to determine when to use each research strategy (Yin, 2009). Table 3.3 further displays three conditions: (a) the type of research questions, (b) the extent of control a researcher has over actual behavioural events underlying each and (c) the degree of focus on contemporary as opposed to historical events, and shows how each is related to the five major research strategies. In column 1 of table 3.3 (form of research question), the basic categorization of the types of research questions is a familiar series: “who, what, where, how and why” (Yin, 2003a). Yin emphasised that two possibilities will arise if research questions focus on “what” questions. First, some types of what questions are exploratory, such as, “What can be learned from the study of risks in megaproject development?” This type of question can be justifiable when conducting 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. The second type of “What” question is in the form of a “How much” or how many line of inquiry. Identifying such outcomes is more likely to favour survey or archival records analysis strategies than others.

In column 2 of table 3.3 (requires control of behavioural events), “How” and “Why” questions become the focus of a research when further distinctions among various research strategies reflect the extent of the researcher’s control over behaviour and the degree of focus on contemporary events. Yin (2003a) emphasised that, histories will be preferred strategy for the “how” and “why” questions when there is virtually no access or control. This implies that, historical methods are for past events where there are no relevant people remaining alive from that historical period to testify. That also implies that, historical methods rely heavily on evidence from primary documents, secondary documents, cultural and physical artefacts.

Also, the case study method is preferred in research when examining contemporary events, but when the relevant behaviour cannot be manipulated in any other manner. Case studies and history strategies can overlap. However, the case study method has much more advantages than the historical method when dealing with the full variety of evidence such as documents, artefacts, interviews and observations beyond what might be available in historical study.

Yin (2003a and 2009) explained that the experiment strategy is done “when an investigator can manipulate behaviour directly, precisely, and systematically”. Yin (2003b) concluded that “even though each strategy has its distinctive characteristics, there are large overlaps among them.” To some extent; the various strategies are not mutually exclusive and as such can be applied as multiple strategies to any given study where necessary. For example, a survey can be applied within a case study or a case study within a survey. Based on Table 3.2 and Table 3.3, the researcher developed research strategies and methods for each research question. Table 3.4 explains further the rationales behind the use of a particular strategy and method for each research question.

Table 3.4: Research Strategies for Each Research Question10

Research question one	What are the generic risk events inherent in transportation megaprojects during construction?
Research strategy	Qualitative research
Research method	Literature survey incorporated with descriptive analysis
Rationales	This is a **'What'** question to explore the phenomena of generic types of risk events that are currently inherent in transportation megaprojects. Current empirical studies have investigated this phenomenon by case studies, statistical and descriptive analyses. There is no researcher access to or control of actual phenomena. As indicated in Table 3.3, the survey and archival record analysis are preferred research strategies. However, to explain meanings of nature of generic risk events in transportation megaprojects is different across projects. Descriptive analyses of qualitative research strategy and literature survey are applicable to the research question. Generally, a literature survey was conducted to collect secondary data from previous empirical studies in order to explore and interpret recognized risk factors and events that affect transportation megaprojects during construction. The researcher reorganized and defined a set of the generic types of risk factors and events that affect project cost, time and quality of transportation megaproject during construction from the collected secondary data based on the researcher's own rational interpretation.
Research question two	How can the qualitative risk effects on project time, cost and quality be quantified while using ANP to prioritized and analysed risks in transportation megaprojects?
Research strategy	Quantitative research
Research method	Questionnaire survey with statistical analysis.
Rationales	This was a 'How much' question to measure the phenomenon of qualitative risk effects on project time, cost and quality. There was no researcher access to or control over actual phenomena. Since each megaproject considered in this research were very unique and different from project to project, their historical data obtained on the qualitative risk effects and probability were also different to some extent and inadequate. The phenomenon for qualifying qualitative risk effects and probability depended on the subjective belief, perception, experience, judgment and prediction of the experts who are experienced in the selected project cases

	and practioners in transportation megaprojects development. In this regard, a decision group composed of academics, project managers, engineers, project stakeholders, and personnel in the selected case studies and some companies involved in the construction of Edinburgh tram network project were contacted through web based and mailed questionnaire surveys. The rationale was to obtain professional practioners' opinion on the level of risks impact on megaproject objectives (cost, time and quality) during construction using the score of a Likert scale 1 to 5 for ranking qualitative risks quantitatively. With suitable statistical techniques, the quantitative results were measured and finally prioritized using the ANP methodology.
Research question three	How can risks interrelationships in transportation megaprojects be modelled?
Research strategy	Qualitative and quantitative research
Research method	Literature survey, questionnaire survey, experts' opinion, computer aided modelling and statistical analysis.
Rationales	This is a **'How'** question to explain the phenomena about the cause-effect for risks and their interactions over transportation megaproject during construction, 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 dynamic, complex and very difficult to be directly observed, investigated, traced and explained by natural laws. Rather, they are able to be explored and processed from existing historical events of completed transportation megaprojects and practices. As indicated in Table 3.3, the preferred research strategies are case studies, historical analyses, archival records analyses, and surveys. Therefore, literature survey, questionnaire survey, experts' opinions, computer-aided cause and effect modelling and statistical analysis are applicable to the research question. A literature survey was first conducted to obtain secondary data from previous empirical studies, which provided some form of physical interaction scenarios for transportation megaproject risk events. Since every project is unique, the secondary data about the risk interrelationships were not supposed to be so close to the reality of a particular megaproject under consideration for model demonstration. Therefore, the researcher used Edinburgh Tram Network Project (ETNP)

	as a case study and inquired into the opinions of some senior project participants and experienced experts outside the case project by conducting interviews as a complementary approach for evidence convergence to reduce the gap between the investigated phenomena of secondary data and reality. Thereafter, data collected from both secondary means and experts were interpreted by causal loop diagrams to represent risk interrelationship over Edinburgh Tram Network Project in the construction phase. Finally, a statistical analysis was performed to formulate the interrelationships of physical risk.
Research question four	How can Project Managers assess the dynamism of risk effects in transportation megaprojects?
Research strategy	Qualitative research
Research method	Computer-aided modelling and simulation
Rationales	This was a **'How much'** question to measure the phenomenon for overall compounding risk effects on the objectives of transportation megaprojects. The rationales for this question are generally the same as those for research question three. A computer-aided cause and effects modelling and simulation will be conducted to estimate the overall risks profile arising from the interactions among identified risks over transportation megaproject in the construction phase.

3.4. The Research Methods

In principle, there are many research methods needed to fulfil various research needs (Wilkinson and Birmingham, 2003). The irony is that while there are indeed many research methods, there is no option an excellence (Schultze and Miller, 2004). Nevertheless, some methods are better suited for tackling specific issues than others. In a good research, the argument is that the choice should be appropriate, reasonable and explicit (Denscombe, 2003). Ignoring these fundamentals can lead to very poor research and may open the research findings to criticisms and doubt (Denscombe, 2003). Figure 3.2 illustrates the overall flow of the proposed framework for this study.

3.4.1. The Qualitative Phase

The qualitative paradigm, comprising such methodologies as action research, case studies, ethnographies, and grounded theory, has been strongly advocated for construction management research by Seymour and Rooke (1995), Rooke and Kagioglou (2007), and in particular for research into risks in construction. The utility of this paradigm as explained by Seymour and Rooke (1995) lies in the deeper understanding of the values and beliefs of others that can be derived by focusing on the points of view of individual practitioners, whilst recognising that the researchers have values and beliefs of their own that cannot be entirely eliminated. Qualitative methodologies are explanatory in nature with the principal aim of trying to unearth answers to ‘how?’ and ‘why?’ questions (Bryman, 2001), or trying to develop themes from the data (Creswell and Clark, 2007). This approach is ideally suited to investigation of risks in megaproject construction and can be conceptualised as an ideational phenomenon (anthropological perspective) or as a root metaphor (organisational perspective).

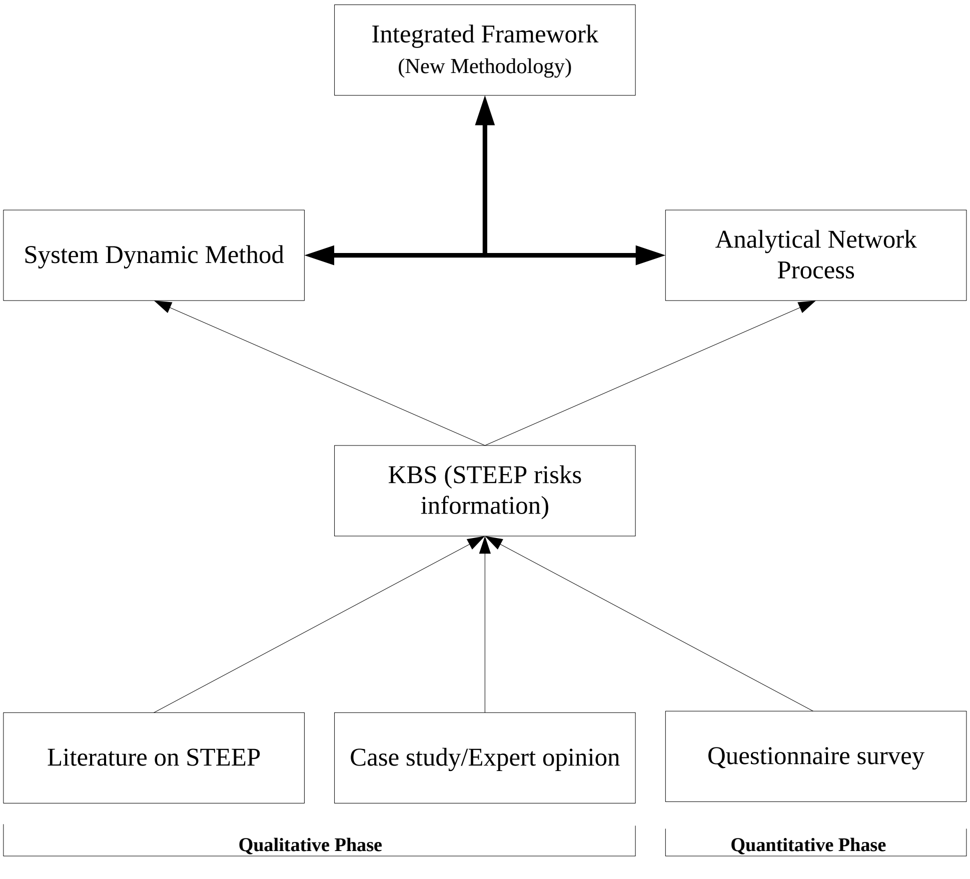


Figure 3.2: Proposed Framework for the Study.

Based on the research objectives and the preceding chapters, it was considered prudent and logical to incorporate elements of the qualitative phase within this research, especially since this would yield greater insight into the dynamism of all risks during megaproject development. Additionally, the method will help to identify aspects or dimensions of risks that were considered important from the construction practitioners' point of view without imposing biases from literature. This phase of the research was thus exploratory in nature.

3.4.1.1. Interviews

Interviews also known as expert opinions in this research were adopted as one of the appropriate research methods to aid the qualitative data in this study. This phase was conducted to enable the exploration of detail risk phenomenon in transportation megaprojects under construction.

Fundamentally, the interviews were to capture a sense of what major sources, from a practitioner point of view, cause project cost and time overruns and quality deficiencies in the construction phase of transportation megaprojects. The interviews were also to identify the fundamental risks areas that project managers, engineers, consultants and contractors have to deal with as construction proceeds in order to mitigate such risks. By conducting these interviews, it was possible to consider the relevance of the risk factors identified in literature as captured in Tables 2.4 and 2.6 of chapter 2. As argued by Dvir *et al.,* (1998), a priori risks dimensions, such as those presented in Tables 2.4 and 2.6 of chapter 2 are only useful to the extent that they are sufficiently relevant and generic. The interviews were therefore an opportunity to test the relevancy and comprehensiveness of these dimensions.

3.4.1.2. Case Studies

Yin (2003b) defined case study as an "empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident." Yin (2003a) identified case study as the preferred research strategy when the phenomenon and the context are not readily distinguishable. Dul and Hak (2008) defined case study as "a study in which (a) one case (single case study) or a small number of cases (comparative case study) in their real life context are selected and (b) scores obtained from these case are analysed in a qualitative manner.

Although case study research is more often associated with contemporary phenomena as highlighted in Yin's, and Dul and Hak's definitions, Eisenhardt and Graebner (2007) pointed out that case studies can also be historical. The definition put forward by Collis and Hussey (2009), also identified some of the possible characteristics of case study strategy. They defined case study as "a methodology that is used to explore a single phenomenon in a natural setting using a variety of methods to obtain in-depth knowledge". Therefore, it can be said that case study research is capable of accommodating different research techniques and is normally used when it is required to obtain in-depth knowledge with regard to a particular phenomenon. Case study research, can accommodate both qualitative and quantitative data (Yin, 2003b; Gerring, 2007), allowing the researcher to get a rich mix of data for the study.

Whilst case study research is a distinctive research strategy which presents many advantages to a research study, and allows in-depth investigation of the issues at hand, it is not without criticism. Yin (2003b) identified lack of rigor, being bias, difficulty to generalise, and taking too long and producing hefty documents as some of the common criticisms of case study research. In response, it was noted that the quality of a case study can be enhanced by following the four tests that are common to empirical research; construct validity, internal validity, external validity and reliability (Yin, 2003b; Fellows and Liu, 2008). These tests will be discussed subsequently.

- **Rationale for Selecting Case Study Research**

The rationale for selecting a case study to support the preferred research strategies adopted in this study are based on the following main factors:

- *Satisfying the criteria for selecting case study strategy*

As stated in section 3.3.2 (Chapter 3), Yin (2003a) recommended satisfying three conditions to decide upon a research strategy. These were:
(a) Type of research questions posed,
(b) The extent of control the researcher has over actual behavioural events, and
(c) The degree of focus on contemporary issues.

Accordingly, case study was preferred when the research questions take the form of "how" and "why". The doctoral research reported here was developed to answer the research questions of (1) what are the generic risk events inherent in transportation megaprojects during construction? (2) How can the qualitative risk effects on project time, cost and quality be quantified while using ANP to prioritize and analyse risks in transportation megaprojects? (3) How can risks interrelationships in transportation megaprojects be modelled and (4) How can Project Managers assess the dynamism of risk effects in transportation megaprojects?

The second condition identified by Yin (2003b), is the degree of control the researcher has over actual behavioural events. In this research, the researcher did not have control over the behaviour of transportation megaproject construction or the risks that impact on them. The researcher was outside the "case"; and was an observer. Further, there was no possibility of manipulating the behaviour of the independent risk variables in the case project in order to investigate their impact on the dependent variables. Again, the issues being investigated were contemporary and about how time, cost and quality objectives of the project are affected, respond and cope with risks; satisfy the third condition for selecting case study research.

- *Appropriateness to investigate the research in hand*

The context of the study was to assess the dynamics of risk in megaprojects and as such, utilising case study research in this context will lead to the observation of new insights that would not have emerged through a strategy like a large survey. This was of particular importance to the research at hand, as the existing literature was limited with regard to response to generic problems such as STEEP risks in the case study megaproject. From a construction industry perspective, the likes of Flyvbjerg (2003), Jennings et al., (2011), Boateng et al., (2013), Poole (2011) and Priemus et al., (2008), just to mention a few among the lot have successfully used the case study method to study megaprojects development, suggesting the applicability of the strategy in studies involving construction of such large projects.

Proverbs and Gameson (2008) mentioned case study as highly relevant to an industry like construction, consisting of different types of businesses and organisations. It was further noted that application of case study research in the construction management domain remains low, and that there is significant scope for further application within the domain. Dainty (2008) identified quantitative methods as the dominant research paradigm within the construction management research, confirming the claim of Proverbs and Gameson (2008) that the application of case study research within the domain is limited.

The above discussions point out that case study strategy has been and can be used successfully to conduct research on transportation megaprojects under construction. In fact, it can be argued that case study strategy, where in-depth knowledge can be obtained, suits the study of dynamic but complex projects like transportation megaprojects; where it is often difficult to make strong generalisations across all megaprojects under construction due to significant differences that exist between them.

- *Ability to accommodate different research techniques*

The objectives and the research questions investigated in this doctoral research informed the choice of different research techniques, in data collection and analysis. For instance, the objective of identifying and describing all significant risks of the partial or entire set of social, technical, economic, ecological and political (STEEP) problems for megaprojects construction and development favoured a questionnaire survey and observational approach in order to identify a range of such risks, whereas the objective of simulating and analysing interactions among all risks favoured a method that warranted in-depth analysis, hence expert opinions and semi-structured interviews were preferred. Adopting the case study strategy allowed the use of multiple sources of data collection and analysis, allowing the researcher to address the research objectives and answer the research questions satisfactorily. Ability to accommodate different research techniques, both qualitative and quantitative, is a salient feature of case study research (Yin, 2003b; Gerring, 2007). Accordingly, it was sought to use semi-structured interviews, questionnaire survey and document review as the data collection techniques, whereas statistical analysis, content analysis, Computer-aided modelling and simulation and quantitative analysis were used for data analysis.

It was thought that opting for a mixed method research design (See Figure 3.1) would also contribute towards methodological pluralism in construction management research, in which quantitative research is dominant, as identified by Dainty (2008). Dainty called for greater use of qualitative approaches and adoption of a diversity of approaches, shifting away from the traditional positivist viewpoint, in order to better understand the complex network of relationships present within the industry. Fellows (2010) concluded that such methods are gaining recognition within the construction management body of knowledge.

- *Compatibility with the philosophical viewpoint*

Based on the researcher's underpinning philosophical views, the research was positioned within the philosophical viewpoint of a pragmatist. According to Saunders et al., (2009, p.109), pragmatism is based on the argument that "the most important determinant of the epistemology, ontology, and axiology a research adopts is the research question." Whilst the research was positioned and approached with a pragmatic viewpoint, the nature of the key research questions meant that the research was narrowed towards interpretivism, subjectivism and value-laden research on the philosophical spectrums of epistemology, ontology and axiology. Although case studies can be conducted by adopting a positivist approach (Rezgui and Miles, 2010), it is often associated with interpretivism/realism and pragmatism (Sexton and Barrett, 2003). Hence, supporting the case that case study is a preferred method to support the research strategy in this study.

- *Suitability of case study research, over other research strategies*

A research strategy like experiment was considered inapplicable to this study as the researcher did not have control over the phenomenon being studied. This was because experimental studies attempt to manipulate independent variables to observe behaviour of the dependent variables (Collis and Hussey, 2009), which was not possible to be achieved in this research. The survey strategy is associated with the deductive approach

(Saunders et al., 2009), and positivist philosophical positioning (Collis and Hussey, 2009). As discussed previously, this research inclined towards postpositivism and interpretivism and undertook more adductive approaches.

Another theory is the grounded theory. This theory seeks to develop a well-integrated set of concepts that provide a thorough theoretical explanation of phenomena under study (Charmaz, 2006). This theory is mostly derived from data, systematically gathered and analysed through the research process in an iterative process (Bryman, 2008). Perhaps, grounded theory can be identified as the next best alternative for this research, due to the nature of research questions being asked. However, this research sought to explore and assess the dynamism of risks in transportation megaprojects under construction in a real-life context. As such, it was not purely attempting to generate theory out of data, but also sought to integrate and apply existing theory to risk assessment in megaproject construction. Hence, grounded theory was deemed less suitable, when compared to the case study strategy.

- *Opportunity presented by being part of a wider research study*

The doctoral research discussed here is part of the Megaproject Management research theme set up by Dr Zhen Chen in June 2012. It is a research unit based within the Centre of Excellence in Sustainable Building Design (formerly the Institute for Building and Urban Design (IBUD)) at Heriot-Watt University. The mission of the group is to promote and support innovation and progress in megaproject development and management across the world through multi-disciplinary practice oriented research. Its research focuses on proactive problem-solving solutions through a megaproject's lifecycle with regard to stakeholders' needs and professional standards related to the built environment. Through publications and presentations, the group offers rigorous independent research outputs that translate knowledge gained from research and development to inform decision making by major stakeholders in megaproject development and management.

The study is also a part of initiatives of megaproject research project that is funded by the European Cooperation in Science and Technology (COST) through COST Action TU1003, which aims at the Effective Design and Delivery of Megaprojects in the

European Union. The Action is chaired by Professor Naomi Brookes in the School of Civil Engineering at the University of Leeds, and there are participants from over 20 countries across Europe. Adopting a case study as part of the research strategy allowed the researcher to utilise his involvement in the above mentioned research projects towards the doctoral study and use some of the research methods to enhance the doctoral study without compromising the objectives, research questions or philosophical positioning of the doctoral research.

- **Validity and Reliability in Case study Research**

As case study research is subjected to criticism, it is vital that the validity and reliability of a case study research is established. The following four tests of construct validity, internal validity, external validity and reliability are adopted from Yin (2003, p.34) to test the trustworthiness of the case study research method in this research. Whilst it is not intended here to discuss these tests in detail, Table 3.5 highlights the case study tactics used and the stage of research in which each tactic occurs in this research to satisfy the aforementioned tests, and thereby ensure the validity and reliability of the research strategy used.

Table 3.5: Case Study Tactics for Four Design Tests

Test	Case Study Tactic	Phase of research in which tactic occurs
Construct validity	- Multiple sources of evidence	- Data collection
	- Review of draft case study reports by key informants	- Composition
Internal validity	- Explanation building	- Data analysis
	- Use of (ANP/SD) models	- Data analysis
External validity	- Use of theory in the single case study	- Research design
Reliability	- Develop case study database (KBS)	- Data collection

Source: Adopted from Yin (2003, Chapter 2, p. 34)

3.4.2: The Quantitative Phase

The instrument for the quantitative phase comprises questionnaire (mailed and online). The approach was considered necessary because it provides stronger empirical research evidence for explaining phenomenon to enable the researcher to address the questions '*how much'* or '*how many*?' More appropriately in the context of this investigation, this kind of research phase enables the researcher to establish which variables are significant, and to what extent, in a scientific way so that the objective of explanatory assertions about the sample can be allowed, and by inference the target population can be achieved.

3.4.3: The Knowledge Based System (KBS)

The key components of any risk management process would include risk identification, assessment/analysis, evaluation, response, and monitoring. In order to perform adequate risk management, it is essential to link identification/assessment steps with their management actions through sufficient understanding (Hillson, 2002). As indicated in Table 2.3: risk identification tools and techniques (Chapter 2, p. 16), there are numerous techniques for identifying project risks. However, as a consolidated list of classified tools and techniques for risk identification, these techniques lack a definite organization of risks and do not help to structure identified risks in the most appropriate hierarchical way (Hillson, 2002). Therefore, the Knowledge Based System (KBS) is proposed in this research as a regulated way to assist project managers in understanding risk categorization in the construction phase of transportation megaprojects. As indicated in Figure 3.3, the KBS is structured such that it will provide an essential and standard strategy for risk presentation, understanding, communication, and management during megaproject execution phases.

According to Tah and Carr (2000) and Hillson (2002), a structured KBS in hierarchical representation of risk sources is known as a hierarchal risk breakdown structure (HRBS). Hillson (2002) defined the HRBS as *"a source-oriented grouping of risks that organizes and defines the total risk exposure of a project or business*." That means the HRBS can be used to structure and guide the risk management process. Another advantage of developing the HRBS within the KBS is that it serves as a basis for a formal model of risk assessment (Tah and Carr, 2000).

For the purpose of this research, risk sources were grouped under criteria that describe the nature of risk. Hence, as indicated in Figure 3.3, the five risk categories (social, technical, economic, environmental and political) described in chapter 2 were used to develop three levels of HRBS within the Knowledge base (KB) of the KBS. Through the process of knowledge acquisition, the knowledge that a project manager or project engineer has gained from experience and from other completed projects can be stored properly in the knowledge base (KB). This domain of specific knowledge of experts can be processed and categorized by type, sieved in the inference engine (IE) and sent back to the KB to be represented into macro layers (levels I and II) and micro layer (level III).

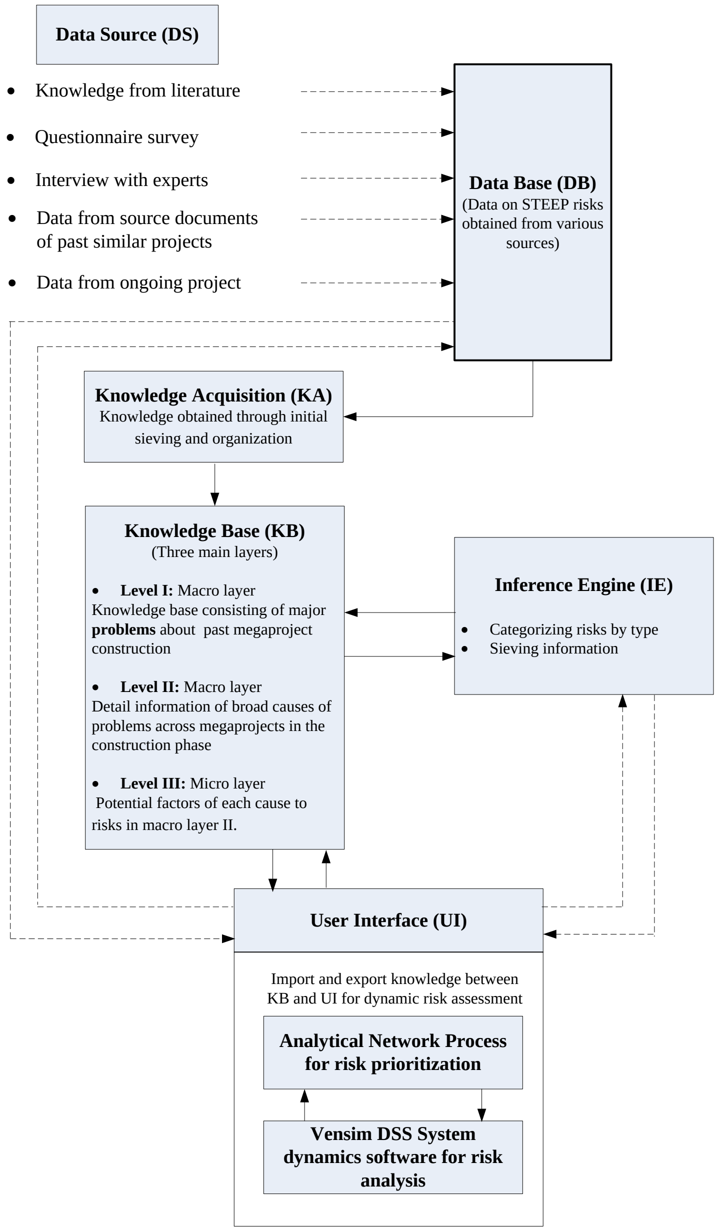


Figure 3.3: Proposed Framework for Risks Categorisation using KBS

Once the potential risk factors for each cause of problems in the micro layer (level III) are organized, they can be imported into the user interface (UI) for dynamic risks assessment. With the support of a computer, the final risk factors can be prioritized by the Analytical Network Process (ANP) and the results used as inputs into the System Dynamics (SD) modelling. The final information can then be made available to users (project analysts, project managers, engineers and contractors) when they consult the KB, IE and the UI to identify recurrence and the dynamics of the project risks impact on performance. Risk response actions can be initiated to control risks as construction proceeds when various simulation scenarios are performed to aid policy formulation and implementation.

In addition, time and effort required to identify, assess and to develop risk response actions can be significantly reduced. Difficulty in interpreting the outcomes of a risk assessment process may be resolved since expert interpretations based on KB are used in analysing risk effects. Repeated uses of KBSs may also reduce the human and organizational resistance.

3.4.4: The Analytical Network Process (ANP)

Figure 3.4 is a schematic that describes the overall flow of the proposed framework for the Analytical Network Process (ANP). As shown in the diagram, risk prioritization originates from project client and managers' requests. The data systems represent the KBS domain used to categorise and store information about STEEP risks in transportation megaprojects. Such information is used to facilitate the data transfer into the decision support system (DSS). The purpose of the DSS is to prioritize identified risks based on their relative importance. It is comprises two interfaces (decision and the prioritization).

3.4.4.1. The decision/Software Interface

The decision interface is composed of the experts' decisions, the weighted quantitative score (WQS) method and the analytical network process. The experts' decisions begin with the risk prioritization survey for selecting potentially "high risks" using a Likert type scale of 1 to 5 to score the level of STEEP risks impact on megaproject objectives (cost, time and quality) in the construction phase. The WQS is a method which translates expert decisions obtained during prioritization surveys into synthetic numerical values to derive the mean scores of importance. The calculations were significantly distinguished based on participant's experience, background and as well as their information in regard to a case study project (Edinburgh tram network project).

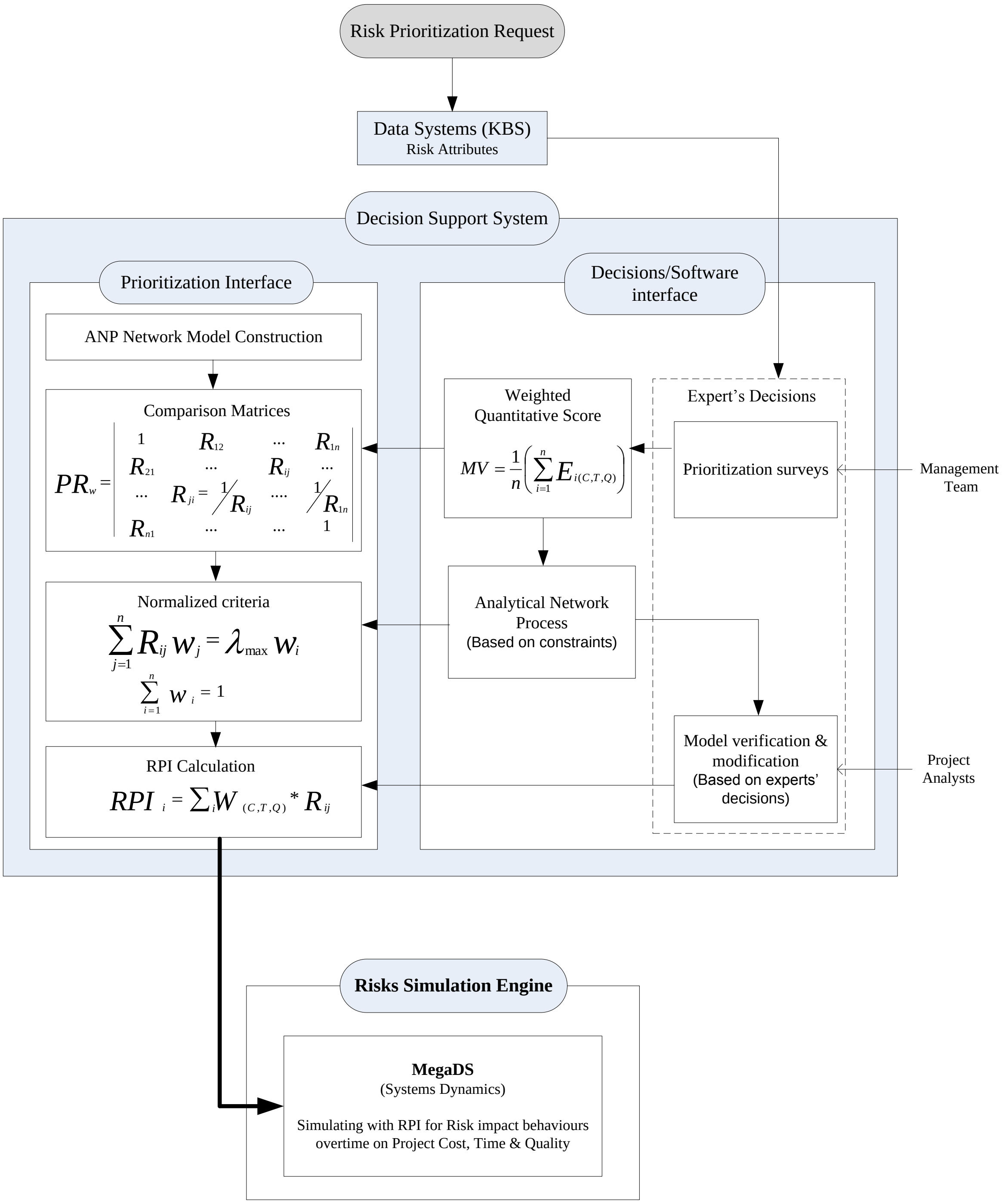


Figure 3.4: Proposed ANP Methodology for Risks Prioritization

As indicated in Figure 3.4, the arrow between the WQS and the comparison matrices represents the correlation between the choices of the experts and the corresponding comparison matrices (PR_W). Likewise, the analytical network is directly correlated to the normalized criteria using the eigenvector algorithm according to ANP. Consensus is built by aggregating the normalized weights, and thus generating the risk prioritization indexes (RPI_S). The analytical network process is a decision tool that allows structuring the decision into criteria, sub-criteria and options (Saaty, 2005). Its purpose is to categorize the decision model in a logical and intuitive tree to model the existing decision hierarchy and to adapt to emerging changes. The experts' decisions are the preset choices made by the experts based on the options defined by the analytical network. These decisions are subject to verification and adjustment due to changing priorities.

3.4.4.2: The Prioritization Interface

The prioritization interface is the platform where the analytical framework is combined with the experts' decisions to produce independent assessments on STEEP priorities without further input from the experts. The purpose of a prioritization interface is to aggregate experts' decisions on risks impacts on project performance into single numerical values to represent a project's overall strategic importance when compared to one another. This single parameter is defined as the Risk Prioritization Index (RPI). The intent of using this figure is to help eliminate human biases during the priority assessment and put a sense of fairness in the evaluation process. Ranked results issued from the prioritization interface become the high risks and are conveyed into the system dynamics modelling for simulation.

Four general procedures for multi-criteria decision-making processes were used to prioritize high risks at this stage. The procedures are: ANP network construction; paired comparisons; criteria normalization through super matrix calculation; and risk priority index (RPI) calculation (Saaty, 2005). The steps are laid out below in four sub sections.

- **ANP Network Model Construction**

In this step, the STEEP risks were structured and conceptualised into networks to determine the control hierarchies as well as the corresponding criteria of the system. According to Saaty (1996), the process allows dependencies both within a cluster (inner dependence) and between clusters (outer dependence) so that variables on each level can be defined together with their relationships with other elements in the system.

As Figure 3.5 illustrates, the ANP network model for prioritizing risk consists of three clusters: ‘Goal’, ‘Criterion’ and ‘Option.’ Cluster ‘Goal’ contains only one element as the statement of the purpose for risk prioritization within which the category of ‘High risks’ are listed according to the results from the pairwise comparison calculation. Cluster ‘Criterion’ consists of potential consequences of elements of potential risks on project cost, time and quality. The cluster ‘Options’ contains potential risks and a list of their potential variables. Detail explanation of these risks and their respective variables in this cluster has been discussed in (Chapter 2). The arrows indicate relationships between elements in one cluster against elements in other clusters. In cluster ‘Criterion’, there are inner dependencies because the elements in this cluster affect each other.

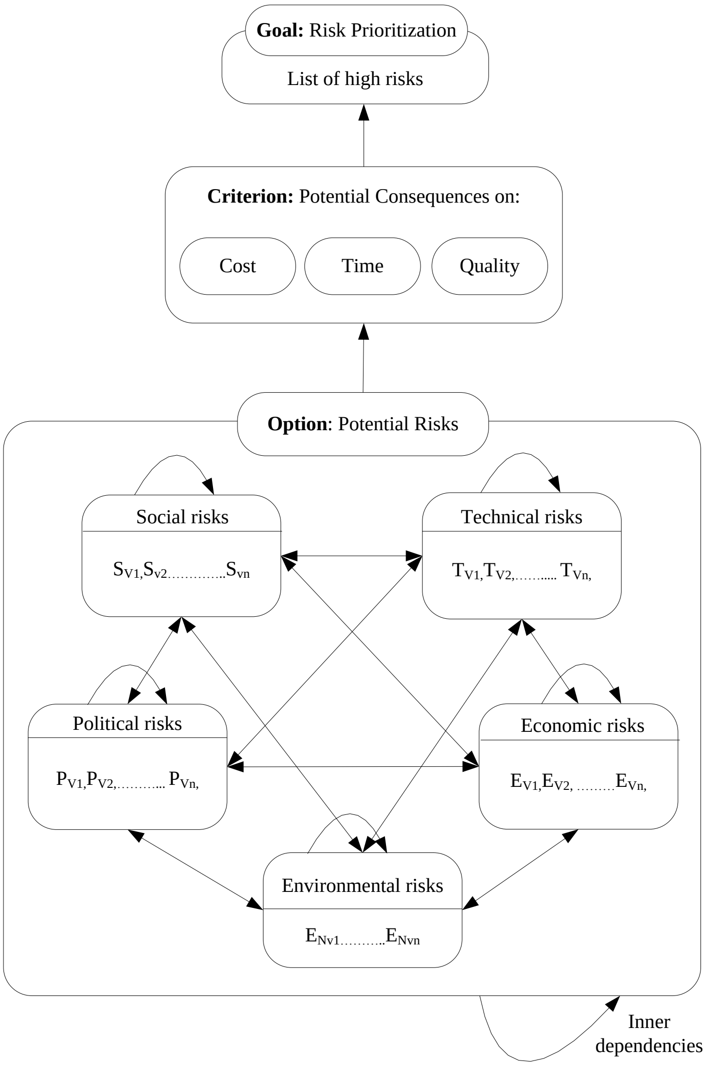


Figure 3.5: ANP Network Model for Risk Prioritization

- **Paired Comparisons**

In ANP, pairwise comparisons of the elements in each level are conducted with respect to their relative importance to their control criterion. The correlation matrices are prepared on a 1-9 ratio scale presented in Table 3.6 to determine the relative preferences for two elements of the hierarchy in the matrix. A score of 1 indicates that the two options have equal importance whereas a score of 9 indicates dominance of the component under consideration over the comparison component matrices.

Table 3.6: Fundamental Scale of Pairwise Judgment and Pair wiser Criteria

Scales of pairwise judgment	Comparisons of pair indicator scores
1= equal	1:1
2= equally to moderately dominant	2:1, 3:2, 4:3, 5:4, 6:5, 7:6, 8:7, 9:8
3= moderately dominant	3:1, 4:2, 5:3, 6:4, 7:5, 8:6, 9:7
4= moderately to strongly dominant	4:1, 5:2, 6:3, 7:4, 8:5, 9:6
5= strongly dominant	5:1, 6:2, 7:3, 8:4, 9:5
6= strongly to very strongly dominant	6:1, 7:2, 8:3, 9:4
7= very strongly dominant	7:1, 8:2, 9:3
8= very strongly to extremely dominant	8:1, 9:2
9= Extremely dominant	9:1

If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*. The results of the comparisons are represented by dimensionless quotients to measure the preference of one option over the other. A direct numerical appreciation is not required from the decision maker, but rather a relative appreciation. The results of each cluster are similar to the comparison matrix described in Equation (1), where PR is the potential risks and R_{ij}, the comparison between risk variables *i* and *j*.

$$PR = \begin{vmatrix} 1 & R_{12} & \cdots & R_{1n} \\ {}^{1}/_{R_{12}} & 1 & R_{ij} & R_{2n} \\ \vdots & R_{ji={}^{1}/_{R_{ij}}} & \ddots & \vdots \\ {}^{1}/_{R_{1n}} & {}^{1}/_{R_{2n}} & \cdots & 1 \end{vmatrix} \qquad (1)$$

Once the pairwise comparison is completed for the whole network, the vector corresponding to the maximum eigenvalue of the constructed matrices is computed and a priority vector is obtained. The **priority** value of the concerned element is found by normalizing this vector as described in equation 2.

$$\sum_{j=1}^{n} R_{ij} w_i = \lambda_{max} w_i \qquad (2)$$

Where 'R' is the matrix of pairwise comparison,

'w' is the eigenvector, and

'λ_{max}' is the maximum eigenvalue of [R]

By substitution, the maximum eigenvalue ($\lambda_{\max}$) is calculated to derive a new matrix (W) by multiplying comparison matrix (R) with (w_i). Finally, the ($\lambda_{\max}$) can be obtained by averaging the value. Computations of the process are listed in Equation (3) and Equation (4) respectively.

$$\begin{vmatrix} 1 & R_{12} & \cdots & R_{1n} \\ 1/R_{12} & 1 & R_{23} & R_{2n} \\ \vdots & 1/R_{23} & \ddots & \vdots \\ 1/R_{1n} & 1/R_{2n} & \cdots & 1 \end{vmatrix} \text{x} \begin{vmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{vmatrix} = \begin{vmatrix} W_1 \\ W_2 \\ \vdots \\ W_n \end{vmatrix} \qquad (3)$$

$$\lambda_{max} = \frac{1}{n}\left(\frac{W_1}{w_1} + \frac{W_2}{w_2} + \dots\dots + \frac{W_n}{w_n}\right) \qquad (4)$$

In this assessment process, a problem may occur in the consistency of the pairwise comparisons. The consistency ratio provides a numerical assessment. If the calculated ratio is less than 0.10, consistency is considered to be satisfactory. The conceptual model is then imported into the ANP software, Super Decision (developed by Adams, W.J. and Satty, R.W.) for the pairwise comparison matrices to be solved. The aim of constructing pairwise matrices is to find out the relative weight of the potential risks.

- **Super Matrix Calculation**

There are three super- matrices: un-weighted super matrix, weighted super- matrix and the limit super matrix associated with the network. The un-weighted super matrix contains the local priorities derived from the pair-wise comparison throughout the network. The weighted super matrix is obtained by multiplying all the elements in a component of the un-weighted super matrix by the corresponding weight. The limit super matrix is derived by raising the weighted super matrix to its powers and the multiplication process is discontinued when the number becomes the same for all columns. The three steps aim to form a synthesised super matrix to allow for the resolution of the effects of the interdependences that exists between the elements (nodes and clusters) of the ANP model. The reason is to obtain useful information for the assessment, thereby calculating super matrixes in three sub-steps, to transform initial super matrix to a weighted super matrix, and then to a synthesised super matrix.

Table 3.7: Formation of Super Matrix and its Sub-Matrix

Super Matrix	Sub-Matrix
$\mathbf{W} = \begin{bmatrix} W_{11} & W_{12} & W_{13} & --- & W_{1n} \\ W_{21} & W_{22} & W_{23} & --- & W_{2n} \\ W_{31} & W_{32} & W_{33} & --- & W_{3n} \\ W_{41} & W_{42} & W_{43} & --- & W_{4n} \\ W_{51} & W_{52} & W_{53} & --- & W_{5n} \end{bmatrix}$ $\begin{array}{llllll} \textbf{Cluster:} & C_1 & C_2 & C_3 & --- & C_n \\ \textbf{Node:} & N_{1(1\sim n)} & N_{2(1\sim n)} & N_{3(1\sim n)} & --- & N_{n(1\sim n)} \end{array}$	$W_{I.J} = \begin{bmatrix} W_1\|_{I.J} & \dots & W_1\|_{I.J} \\ W_1\|_{I.J} & \dots & W_1\|_{I.J} \\ \dots & \dots & \dots \\ W_i\|_{I.J} & \dots & W_i\|_{I.J} \\ \dots & \dots & \dots \\ Wn_{I1}\|_{I.J} & \dots & Wn_{I1}\|_{I.J} \end{bmatrix}$

Note: *I* is the index number of rows; and *J* is the index number of columns; both *I* and *J* correspond to the number of cluster and their nodes [*I, J* ϵ (1,2, …, m)], N_I is the total number of nodes in cluster *I*, n is the total number of columns in cluster *I*. Thus an *m* x *m* matrix is formed.

The general form of the super-matrix is described in Table 3.7 where C_n denotes the Nth cluster, $N_{n(1\sim n)}$ denotes the nth element in the nth cluster, and W_{ij} is a block matrix consisting of priority weight vectors (W) of the influence of the elements in the ith cluster with respect to the jth cluster. If the ith cluster has no influence to the ith cluster itself (a case of inner dependence), W_{ij} becomes zero. The super-matrix obtained in this step is called the initial super-matrix. The eigenvector obtained from cluster level comparison with respect to the control criterion is applied to the initial super-matrix as cluster weight. This result is the weighted matrix.

- **Risk Priority Index (RPI) Calculation**

This step aims to calculate risk priority indexes (RPIs) to support final decision making. The criterion to make this selection is the weights of alternatives that can be taken from the synthesised super-matrix. Although the RPI can be performed manually with equation 5, it was performed by the Super Decisions software in this study. Computation priorities command was used to determine the priorities of all the nodes in the network

$$RPI_i = \sum_i W_{(C,T,Q)} * R_{ij}$$

Where

'RPI_j' represents the global priority of the risk options i,

'$W_{j,}$' the weight of the criterion j with respect to project cost, time and quality, and

'R_{ij}', the local priority

After computation, the RPIs can further be classified into five states of likelihood and consequence on project cost, time and quality and assessed by five-by five matrices to classify risks as either "very high", "high", "moderate", "low" or "very low".

- *Very High and High-Risk Events*

High-risk events can be so classified either because they have a very high likelihood of occurrence coupled with at least a high impact or they have a high impact with at least moderate likelihood. In either case, specific direct management action is warranted to reduce the probability of occurrence or the risk's negative impact.

- *Moderate-Risk Events*

Moderate-risk events can either be high-likelihood, low consequence events or low-likelihood, high-consequence events. An individual high-likelihood, low-consequence event by itself would have little impact on project cost, schedule and quality outcomes.

However, most projects contain myriad such risks (material prices, schedule durations, installation rates, etc.); the combined effect of numerous high-likelihood, low consequence risks can significantly alter project outcomes.

Commonly, risk management procedures accommodate these high-likelihood, low-consequence risks by determining their combined effect and developing cost and/or schedule and quality contingency allowances to manage their influence. Low-likelihood and high-consequence events, on the other hand, warrant individualized attention and management. At a minimum, low-likelihood and high consequence events should be periodically monitored for changes either in their probability of occurrence or in their potential impacts. Some events with very large, albeit unlikely, impacts may be actively managed to mitigate the negative consequences should the unlikely event occur.

- *Low and very Low-Risk Events*

Risks that are characterized as low and very low can usually be disregarded and eliminated from further assessment. As risk is periodically reassessed in the future, these low/very low risks are closed, retained, or elevated to a higher risk category. Although, there is no standard for estimating risk probability value, the study uses a likelihood ratings proposed by Cooper, et.al, (2005) as shown in Table 3.8,

Table 3.8: Likelihood Rating

Rating	**Likelihood description**
Almost certain	Very high, occurs frequently
Likely	High, (has before, will again)
Possible	Possible, but not common
Unlikely	Not possible (unlikely to occur)
Rare	Very low (very unlikely to occur)

Partially adapting from Cooper, et.al, (2005), the study uses a multi-attribute potential consequences based on the research objectives of five risk elements impacts i.e. Social technical, economic, environmental, and political issues. The expected output of this filtering stage is a list of potential risks categorized into "high-risk". Finally, the numerical RPIs are fed into the simulation engine as numerical fields for exogenous variables and initial values for stocks to facilitate the dynamic simulation process.

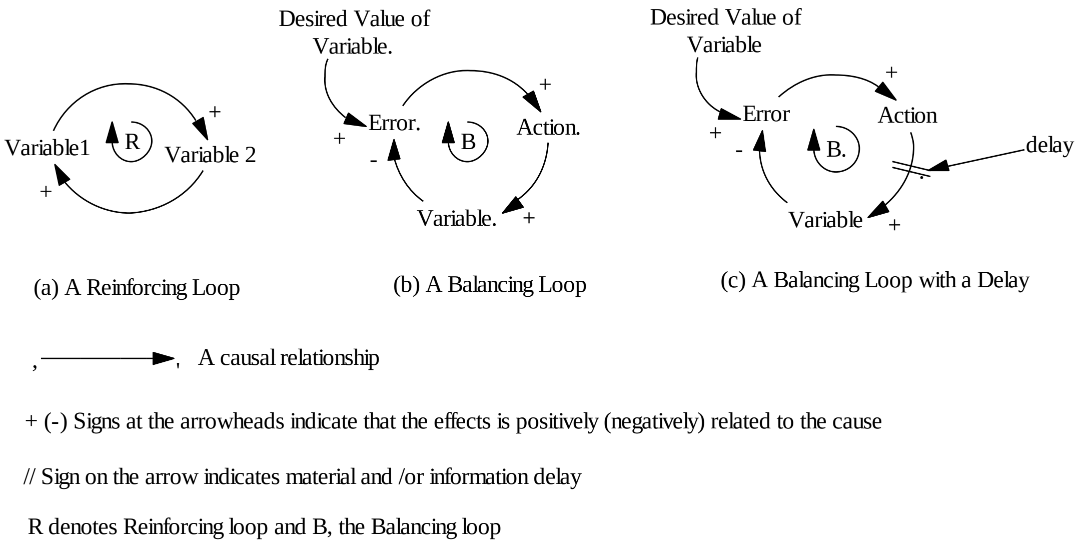
3.4.5: System Dynamics

The systems dynamics (SD) methodology is adopted in this study. The SD methodology is a field created at MIT by computer pioneer Jay Forrester in mid 1950s for modelling and analyzing the behavior of complex social systems in an industrial context (Sterman, 2000). It was designed to help decision-makers learn about the structure and dynamics of complex systems, to design high leverage policies for sustained improvement, and to catalyse successful implementation and change. In recent years, the SD has been used by researchers and project managers to understand various social, economic and environmental systems in a holistic view (Rodrigues, 1996; Towell, 1993; Sycamore, 1999; Mawby, 2002; Love, 2002; Ogunlana, 2003, Williams, 2003 and Naseena, 2006).

System Dynamics approach is primarily based on cause-effect relationship. This cause-effect relationship is explained with the help of stock, flow and feedback loops. Stocks and flows are used to model the flow of work and resources through the project. Feedback loops are used to model decisions and project management policies. System Dynamics can be used to model processes with two major characteristics (1) those involving change over time, and (2) those that involve feedback (Ogunlana, 2003).

The central concept of System Dynamics is to understand how the parts in a system interact with one another and how a change in one variable affects the other variable over time (Senge, 1990), which in turn affects the original variable (See Figure 3.6). Systems can be modelled in a qualitative and quantitative manner. The models are constructed from three basic building blocks: positive feedback or reinforcing loops, negative feedback or balancing loops, and delays. Positive loops (called reinforcing loops) are self-reinforcing while negative loops (called balancing loops) tend to counteract change. Delays introduce potential instability into the system.

Figure 3.6a shows a reinforcing loop, which is a structure that feeds on itself to produce growth or decline. Reinforcing loops correspond to positive feedback loops in control theory. An increase in variable 1 leads to an increase in variable 2 (as indicated by the "+" sign) and that leads to an additional increase in variable 1 and so on. The "+" sign does not mean the values necessarily increase, only that variable 1 and variable 2 will change in the same direction (polarity). If variable 1 decreases, then variable 2 will decrease. In the absence of external influences, both variable 1 and variable 2 will clearly grow or decline exponentially. Reinforcing loops generate growth, amplify deviations, and reinforce change.



(a) A Reinforcing Loop

(b) A Balancing Loop

(c) A Balancing Loop with a Delay

→ A causal relationship

+ (-) Signs at the arrowheads indicate that the effects is positively (negatively) related to the cause

// Sign on the arrow indicates material and /or information delay

R denotes Reinforcing loop and B, the Balancing loop

Figure 3.6: The Three Components of System Dynamics Models.

A balancing loop indicated in Figure 3.6b is a structure that changes the current value of a system variable or a desired or reference variable through some action. It corresponds to a negative feedback loop in control theory. A (-) sign indicates that the values of the variables change in opposite directions. The difference between the current value and the desired value is perceived as an error. An action proportional to the error is taken to decrease the error so that, over time, the current value approaches the desired value. The third basic element is a delay, which is used to model the time that elapses between cause and effect. A delay is indicated by a double line, as shown in Figure 3.6c. Delays make it difficult to link cause and effect (dynamic complexity) and may result in unstable system behaviour. In Systems Dynamics, verbal descriptions and causal loop diagrams are more qualitative; stock and flow diagrams and model equations are more quantitative ways to describe a dynamic situation. Since Systems Dynamics is largely based on the soft systems thinking, (learning paradigm), it is well suited to be applied on those managerial problems which are ambiguous and require better conceptualization and insight (Sushi 1993).

- **System Dynamic Modeling Approaches**

Strictly speaking, there is no formal methodology process defined for the development of system dynamic (SD) models. Several authors in related literature, including Forrester (1961/71), Roberts (1964), Randers (1980b), Richardson and Pugh (1981), Bossel (1992), and Coyle (1996), suggested sequences of SD modelling steps.

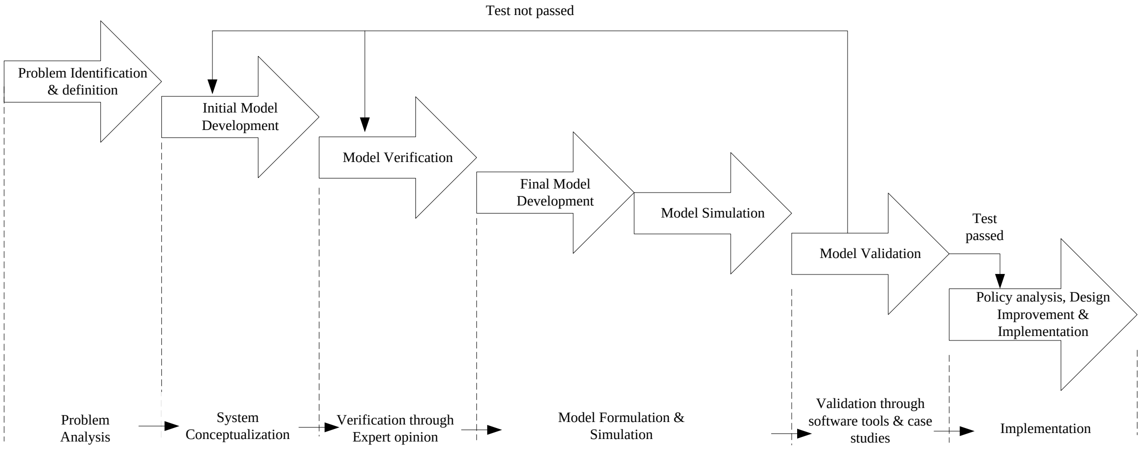


Figure 3.7: Basic Steps for SD Simulation Approach for Assessing Risks in Megaproject during Construction

Although there are variations, modelling is entirely dependent on the nature of the problem and style of the modeller. With regard to this research, the process indicated in figure 3.7 provides six basic modelling steps adopted to model the dynamic of risk impact on the performance of transportation megaproject in the construction phase overtime. The steps are:

i. Problem identification and definition
ii. Initial model development
iii. Model verification (expert opinion)
iv. Final model development and simulation (Analysis of model behaviour)

vi. Model validation using software tools and a case study
vii. Policy analysis, model use or implementation

i. Problem Identification and Definition (Purpose)

The purpose of this step is to study the dynamic problem of risks impact on megaproject performance (applied or theoretical). A large body of literature indicated that risks of cost and time overruns and quality deficiency are significant problems faced by megaproject owners and developers from the past until present. By discussing with experts, it was understood that problems related to STEEP risks' impact on project performance is vital. They lead to prolonged delay, increase in project cost, and quality deficiency. Since risks in the construction phase of megaprojects are complex and dynamic in nature, they need in-depth investigation for assessment. Therefore, to facilitate deep understanding of such problems, a case study method was applied to provide the opportunity to simulate the dynamics of such problems over time. Hence, Edinburgh Tram Network Project (ETNP) under construction in Scotland, UK is selected for case study.

ii. Initial Model Development and Verification

Causal loop diagrams in the model were used to describe the conceptual model structure derived from a modeller's understanding of system and show the dynamic of variables involved in the system (Park et al., 2004). Model boundary chart and subsystem diagram were drawn to provide the boundary and architecture of the model causal loop diagrams. The model causal loop diagrams indicate how the variables are related with each other in the system. Causal links can be established in ways such as direct observation, reliance on accepted theories, hypotheses, or assumptions, and statistical evidence (Coyle, 2000, cited in Park, 2004). Stock and flow maps were emphasized by the underlying physical structure of causal loop diagrams.

iii. Final Model Development and Simulation

Once the causal loop diagram was formulated, a formal simulation model known as stock and flow diagram was created. Coyle (1996) mentioned that simulation model is another version of mental model or casual loop diagram, but written in equations and computer code. In the process of model behavior, computer simulation was used to determine how all the variables within the system behave over time. The formalization helped to recognize vague concepts and to resolve contradictions that went unnoticed during the conceptualization phase. Vensim DSS, a Windows based graphical system dynamics modelling package was used for the model development. It supports both flow diagrams and causal loop diagrams. After the model structure was defined, the underlying equations were entered to create the simulation model. Finally, the simulation models were tested for consistency with their purpose and boundary.

iv. Model Validation Using Software Tools and a Case Study

Several SD tests were carried out in this research to validate the models. Among them was the test for robustness used to check the models for realistic behaviour when stressed to extreme conditions. Policies aimed at achieving desired goals or improving model behavior were then assessed to indicate how the real system can be modified (Ogunlana et al., 1998). The testing proved whether the models are consistent with the system behavior with respect to their purposes. Where tests failed, iterations were carried out in the modelling process to develop a valid model.

v. Policy Analysis, Design and Improvement

Once the tests proved the validity of models, they were experimented for various practical consequences. The aim of the experiment was to identify the weakness in the existing risk management procedure and recommend some new policy to assess risks at the early stage of megaprojects development before construction commenced.

3.4.6. The Integrated Framework (SDANP)

Figure 3.8 illustrated the combine methodologies for the research.

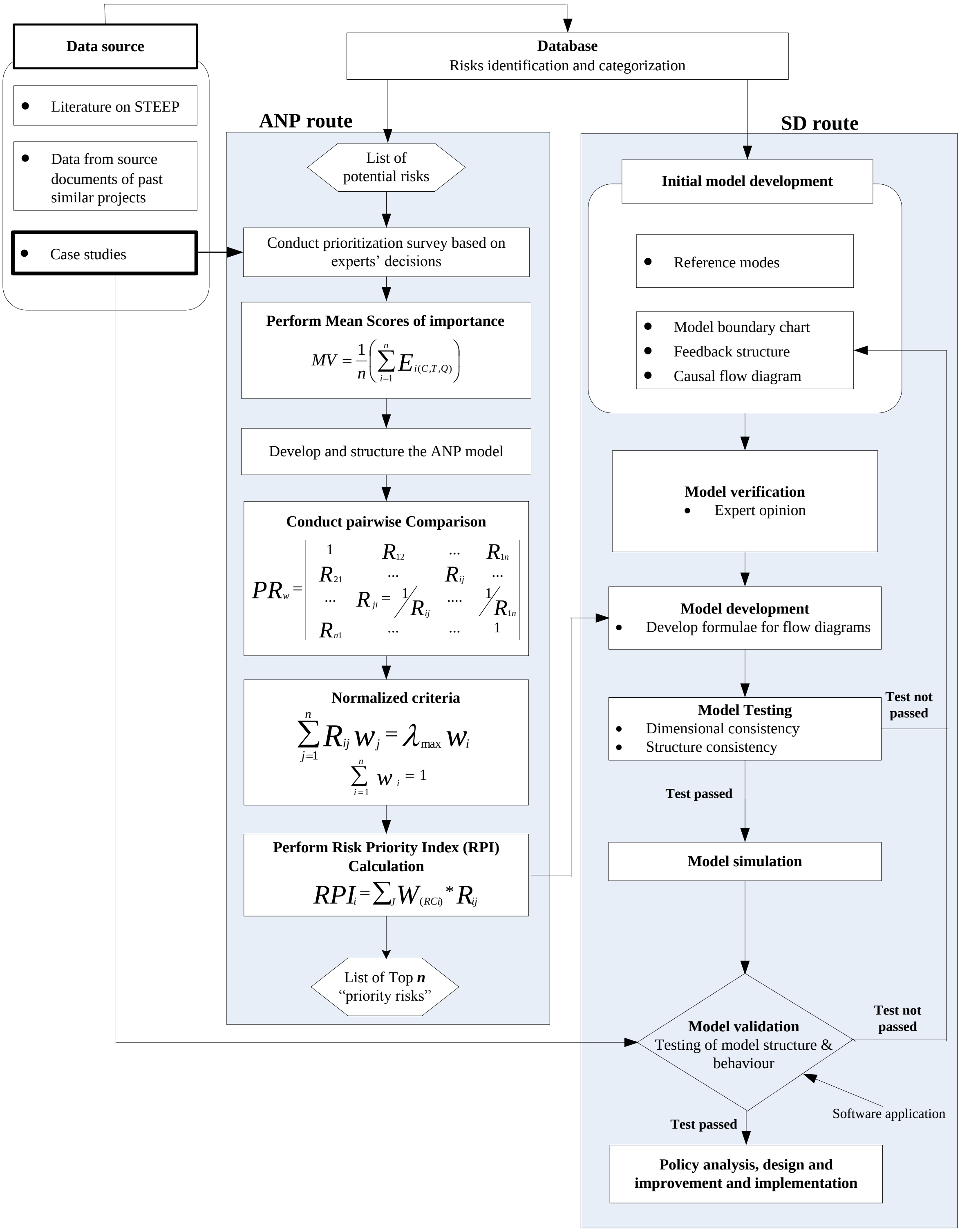


Figure 3.8: The Proposed SDANP Methodology for the Research

In an attempt to develop the new methodology, the work of Tesfamariam and Lindberg (2005) was reviewed and used to achieve the objective four of this research as stated in section 1.3. The motivation is that Tesfamariam and Lindberg in their research proposed the use of ANP/SD methodologies for a rapid and strategically consistent decision-making in a manufacturing system design. This then informed the decision to use the integrated SD and ANP methodologies called SDANP method that complements both the qualitative and quantitative research strategies for assessing risks in megaprojects at the construction phase over time. As indicated in Figure 3.8 the new methodology comprises the System Dynamics modelling and the Analytical Network Process routes (SDANP). Within the combined approach, the risk priority indexes (RPIs) derived from the Analytical Network Process will be integrated into the System Dynamics stock and flow modelling at the risk simulation stage to analyse the behaviour and level of risks impact on project performance over time. Subsequently, simulation scenarios will be performed in order to experiment various practical consequences of the new methodology so that policies can be designed and recommended to project managers, contractors and consultants on STEEP risks at the early stage of megaprojects construction for effective risk assessment.

3.5: Ethical Considerations

According to a dictionary definition, to be ethical is to be in accordance with the accepted principles of right and wrong that govern the conduct of a profession. Therefore, all members of the Heriot-Watt University (HWU), including research students, are under an obligation to observe the highest standards of professional conduct. Failure to do so not only defeats the object of scholarly enquiry, but brings both the researcher and the entire university into disrepute. Hence, the need for researchers to comply with strict ethical guidelines is especially important to the university.

In conforming to the established trend, the School of Built Environment (SBE) of the Heriot-Watt University (HWU) has put in place a rigorous ethical validation procedure to assist researchers conform to a reasonably accepted standard. Among others is the code designed by the SBE of the HWU to ensure that:

- There is no interference with participant's' physical and psychological well-being.
- The research procedure is not likely to be stressful or distressing

- The research materials are not sensitive, discriminatory or inappropriate
- The research design is sufficiently well-grounded so that the potential participants' time is not wasted during the data collection.

The research instruments used for this study were submitted to the SBE of the HWU ethical research committee. In so doing, the following parameters in respect of the instrument had to be explained and justified where necessary: the rationale for and the expected outcome of the study; details of methods, materials, designs and procedures; details of how information would be held and disposed and details of how the results will be fed back to the participants.

Having addressed and satisfied these criteria in a formal application, the ethics committee granted permission for the field work to commence.

3.6: Pilot Study

Prior to the major survey, a pilot survey was undertaken in Edinburgh (Scotland, UK). The pilot study is a trial run that can help the researcher to smooth out the survey instrument to ensure that the participants in the main survey experienced no difficulties in completing it (Moore and Abadi, 2005). The aim of the pilot study was to test the wording of the questionnaire, identify ambiguous questions, test the intended technique for data collection and measure the effectiveness of the potential response.

Using purposive sampling techniques, 10 experts were identified for the pilot study. These experts include academic research staff within the School of Built Environment of Heriot-Watt University and experts involved in the European Cooperation of Science and Technology (ECOST) on Megaproject to test the intelligibility, ease to answer or ambiguity of the questions. It is worth noting that the 10 participants identified for the pilot study were thereafter not included in the main survey. The questionnaires were accompanied by a covering letter explaining the purpose of the pilot study. Subsequently, the respondents were asked to critically appraise the questions and provide feedback as to the relevance and sensitivity of the questions, length and time for completing and suggestions for improvement. Within a period of three weeks, all 10 completed questionnaires were retrieved.

Valuable feedbacks were later received to improve the quality of the questionnaire and refinement. Generally the feedback was very helpful and suggested that the survey instrument was likely to work in the manner intended. A preliminary analysis of the data also gave the opportunity to test the intended technique for analysing the data and this was quite a useful exercise.

3.7: Data Collection

This section introduces issues relating to the collection of data and is grouped into two sub-sections. Section 3.7.1 addresses the sample frame and the potential respondents for the main survey. This is followed by a discussion of the method for choosing the appropriate sample size in section 3.7.2 and finally, a summary of the methodology chapter in section 3.8.

3.7.1: The Sampling Frame and Survey Participants

The sample frame and potential respondents for the study were drawn from Bilfinger-Berger and Siemens (BBS) consortium involved in the Edinburgh Tram Infrastructure and Maintenance Contract (INFRACO) contract, its subcontracting firms, some members of the City of Edinburgh Council (CEC) and owners/employees of businesses along the tram routes. The primary business of the BBS consortium is to operate as a management contractor letting out packages to firms such as Barr, Graham, Raynesway, Bam Rail, Laing O’Rourke, MacKenzie, Crummock, Farrans and McKean corresponding to the sections of the works. Bilfinger-Berger is responsible for the civil engineering works whilst Siemens is in charge of the electrical works.

Other companies from which survey participants were drawn from include Scottish Water (SW) and Turner and Townsend (T & T). T and T is a cost consultant brought in by CEC to replace Transport Initiative Edinburgh (TIE), the council-owned company set up to deliver major transport projects after ETNP is over budget and behind schedule. The main duty of T&T is to ensure effective oversight and delivery of the project.

As experts in the construction industry, these participants are believed to have detailed knowledge and understanding of risks in their respective sectors and should (based on their experience) be able to provide realistic answers to the survey questions and should be in a better position to provide relatively accurate responses to the interview to be conducted. Companies of participants and their respective organisations are provided Appendix (B). Due to the need to maintain strict confidentiality, the names and designation of interviewees were not disclosed. Consequently in establishing the sampling frame, a decision was also taken to exclude a few members whose telephone details were not available on the list provided. To this effect the sampling frame was eventually fixed at 400.

3.7.2: Establishing an Appropriate Sample Size

There is no definitive answer to what sample size is required for a survey. Usually, large samples with rigorous selection are more powerful as they will yield more accurate results, but data collection and analysis will be proportionately more time consuming and expensive. Essentially, the target sample size for a survey depends on three main factors: availability of resources, the aim of the study and the statistical quality needed for the survey. In this research, the sample size needed for the qualitative surveys such as interviews would be smaller than the quantitative survey data to be collected by the questionnaire. Sample size calculations and data analysis would be performed using an “analyse-it” add-on to Microsoft Excel for statistical analysis.

Larger samples give a better estimate of the population but it is rare in this research that everyone asked to participate in the survey will reply. To ensure a sufficient number of responses, an estimated non-response rate of 5% was added to the sample size. Biases in response rates are real and as such can be misleading and only represent those who reply. Therefore, it is unwise to define a level above which a response rate is acceptable, as this depends on many local factors; however, an achievable and acceptable rate is 75% for interviews and 65% for self-completion postal questionnaires (Arber, 2011). Useful review methods to maximize response rates in postal survey can also be found in Edwards et al., (2002).

Given that it is highly uncommon to achieve a survey response of 100%, an appropriate sample size would have to be adopted that would help achieve reasonable target as far as possible. Subsequently, drawing on typical response rates to surveys undertaken on a sensitive Edinburgh Tram Network Project in Scotland, UK, a 50% response rate was assumed. It was therefore decided to target up to 300 participants for the survey.

3.8: Summary

This chapter has introduced some important issues relating to the research methodology adopted for the study, in particular the epistemological and philosophical applications. A clear distinction has been made between research methodology and research methods. Drawing on the epistemological, ontological and axiological assumptions, both positivism and interpretivism were chosen as the appropriate paradigms. A review of the research methods revealed that survey and interviews were the most appropriate approaches for eliciting the relevant data to support the analytical network process and the system dynamics methodology for risk assessment. Subsequently the design of the survey instrument was described following a commentary on piloting of the questionnaires.

The survey characteristics including the sampling frame and size and techniques for eliciting the relevant data have also been explained. The next chapter introduces a description of the case study for this research.

CHAPTER FOUR: CASE STUDY

{The Edinburgh Tram Network (ETN) Project}

4.1. Introduction

Following the results of chapter two, which provided the theoretical basis of risks in transportation megaprojects in the construction phase, this chapter provides an overview of ETN project as the main case study for this research. The objective for selecting ETN project is to deliver a critical review of the entire project and to identify at the construction phase mistakes and pitfalls which led to risks of project cost and time overruns and quality deficiency. The chapter starts with the background of the case project followed by a summarised detail of risks encountered in the project at the construction phase.

4.2. Background to the Project

4.2.1. The 1871 to 1956 Era

Originally, ETN project can be traced back to the 1870s when Edinburgh had trams of various design running through city streets between 1871 and 1956. In November 1871, Edinburgh Street Tramways Company ran the very first horse-drawn tram from Haymarket in the west of Edinburgh, to Bernard Street in the heart of Leith. In January 1888, the Northern Tramways company in Edinburgh launched the first cable-pulled (or cable hauled) trams to run in Edinburgh. By the year 1894 most tram lines were operated by Edinburgh and District Tramways, and by 1920 Edinburgh Corporation had taken control of all of Edinburgh’s trams, including Leith which had electric trams running. The rest of Edinburgh city gained electric trams in 1922, with the very last cable-hauled tram operating in Edinburgh in June of 1923. By 1954, tram service ceased in Musselburgh. However, the electric trams continued to serve the people in other parts of Edinburgh until November 1956. The Edinburgh Corporation operated trams with the red and white colours still used by Lothian buses in Edinburgh today. A tramcar from 1948 has been preserved with these colours and can be seen in the National Tramway Museum in Derbyshire (“History of Trams in Edinburgh” (2012). Available at (http://www.edinburgh-history.co.uk/edinburgh-trams.html)

4.2.2. The New Edinburgh Tram Network

In January 2004, a proposal was submitted to the Scottish Parliament to reintroduce a tram network to Edinburgh which received Royal Assent in spring 2006 (Edinburgh Tram Line One and Two Act 2006). As indicated in Figure 4.1, the proposed tramline consisted of three lines. Phase 1a incorporated the construction of an 18.5-kilometre line from Newhaven to Edinburgh Airport through Princes Street, combining parts of lines 1 and 2. Phase 1b involved the construction of a 5.6-kilometre line from Haymarket to Granton Square via Crewe Toll, comprising most of the remainder of line 1. Phase 2 linked Granton Square and Newhaven together, completing the line 1 loop. Phase 3 would have the airport line extended to Newbridge, completing line 2. It can also be noted on Figure 4.1 that, the line one of the trams involved a circular route running around the northern suburbs, while the other two formed radial routes running out to Newbridge in the west and to Newcraig hall in the south (Trams facts 8-CEC, 2006). All lines were designed to run through the City Centre of Edinburgh.

After extensive scrutiny, the Scottish parliament passed the tram bills in March 2006 (Edinburgh Tram Line One and Two Act 2006). However, funding the construction of the entire network (three phases) was impossible, and for this reason, only two of the line one with physical dimensions of 18.5km for line 1a and 5.5 km of line 1b received parliamentary permission. In 2007, the Final Business Case for the tram network was passed by the City of Edinburgh Council (CEC) (The Scotsman: 22 December 2007, retrieved 21 November 2011). Transport Initiatives Edinburgh (TIE), a private limited company, wholly owned subsidiary by the CEC was formed in 2002 to deliver the tram system and other major transport projects for the CEC. Contracts to build the network were concluded in April/May 2008 (The Scotsman: 25 October 2007, retrieved 21 June 2012) and construction was due to be originally completed in summer 2011 with an estimated completion cost of £545 million.

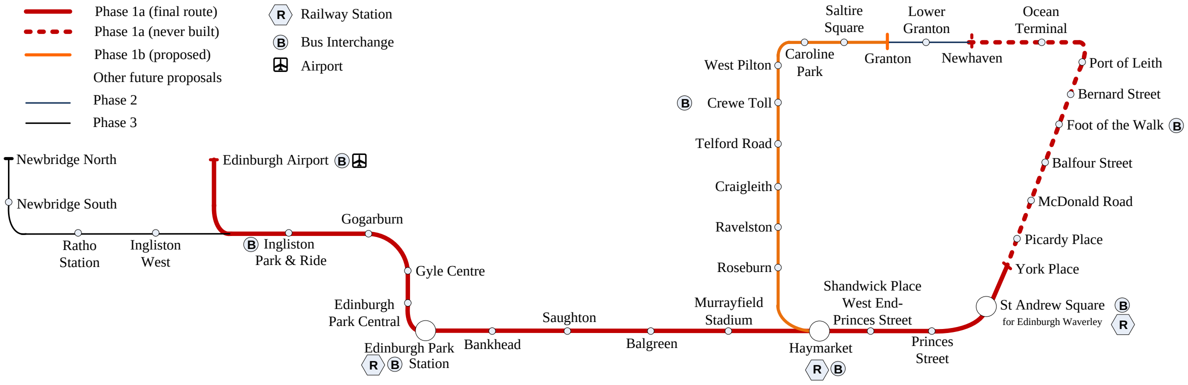


Figure 4.1: Proposed Route of the Edinburgh Trams

Source: The City of Edinburgh Council, 2013.

Due to funding issues, changes were made to the delivery of the original route (See Figure 4.1). For instance in April 2009, Phase 1b consisting of the tram line between Roseburn and Granton Square was postponed due to the economic downturn (Johnson, 2008 and BBC News: 24 April 2009, retrieved 11 January 2012). Delays, cost overruns, contractual disputes between TIE and BB & S and funding problems had caused further changes to the route. In September 2011, the City Council voted for the first phase of the tram route to go from the city's airport to the York Place, a location near St. Andrews Square and took direct control of the project. While legislative approval was obtained for all three phases of the project, only Phase 1a is currently being progressed.

For details of the entire project, a summary of its basic information is presented in Table 4.1. Stakeholder Relationship Map in Figure 4.2 and original tram project board of governance in Figure 4.3. It is intended that the project would support and promote a growing local economy for Edinburgh and create a healthy, safe and sustainable environment when completed (Audit Scotland, 2007). According to CEC, the trams will carry large volumes of passengers, quickly along their route and will not be hampered by general traffic when completed. The new modern tram system, they said, will offer an environmental friendly future as they are electrically powered, so there will be no vehicle emissions. They will create a fast and high capacity service that has proven popular and successful in many European cities. The tram is expected to be operational in 2014.

Table 4.1: Basic Information of Edinburgh Tram Network Project

Project Title	Edinburgh Tram Network (ETN) Project
Location	Scotland, UK
Purpose	- To support the local economy by improving accessibility. - To promote sustainability and reduce environmental damage caused by traffic. - To reduce traffic congestion. - To make the transport system safer and more secure. - To promote social benefits.
Scope	The Tramline will be double track to: - Connect Edinburgh Airport to the City Centre - Link with development areas in North and West Edinburgh
Contractual Framework	The key contracts are as follows: - Development Partnering and Operating Franchise Agreement (DPOFA); - System Design Services (SDS); - Joint Revenue Committee (JRC); - Multi Utilities Diversion Framework Agreement (MUDFA); - Infrastructure provider and maintenance (Infraco); and - Vehicle supply and maintenance (Tramco).
Relevant Physical Dimensions	Total length: 24 km in two phases - Phase 1a: 18.5km, is being developed (Case study) - Phase 1b: 5.5 km, to be developed later
Cost (£ million)	- Planned project budget = 545 - Validated budget = 776 - Cost variation = 231
Year of completion	- Original planned date was 2011 - Expected new date is 2014

Source: Edinburgh Tram Project, the City of Edinburgh Council report no. CEC/41/11-12/CE

Table 4.1: Basic Information of Edinburgh Tram Network Project (Continued)

Stakeholders		**Category**	**Bodies Involved**	
Internal	Supply Side	Client	City of Edinburgh Council (CEC)	
		Financiers	Transport Scotland (TS) and City of Edinburgh Council (CEC)	
		Sponsors	Transport Initiatives Edinburgh (Tie) and Transport Edinburgh Limited (TEL)	
		Client’s Customers	UK Tram, Edinburgh Trams	
		Client’s Owners	Transport Initiatives Edinburgh (Tie), Transport Edinburgh Limited (TEL), Lothian Buses (LB)	
		Other internal supply side categories	Category	Case-Study
			Tram Project Board (TPB)	A formal sub-committee of TEL. Delegated authority to monitor the delivery of the trams project
			Council Audit Committee (PAC)	Project Audit
			MPs/ Ministers	Parliamentary & political parties representatives
	Demand Side	Main Contractor	Bilfinger Berger Siemens (BBS) - Responsible for infrastructure construction (INFRACO).	
		First Tier Contractors	Construcciones y Auxiliar de Ferrocarriles SA (CAF) - Responsible for tram vehicle construction (TRAMCO).	
			Alfred McAlpine Infrastructure Services/Carillion-Responsible for utilities diversion work	
			Parsons Brinkerhoff/Halcrow - SDS provider to facilitate the early identification of utility diversion works, land purchase requirements and traffic regulation requirements and the completion of design drawings.	
		Second Tier Consultants	Faithful & Gould: Construction cost management consultants responsible for risk management procedures. Hg Consulting - Independent Certifier with a duty of care to CEC Steer Davies Gleave (SDG) – Assessed economic costs and benefits of the Trams project in December, 2007.	
		Professional Services Providers	Transdev- was appointed as the tram operator in May 2004 to assist planning of an integrated service network with TEL. Transdev was later cancelled in December 2009 as a cost saving measure.	
		Other internal supply side categories	Category	Case-Study
			Financial, Commercial and Legal Committee (FCL)	Financial management - Reporting, control, audit, risk management, insurance; and Contract management – Reporting, compliance, interface with delivery, claims and variations.

Source: Edinburgh Tram Project, the City of Edinburgh Council report no. CEC/41/11-12/CE

Table 4.1: Basic Information of Edinburgh Tram Network Project (Continued) - Stakeholder Identification (External)

Stakeholders		**Category**	**Bodies Involved**	
External	Public	Regulatory Agencies	SEPA, Scottish Water, Parliament, Planning, Road & aviation authority, Network rail, Historic Scotland, Building Standards	
		Local Government	City of Edinburgh Council (CEC)	
		National Government	Scottish Government	
		Other internal supply-side categories	Category	Case-study
			CEC councillors & officials,	CEC representatives
	Private	Local residents	Edinburgh residents (Randolph Crescent, Queen Street, Moray Feu, Blenheim, Shandwick, Picardy , Leith Walk, Forth Ports etc..)	
		Local Landowners		
		Environmentalists	SEPA, Friends of the Earth Scotland; Sustainable Scotland Network; Lothian & Edinburgh Environmental Partnership; Scottish Environment Link; Scottish Natural Heritage (SNH). Scottish Executive’s Countryside and Natural Heritage Unit (CANHU).	
		Conservationists		
		Archaeologists	Headland Archaeology (UK) Limited; City Council Archaeologists –Edinburgh, Glasgow University Archaeological Research Division (GUARD)	
		Other External Private stakeholders	Category	Case study
			B.A.A Edinburgh Airport; Henderson Global Investors (St. James Centre); Forth Ports; Edinburgh Business Forum; Essential Edinburgh; Federation of small businesses- Scotland; Edinburgh Chamber of Commerce; and representatives of local communities impacted by the Trams.	Key business and other stakeholders

Source: Edinburgh Tram Project, the City of Edinburgh Council report no. CEC/41/11-12/CE

Table 4.1: Basic Information of Edinburgh Tram Network Project (Continued)

External Stakeholder	**External Stakeholder's Attitude to this Project**	**External Stakeholder's Influence on project**	**Impact of Project on External Stakeholder**
B.A.A Edinburgh Airport	Positive	High	Low
Henderson Global Investors (St. James Centre)	Positive	High	High
Forth Ports	Positive	High	Low
Edinburgh Business Forum	Positive	High	High
Essential Edinburgh	Positive	Low	High
Federation of small businesses- Scotland	Positive	Low	High
Edinburgh Chamber of Commerce	Positive	High	Low
Representatives of local communities impacted by the Trams.	Positive	Low	High

Table 4.1: Basic Information of Edinburgh Tram Network Project (Continued) - Project Organisation

Client Project Team Size & Structure	350
Contractor Project Team Size and Structure	3000
Sub-Contractor Project Team Involvement	n/a
Project Tools and Techniques	Life-Cycle Costing Approaches , Stakeholder Involvement, Building Information Modelling (BIM), Project Management Software, Relationship Management Tools, Project Knowledge Management Tools, Project Knowledge Management Tools, Team Building Tools,

Source: Edinburgh Tram Project, the City of Edinburgh Council report no. CEC/41/11-12/CE

Table 4.1: Basic Information of Edinburgh Tram Network Project (Continued)

Political Project Environment	The political project environment for ETNP varies in influence according to the number of political seats or elected members within the City of Edinburgh Council (CEC).
Legal and Regulatory Project Environment (regionally, nationally and Europe wide)	ETNP is governed by the following Legal and Regulatory frameworks (regionally, nationally and Europe wide) - Edinburgh Tram Acts - New Roads and Street Works Act (NRSWA) - Code of Construction Practice (Buildings, Roads, Bridges) - The Road Traffic Regulation for the tram - The Local Authorities' Traffic Orders (Procedure) (Scotland) Regulations 1999 as amended. - Environmental Impact Assessment (Scotland) Regulations (covering: Traffic and Transport, Land Use, Geology, Soils and Contaminated Land, Landscape and Visual Impacts, Ecology and Nature Conservation, Water Quality, Cultural Heritage, Socio Economic Effects, Noise and Vibration, Air Quality). - Environmental Impact Assessment (EU) Regulations.
Economic Project Environment	Economic Project Environment for ETN project is based on the following economic benefits: - Reduction of travel time. - Economic efficiency. - Employment development. - Employment generation. - Residential development - Economic growth.

Source: Edinburgh Tram Project, the City of Edinburgh Council report no. CEC/41/11-12/CE

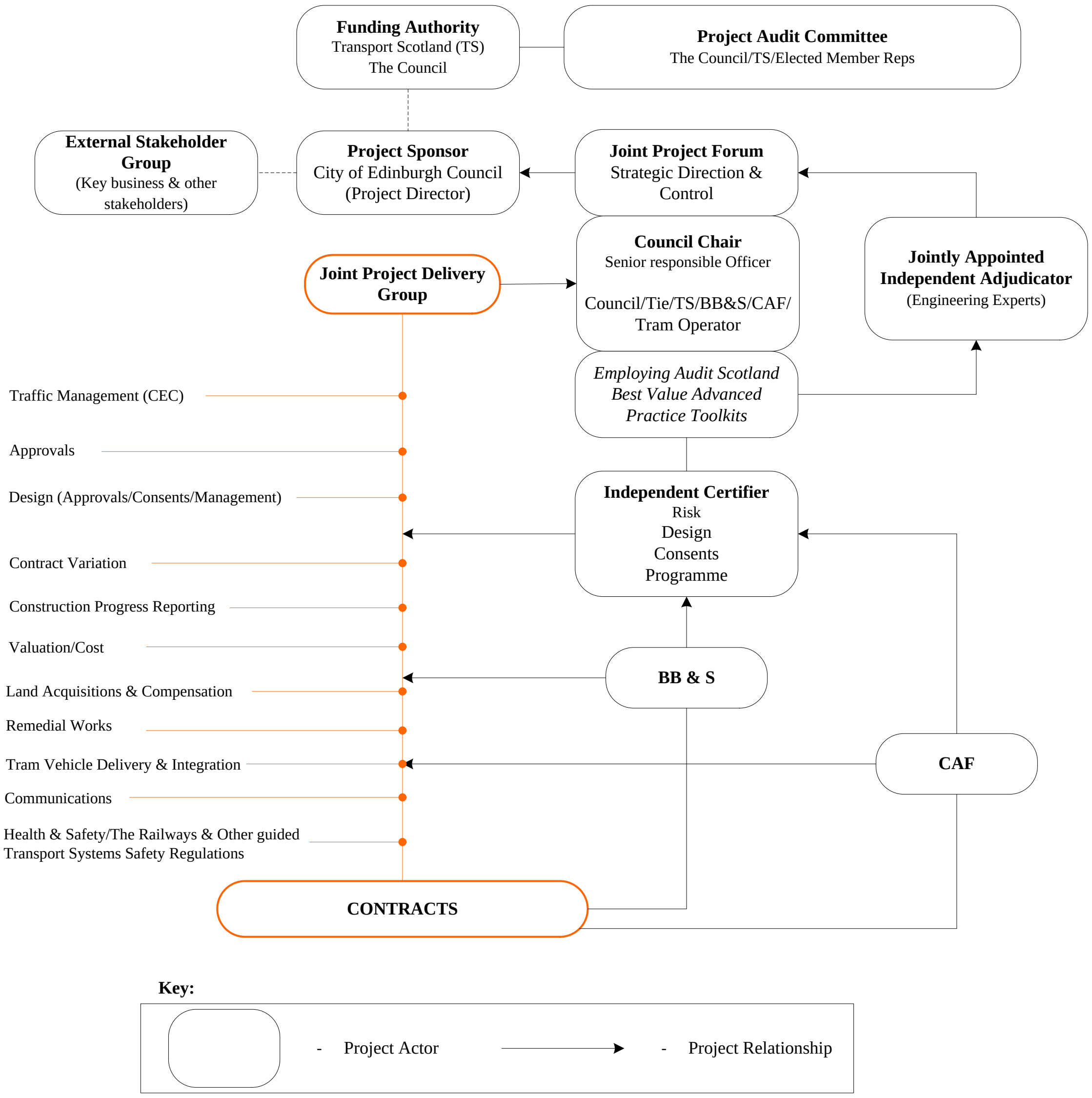


Figure 4.2: Stakeholder Relationship Map for Edinburgh Tram Network Project

Source: Audit Scotland (2011).

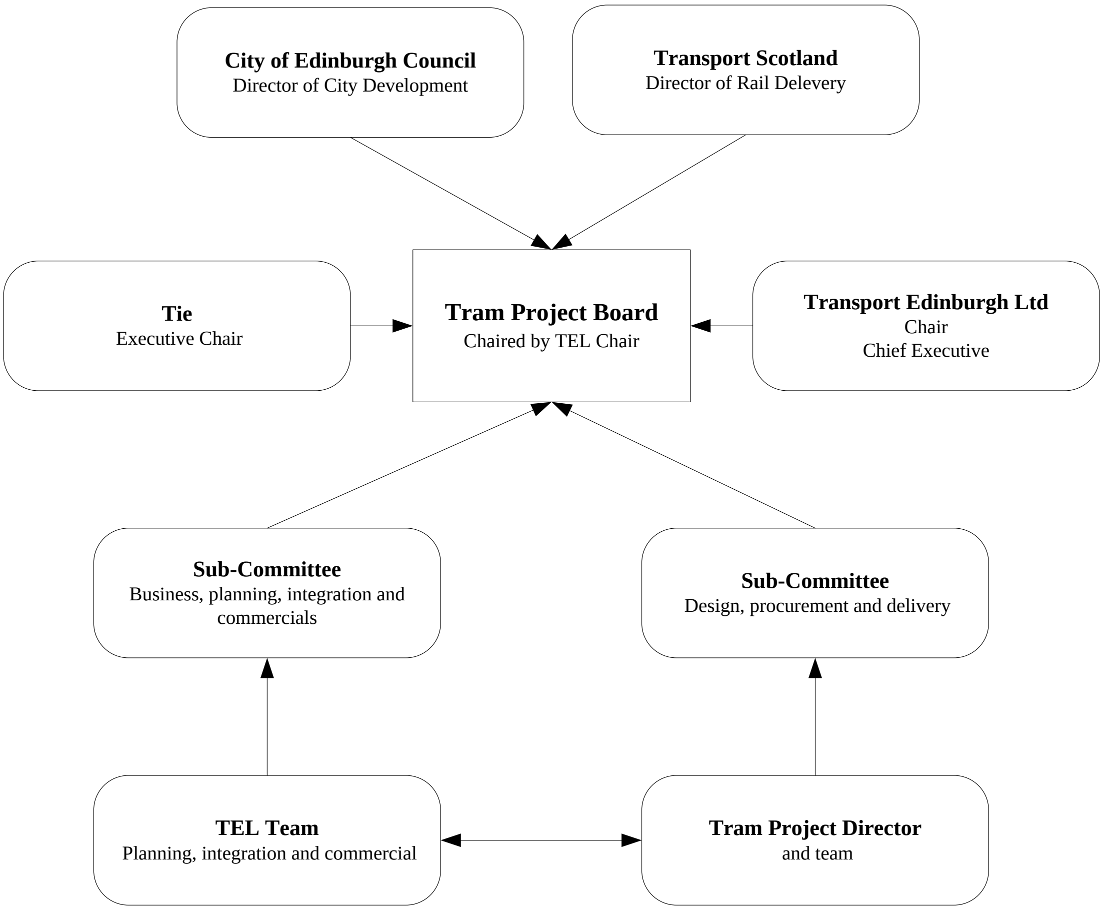


Figure 4.3: Original Tram Project Board Governance Structure
Source: Audit Scotland (2011)

4.2.2.1. Tram Network Construction and Civil Engineering Works

Until August 2011, the construction of ETNP was overseen by Transport Initiatives Edinburgh (TIE), a company wholly owned by CEC who were responsible for project-managing the construction of the tramway (Henderson, 2009). The construction involved new bridges, retaining walls, viaducts, the tram depot and control centre, electrical sub stations to provide current to the overhead lines at 750 volts, track laying and tram stops.

In July 2007, work to divert utilities (See Exhibit 1) along the tram route started under the Multi-Utilities Framework Agreement (MUDFA) to pave way for track-laying in Leith (BBC News, 9 July 2007). These works were followed by the System Design Services (SDS), which was jointly led by Parsons Brinckerhoff and Halcrow Group

Limited. In May 2008, the final contracts to build the tram system were awarded to a consortium of Bilfinger Berger and Siemens (BB&S) and Spanish tram builder Construcciones y Auxiliar de Ferrocarriles (CAF) (Rowson, 2008).

Exhibit 1: Utility Diversions for Edinburgh Trams Network Construction

Leith Walk

West Maitland Street & Haymarket

West End -Princes Street

Source: The City of Edinburgh Council, 2013.

As part of the project, 12 new bridges were built at - Balgreen Road Bridge, Balgreen Road Access Bridge (Network Rail); Carrick Knowe Bridge; Depot Access Bridge; Edinburgh Park Station bridge; Gogarburn Bridge; Roseburn Street Bridge; Russell Road

Bridge; South Gyle Access Bridge and the Water of Leith Bridge. A tunnel under the A8 near the Gogar roundabout was also built (See Exhibit 2) while the Murrayfield Viaduct was adapted for trams to pass under it (Railway-technology, 2013). Some demolishing works such as buildings listed to fall under Category C(S) in the former Caledonian Alehouse on Haymarket Terrace (Edinburgh Tram Line One Bill of Environmental Statement) were carried out to allow the building of a tram interchange at Haymarket station. Table 4.2 presents the bridges built and their individual lengths and widths in metres.

Table 4.2: Bridges Built to accommodate Edinburgh Tram

Bridge	**Length (M)**	**Width (M)**
Balgreen Road bridge	25	9
Balgreen Road - Network Rail access Bridge	9	4
Carrick Knowe Bridge	32	12
Depot Access Bridge	28	20
Edinburgh Park Station Bridge	232	10
Gogarburn bridge	17	10
Roseburn Street Bridge	34	11
Russell Road Bridge	16	20
Haymarket Viaduct	55	13
Haymarket Depot Access Bridge	12	10
South Gyle Access Bridge	43	10
Water of Leith Bridge	63	10

Source: The City of Edinburgh Council, 2013.

Also, sections of some on-street track were laid into a special foundation with cobbled road surfacing designed to be sympathetic with the existing style of the streets in Edinburgh. However, this cobbled road surfacing was taken off in many places due to oppositions from cyclists (CEC: Prior Approval 12/00915/PA at York Place).

Tracks over the Carrick Knowe Bridge

Completed Tram Bridge over Roseburn Street leading to Murray field tram stop

Water of Leith Bridge situated between Balgreen road and Murray field tram stops

South Gyle Access Bridge

A8 Roadway Tunnel

Russell Road Bridge

Murray field Viaduct under construction

Exhibit 2: Edinburgh Trams Bridge Photos

Source: The City of Edinburgh Council, 2013.

In late 2011, Transport Initiatives Edinburgh (TIE) was released from managing the ETNP. Turner & Townsend, a project management consultant was brought in by CEC to ensure effective oversight and delivery of the project. Work in 2012 continued smoothly on schedule with a new governance structure indicated in Figure 4.4 under the management of Turner and Townsend.

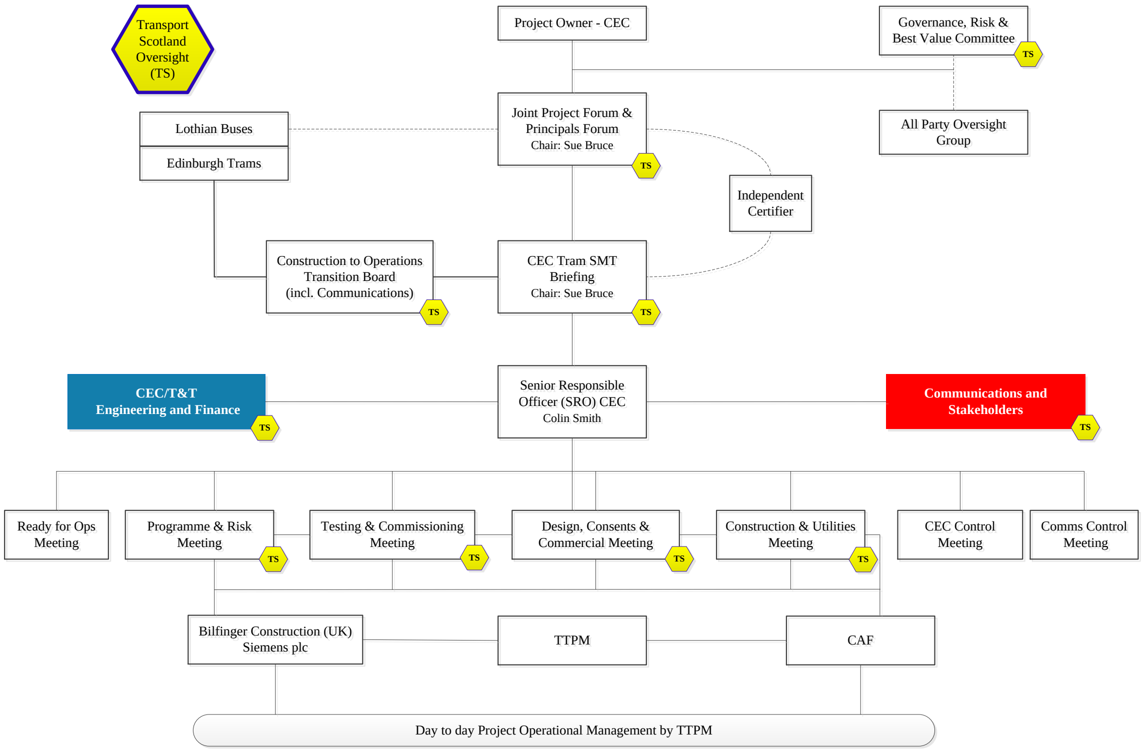
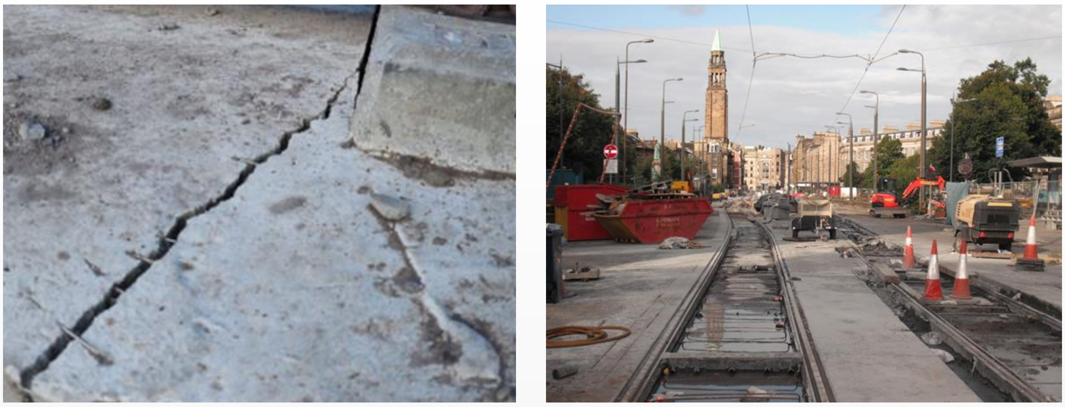


Figure 4.4: Governance Structure for Edinburgh Tram Network Project as at June 2013

Source: The City of Edinburgh Council, 2013.

However, in May 2013, it was revealed that more than 150 metres of concrete track bed was not laid to the correct specifications between Shandwick Place and Haymarket and as a result, needed replacement (See Exhibit 3). The City of Edinburgh Council (CEC) issued assurances that this would not affect the original deadline of the project (The Scotsman, 31 May 2013). BB & S later admitted the deficiency with regard to the concrete track bed and began to remedy it. This led to further disruption of Shandwick Place and Haymarket, which was intended to be free of track works by September 2013 (The Scotsman, 9 August 2013). In June 2013, overhead electric wires were installed on the city centre portion of the route (See Exhibit 4). This has been considered the “last major step” in the construction process (RailStaff, 21 June 2013)



Cracks in tram track bed

Concrete bed stripped off

Concrete bed re-laid in progress

Concrete re-laid

Exhibit 3: Relaying of concrete bed for tram track between Shandwick Place and Haymarket.

Source: Miller, D. (2013). Edinburgh News (09 August 2013)

The trams are powered by overhead cables attached to purposely-built poles and some mounted to the sides of buildings (The Scotsman, 10 August 2013). Out of nine electrical sub-stations (underground and above-ground) proposed for the line to Newhaven, only five are in place due to the truncation of the tramline to York Place (BBC News, 24 April 2008).

Exhibit 4: Overhead Electric wire installation on the Princes Street
Source: The City of Edinburgh Council, 2013.

Talks between the Scottish Government and Edinburgh Council revealed on the 17 September 2013 that works on the tram scheme were running two months ahead of schedule, and would be opened by May 2014 (BBC News, 17 September 2013). In October 2013, all tram and road works were completed (BBC News, 18 October 2013). On 8 October 2013, testing of the trams began between the depot and Edinburgh Park. This was followed by the energising of tram wires from Bankhead tram stop to York Place in November 2013, marking the first time that the route was completely energised (City of Edinburgh Council, 19 November 2013). Testing along the full length of the route is scheduled to begin by December 2013 (Edinburgh Evening News, 9 October 2013 and 17 September 2013). The network will be operated from a depot at Gogar, close to the A8 roundabout, just north of the Gyle tram stop (Barr Construction, 2011).

4.2.2.2. Contractual Disputes

Until February 2011, contractual disputes (See Figure 4.4) and further utility diversion works resulted in significant delays to the project beyond the originally planned programme (See Figure 4.5).

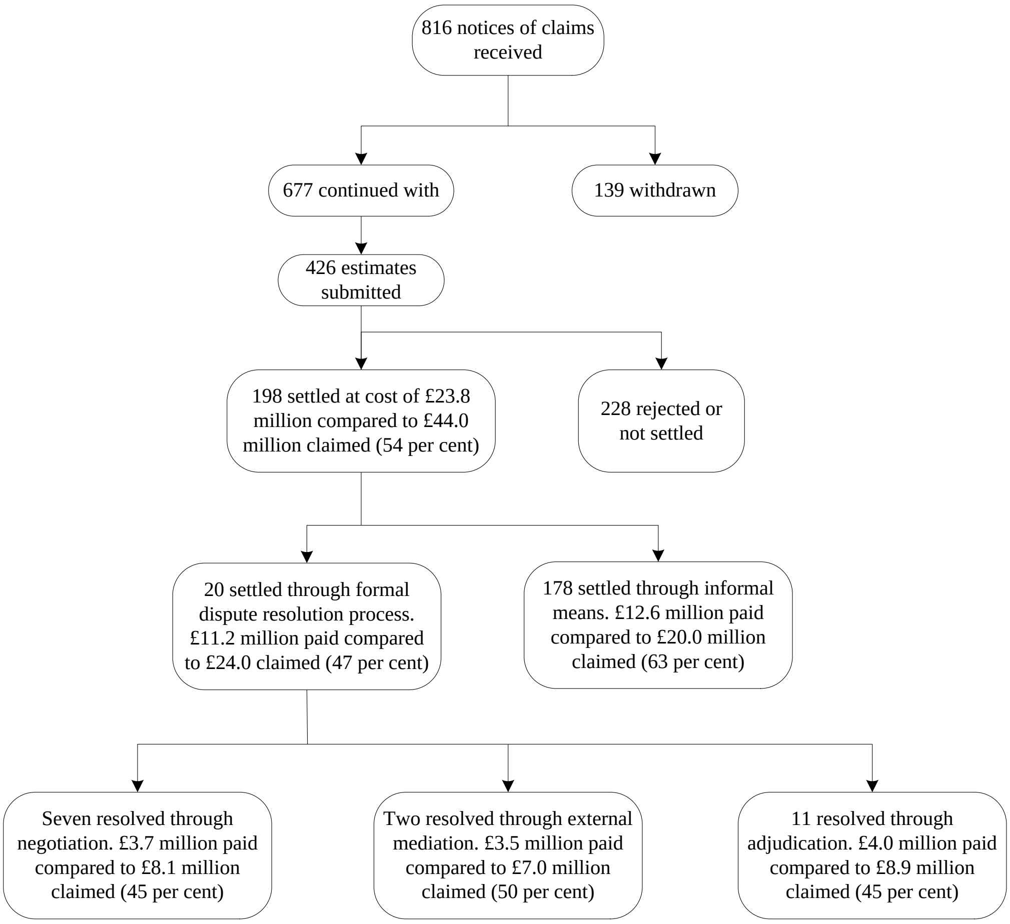
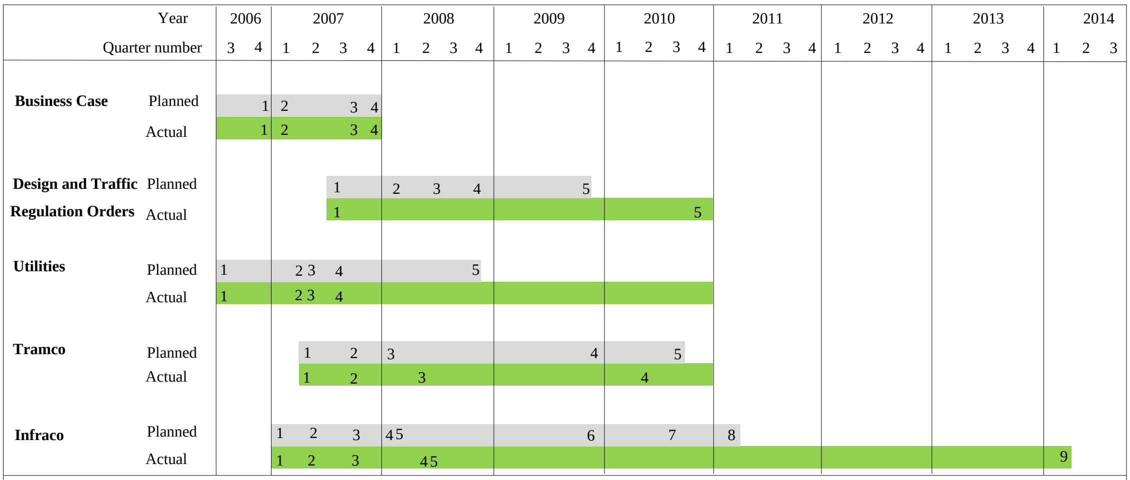


Figure 4.4: Disputes and Changes in Edinburgh Tram Network Project

Source: Audit Scotland (2011)

To the end of December 2010, BB&S has submitted 816 notices to claim of which 139 were later withdrawn. BB&S has submitted cost estimates in respect of 426 out of the remaining 677 notices to claim. TIE and BB&S have settled 198 of these claims with the others either rejected or not yet agreed. The cost to TIE of those settled has been £23.8 million compared to the £44.0 million claimed by BB&S (54 per cent). Included within the 198 settled are 20 which have been settled through formal dispute resolution procedures, as allowed for in the contract. These have reduced BB&S's claims for additional payment from £24.0 million to £11.2 million (47 per cent). A further five cases being resolved through dispute resolution procedures have been referred for external adjudication or negotiation is in progress. TIE considers these adjudications have helped clarify some of the contractual issues which were in dispute with BB&S.



Key Milestones

Business Case
1 Approval of draft final business case by CEC
2 Confirmation of Infraco tender prices to CEC
3 Approval of final business case by Tram Project Board
4 Approval of final business case by CEC

Design and TROs
1 TRO process commences
2 Completion of construction drawings – Utilities diversions
3 Completion of planning drawings
4 Completion of detailed design construction drawings
5 TRO process complete

Utilities
1 Award of utilities diversion contract
2 Completion of pre-construction period of utilities diversion contract
3 Commencement of utilities diversion works trial site
4 Commencement of utilities diversion works
5 Completion of utility diversion works

Tramco
1 Completion of initial evaluation/negotiation of bids
2 Recommendation of preferred bidder
3 Award of Tramco contract
4 Delivery of first tram
5 Delivery of all tram

Infraco
1 Return of Stage 1 bid
2 Completion of evaluation/negotiation of Stage 2 bid
3 Recommendation of preferred bidder
4 Award of Infraco contract
5 Construction of tract and tram depot commences
6 Depot completion
7 Commencement of test running
8 Delivery into revenue services (Never met)
9 Expected delivery into revenue services

Figure 4.5: Project Delivery against Key Milestones

Source: Audit Scotland, 2007

4.2.2.3. Risks

- **Social Issues**

Although extensive consultations and involvement of stakeholders were carried out on ETNP, impacts by the project during its construction phases on the social environment have generated controversy and/or opposition. Delays in the tram works caused many grievances and criticisms by local businesses along the tram routes, who claimed that their income has been adversely affected by long-term road closures in the centre of Edinburgh since 2008 (BBC News, 29 April 2008) and by Edinburgh residents who have expressed displeasure over the delays (BBC News, 29 April 2008). CEC and the developer were further criticized when construction works were delayed in 2009 causing obstruction across the city during the Edinburgh Festival and Fringe (McIntosh, 2009). Further obstruction occurred in January 2010, when construction was suspended due to unexpected freezing temperatures during winter (Edinburgh Evening News, 9 January 2010).

- **Technical Issues**

Disruptions from tram works were also a concern to Edinburgh residents. For example, cycling groups in the city voiced safety concerns after some cyclists suffered accidents when their bicycle wheels became caught in tram tracks. Road surfaces around the tracks in some parts of the city were also reported to be crumbling, raising further safety problems. In response, TIE carried out road repairs while Edinburgh Trams agreed to fund special training for local cyclists (BBC News, 7 December 2009). Further safety concerns were raised in 2010 by residents along the tram routes about the suspension of overhead electric cables from residential buildings, with some property owners refusing to give permission for the cables to be attached (Marshall, 4 March 2010).

In September 2011, Princes Street was again closed to all traffic for around 10 months to allow repairs on the crumbling tarmac around the tram lines before they had been used (The Scotsman News, 09 March 2011; BBC News, 17 September 2011). In just after two months, the city centre residents filed a complaint with the United Nations Economic Commission for Europe (UNECE) Aarhus Convention Compliance Committee in December 2011, arguing that traffic diversions through residential streets during the protracted construction of the tramline has resulted in environmental (increased pollution and noise) and social (health issues) risks impacts on residents. The Council countered that monitoring was on-going and no sites data breached EU limits (BBC News, 13 December 2011).

However, motorists and commuters in the capital continued to face new disruption in January 2012 when the project entered its critical phase. On January 7, 2012, St Andrew Street, near Waverley Station and Edinburgh's bus interchange, were closed to traffic to allow work to begin on the route which was expected to last throughout 2012, while Shandwick Place, west of the city centre, was also closed a week later, with work due to be completed by spring 2013.

- **Environmental Issues**

In December, 2003, the full Environmental Statement (ES) of ETNP line one was published. This was done in accordance with the standing orders of the Scottish Parliament and determinations by the Presiding Officer, which require that projects approved by private Act of Parliament must be subjected to Environmental Impact Assessment (EIA) and under the scope of the Environmental Impact Assessment (Scotland) Regulations 1999 (the EIA Regulations). Since the proposals for Line One of the ETNP exceeded the threshold of EIA Regulations (more than one hectare), the project's characteristics during development were considered likely to have significant environmental effects. This resulted in TIE commissioning Environmental Resource Management (ERM) to undertake an assessment of the proposals.

The assessment by the ERM considered the potential environmental impacts of the tram proposals on people, property, the natural and cultural heritage, including effects of the permanent development of land and structures for the scheme, short term, and temporary impacts during construction, and long term effects resulting from tram operations. Hence the Environmental Statement (ES) for Edinburgh Tram Line One was produced in accordance with the requirements of the EIA Regulations. Prior to preparation of the ES, a scoping study was undertaken early in the EIA process, and an Environmental Scoping Report was prepared following consultations with statutory and non-statutory environmental organisations indicated in Table 4.3 as an important part of the EIA process. The first was undertaken early in the process to identify key issues and to guide the scope of the EIA. The findings of this part of the EIA process were reported in an Environmental Scoping Report.

Table 4.3: Organisations and Groups consulted during the EIA for ETNP Line one.

Statutory Authorities and Agencies	Non Statutory Groups and Organisations
– City of Edinburgh Council (Planning and Strategy; Archaeology; Environmental & Consumer Services; Biodiversity). – Health and Safety Executive – Historic Scotland – Scottish Environment Protection Agency (SEPA), East Region – Scottish Executive Environment and Rural Affairs Department – Scottish Executive Development Department, Planning Division – Scottish Natural Heritage (SNH) – Scottish Water	– Architectural Heritage Society of Scotland – Cockburn Association – Cyclists Touring Club – Edinburgh and Lothian Badger Group – Edinburgh Architectural Association – Edinburgh World Heritage Trust – Friends of the Earth Scotland – Lothian Bat Group – National Trust for Scotland – Royal Fine Art Commission for Scotland – Royal Society for the Protection of Birds(RSPB) Scotland – Scottish Civic Trust – Scottish Enterprise Edinburgh & Lothian – Scottish Rights of Way and Access Society – Scottish Wildlife Trust – SPOKES Lothian Cycle Campaign – Sustrans – VisitScotland

Source: Edinburgh Tram line one environmental statement (2003)

In addition to the specific consultations, a programme of public consultations was held from 14 May 2003 to 10 July 2003 for the EIA. These included leaflet distribution; press launches; touring exhibitions at a series of locations; a static city centre exhibition; a series of public meetings; and consultations with a range of third parties including community groups, political parties, business and tourism groups, disability and transport groups. In all, many published information leaflets were delivered to over 100,000 homes and businesses to raise awareness of the tram proposals and its effects on both the society and the environment.

Despite the numerous consultations and environmental impact awareness creation, a visit to ETNP sites during the early 2011 and mid-2013, revealed environmental related track repair works on the Princes Street and the Haymarket respectively. The repairs were believed to have been caused by the extreme weather conditions suffered in 2009 and 2010 which both the contractors and project owners had no control over. This points out to the fact that significant risks of project time and cost overruns and quality deficiency in the project are largely related to environmental problems.

- **Political Issues**

As in any major national project, the Edinburgh Tram Network Project had been marred with political issues from the early stages of the project's life. Political disputes between the Scottish National Party (SNP) on one side, who have opposed the project and other political parties including Labour, Liberal Democrats, Conservatives and Green Party on the other who have generally backed the scheme, had been on the increase.

The SNP councillors did not see themselves bound to support the project and as such lost some opportunities in tackling the project even though they were part of the administration sponsoring it. The political disagreement was stronger and ran through the middle of the ruling coalition on CEC until the Scottish Government cancelled the Edinburgh Airport Rail Link in favour of making the trams the means of linking the City Centre and the main line rail network to the airport. The Scottish Government later committed itself to building a new station on the Edinburgh-Fife/Aberdeen line at Gogar to link with the trams and the airport.

Road closures for the MUDFA contract generated grievances, anger, bitterness and a feeling of displeasure for the new tram project from the public as the disruption increased. This was not helped by some inaccurate media reports in the local press and comments by some opposition politicians. Certainly, public opinion during early consultation indicated support for the project before construction commenced and will certainly be in favour of it during operation. However, the never-ending road works and street closures with barriers in place in the City Centre forced some political affiliated Edinburgh residents and some politicians to oppose and contend against one another.

4.3: Summary

This chapter presents the case study adopted for the research. It summarizes the background of the ETNP starting from its history through to the risk issues that caused changes in the project performance between the initial estimate of time, cost and scope to the current project completion time, cost and scope. The changes in performance (usually delays, over budget and quality deficiency) that caused a shift in the estimated midpoint of construction were identified to be attributed to specific social, technical, economic, environmental and political risks present in the project environment. While it is not practical to discuss the full implications of all the risks identified in the project, Tables 4.4 and 4.5 demonstrate a summary of specific risks impacting on the project environment and the specific technical risks impacting on the social and natural environments respectively.

Table 4.4: Specific Risks Impacting on the Project Environment

Specific risks	Risk type	References
Social	Social grievances	BBC News, (29 April 2008); The Scotsman, (22 December 2009); McIntosh, (2009); BBC News, (7 December 2009)
	Multi-level decision making bodies	Transport Initiatives Edinburgh, (2007).
	Disputes	Henderson, (2010a); Dalton, (2010); Aitken (2009).
	Legal Actions	Henderson, (2010a); Gilbert, (2008).
	Stakeholder's criticism/pressure	Marshall, (2010); BBC News, (7 December 2009)
	Social Issues	BBC News, (29 April 2008); The Scotsman (22 December 2009); McIntosh (2009); BBC News (7 December 2009).

Source: Desktop Search and Field Survey 2013.

Table 4.4: Specific Risks Impacting on the Project Environment (continued)

Specific risks	Risk type	References
Technical	Project scope changes	BBC News, (17 September 2011);Ferguson, (2010),
	Ground conditions on given project sites	Severin (2011)
	Inadequate project complexity analysis	BBC News, (17 September 2011)
	Modification to project specification	The Scotsman, (31 May 2013)
	Technical difficulties in utilities diversions	Audit Scotland (2007)
	Engineering and design change	BBC News, (17 September 2011)
	Project quality deficiency	The Scotsman, (9 March 2011); BBC News, (17 September 2011); The Scotsman, (31 May 2013); The Scotsman, (9 August 2013)
	Supply chain breakdown	Mumford (2011)
	Rework	The Scotsman, (31 May 2013); The Scotsman, (9 August 2013)
	Project time overruns	Millet (2009); Henderson, (2010b); Henderson, (2009); Marshall, (2010); STV News, (10 March 2010); Wright, (2010).
	Project cost overruns	Severin, (2011); Marshall, (2011); Ferguson, (2010); Wright, (2010); BBC News, (19 August 2011)
Economic	Incorrect project cost estimate	Severin, (2011); Marshall, (2011); Ferguson, (2010); Wright, (2010); Leask, (2010); BBC News, (19 August 2011)
	Incorrect project time estimate	Henderson, (2010a); Gilbert, (2008); STV News, (10 March 2010)
	Wage inflation	Wright, (2010); BBC News, (20 June 2012)
	Global economic recession	Johnson, (2008), BBC News, (2009)
	Cost and delays due to utilities diversions	Henderson, (2009); Marshall, (2010); Wright, (2010).
	Changes in inflation as construction works proceed	BBC News, (2 September 2011); The Scotsman, (23 June 2010).
	Funding problems	Audit Scotland, (2007); Severin, (2011); BBC News (30 August 2011)
Environmental	Freezing temperatures	Mumford, (2011); The Scotsman, (9 January 2010).
	Pollution (water, air, noise etc.)	BBC News, (13 December 2011)
Political	Lack of political support (opposition)	Audit Scotland, (2007); BBC News (30 August 2011)
	Lack of partner support	Audit Scotland (2007), BBC News, (30 August 2011)
	Political indecision	BBC News, (30 August 2011)
	Project termination	Millet (2009),
	Contractual disputes	Henderson, (2010a); Dalton (2010); Aitken (2009).

Source: Desktop Search and Field Survey 2013.

Table 4.5: Specific Technical Risks Impacting on the Social and Natural Environments

Project phase	Source of impacts	Potential impacts	
		Environmental	Social
Construction	− Drilling/piling operations − Demolishing works − Earthworks − Concrete works − Machine operation (Heavy duty vehicles and equipment)	− Vibration − Disturbances − Vegetation loss − Damage to ecosystem − Contamination of the local environment − Damage to cultural heritage − Pollution (Air, noise etc.) − Habitat changes − Effects on air quality − Footprint impacts to habitats/flora − Disturbance of fauna − Noise impacts on animals − Temporary/ permanent loss of habitat.	− Vibration − Noise − Disturbances − Health problems − Property loss − damage to structures − traffic congestions − loss of income − decreased recreational activities − Loss of rent value − Clean-up cost

Source: Desktop Search and Field Survey 2013.

CHAPTER FIVE: DATA COLLECTION AND ANALYSIS

5.1. Introduction

This chapter introduces the first part of the data analysis. Having concluded the research introductory, the relevant literature review and the research methodology chapters, a preliminary analysis is undertaken as a prelude to the substantive analysis which led to the development of the MegaDS model for the assessment of risks in transportation megaprojects. This distinction was considered important so as to develop a better understanding of the data and also to reduce it to a manageable size. In this respect, the analyses presented here are based on respondents' perception towards risk factors impacting on project time, cost and quality of transportation megaprojects during construction.

Data analysis is based on the structure of both the questionnaire surveys and opinions from professionals in the construction industry. The demographic data for both the quantitative and qualitative approaches is analysed using descriptive statistics (specifically percentages) while the dependent risk variables are analysed using Weighted Quantitative Score (WQS) method, the Analytical Network Process for pairwise comparison and subsequently system dynamics modelling. WQS is first implemented to reduce the results of the potential risk variables to a manageable value and size towards the subsequent development of the ANP models.

5.2. Results and Discussions

As noted in Section 5.1, qualitative and quantitative approaches were employed to understand the perception of construction professionals towards risk factors influencing project time, cost and quality of transportation megaprojects in the construction phase. The aim was to seek experts' opinions through interviews and the administration of questionnaire surveys on a transportation megaproject under construction in Edinburgh (UK). Accordingly, data was collected between April 2013 and July 2013. Results of the data collected and detailed preliminary analysis are discussed in sections 5.2.1 and 5.2.2.

5.2.1. The Qualitative Approach

In all, 20 experienced personnel, who are involved in transportation megaproject development in the UK, were interviewed. Although, interviewees varied in their trade, they were selected randomly. Due to the need to maintain strict confidentiality, the names and designation of interviewees will not be disclosed. The structure and format of the interviews is illustrated in Appendix (B). The interviewer was free to ask additional questions that focused on issues arising during the course of the interview. The freedom to follow the interviewee, to ask for clarifications, and to focus on specific risks and other issues impacting on project performance made the interviews insightful.

As Table 5.1 indicates, interviewees had extensive experience in the construction industry ranging from 12 years to 23 years. The total professional experience of the 20 interviewees is 309 years and an average of 15.45 years. Interviewees chosen are seniors in their respective companies. They are more directly related to the construction environment and their positions interact with the organizational policies and practice. As such, respondents have enough technical background and experience in dealing with risk issues in megaproject development at the construction phase.

Respondents were asked to identify the generic risk events inherent in transportation megaprojects that affect project performance during construction. For contractors, consultants and project engineers, the responses fell generally into two categories. First and most often cited was that contractual disputes, funding issues, tight environmental regulations and political interference in the project impact on megaproject development. Second, technical difficulties such as ground condition problems, utility diversion issues and archaeological finds in certain portions of the project during construction result in added delays and extra cost to the main contractors.

Further to the generic risk events, other issues identified as most important by nearly all respondents was the source of funding and its stability for a megaproject development. Owners emphasized the criticality of ensuring that the business case and the economic model of a megaproject are realistically aligned. Owners were also concerned with potential problems with unnecessary claims from contractors, social unacceptability at some points, and issues of security and safety. They also noted the importance of dealing with reputable and qualified contractors.

Table 5.1: Summary of Interviewees Profile and Demography

Type of organisation	Type of project	Size of project (£)	Designation	Interviewee (i)		
				Number (N)	Year of experience (Ye) per (i)	Total (N*Ye)
Client	Building	> 0.5 billion	Site manager	4	13	52
Consultant	Building	0.5-1 billion	Project manager	3	15	45
Contractor	Transportation	0.5-1billion	Project engineer	4	23	92
Consultant	Utility diversion	< 0.5 billion	Project manager	5	12	60
Contractor	Build-Infra	>1 billion	Project engineer	4	15	60
Total =				20	64	309 yrs.
Average experience =		∑ (N*Ye) per (i) / N = 248 /20 = 15. 45 years				

When asked about how the qualitative risk effects on the project performance can be quantified and analyzed to reduce under performances in megaproject construction, almost all of those interviewed, reported that every organization on the project had specific requirements and a set down process used to identify, assess, and manage risks. A third of the respondents noted that a number of firms undertook risk assessments on an ad hoc basis where location or sub contract type and size dictate whether an assessment or analysis would take place. It appeared that larger projects had a much greater chance of quantifying risks to the project management team for a formal assessment.

Some of the project management team representatives interviewed were noted to be very familiar with the use and applications of quantitative and financial risk modelling techniques for assessing the impact of risk on megaprojects. However, they expressed the difficulties with transforming the results to risk management strategies for project managers or for use on specific projects. These organizations were very knowledgeable of risk management theory, concepts, and principles but noted the difficulties of determining the relevance of issues and what risks are of most significant for their own concerns as well as for other project participants.

Respondents were further asked to judge the effectiveness of their risk assessment practices for megaprojects during construction. Only three respondents noted that their current process and practices were completely adequate and effective in identifying and assessing interrelationships of the portfolio of risks for the megaprojects they had participated in. The majority of respondents identified the on-going risk assessment practices as only fairly adequate/inadequate and less effective as a mechanism to identify and prioritize and assess risks. Many interviewees described their procedures as either too subjective or too quantitative, and most noted that analysis results could not be used across projects. About a third of the respondents reported the use of quantitative methods to assess project risk, with the majority relying on subjective judgment. This revealed disparities between decision makers and project personnel that can affect the project outcomes.

In summary, it can be concluded from the interview results that there is no standard and effective technique or practice specifically targeted for assessing risks in megaproject construction. However, there is a variety of techniques and practices existing to identify and assess risks that occur on megaprojects during construction. The results further revealed that decisions on country-specific risks were often made by top management and separated from other business, technical and operation risks of the project. Few project participants have a complete understanding of the generic risks that happen on the project, especially at the construction phase. As such, categorizing risks occurs when participants only identify, assess and/or manage risks using a specific perspective. Megaprojects are often noted to be organized and managed in ways that create information and communication disconnects.

For a transportation project like ETNP, contracts and contract language are often viewed as the most important method to control and allocate project risks, but only few project participants understand how risks should be allocated by contract. Misconceptions and assumptions about who owns and controls the risk also seemed to be common in this project. As a result, interviewees were receptive to the development of a structured risk identification, assessment, and management process that gives consideration to the entire life cycle of megaprojects.

5.2.2. The Quantitative Approach

Edwards P et al., (2002) advises that in a study of this nature, the method used for the main survey should not be significantly different from the method used in the pilot survey otherwise the logic of the research method might be defeated. Given that the method used for the pilot survey proved reliable and successful, the same method was employed for the main survey. Subsequently, the survey instruments were (as in the pilot survey) distributed manually to construction professionals working on Edinburgh Tram Network Project (ETNP) in Scotland (UK). Nevertheless, notification was sent to two of the main contractor's offices in Haymarket and Gyle Centre in Edinburgh regarding the intended purpose of the research and how the data obtained would be handled. The information was sent in person by the researcher in the latter part of April 2013. The main objective was to inform the potential respondents so that they can be prepared to participate in the survey. Indications are that such methods can help improve response rates in surveys.

Two weeks after sending the prior notification, the survey instruments were despatched manually and others by email as attachments. As in the pilot survey, the instruction to residents and businesses along the routes of ETNP was delivered and retrieved in person. This decision to distribute the greater part of the questionnaires and to retrieve them in person was taken for two reasons; first, to ensure that the survey instruments got to the intended recipients and secondly, to help improve the response rate.

Out of the 400 research questionnaires intended for the survey, only about 300 fully addressed instruments, each with a covering letter (see Appendix A) were successfully distributed due to lack of adequate number of target groups on the case study project. It turned out that some of the potential respondents (Contractors, Engineers, Project managers and Client's representatives), albeit on the ETNP list used in drawing up the sampling frame, had ceased operations and/or could not be traced. While the fieldwork was on-going, random phone calls were made to some of these respondents in other parts of UK to establish progress. A period of up to four weeks was allowed for the fieldwork and all completed survey questionnaires were retrieved latest by the first quarter of June 2013. After several efforts to help improve the response rate, especially when the four week period projected had expired, survey questionnaires that were not retrieved by mid July 2013 were declared non-responsive. That is, within a six-week period, all survey questionnaires retrieved were put together as indicate in Table 5.2 for analysis.

Out of the 300 instruments delivered, 145 completed questionnaires were successfully retrieved representing a 48.30% response rate. Of the 145 completed research instruments, 5 were partially answered and as a result, were screened out for data analysis. Hence, 140 were actually used in developing the substantive ANP models, described in chapter six.

Table 5.2: Summary of Survey conducted

Parameters	**Values**
Number of questionnaires distributed	300
Number of responses received	145
Number of invalid responses	5
Number of valid responses	140
Percentage of responses received	48.30
Percentage of valid responses	46.60

Source: Field work (2013)

5.2.2.1. Descriptive Quantitative Results and Analysis

To generate confidence in the credibility of data collected, Table 5.3 was produced to indicate a summary of the descriptive results and the analysis for the questionnaire survey. The aim is to provide an understanding of the profile of the respondents and the role they play in the case study project. As Table 5.3 indicates, the majority of the respondents (98) representing 70% are working with the contractor organisations followed by others who did not provide their company designation (24) and the consultant organisations (18) representing 17.14% and 12.86% respectively.

Out of the 140 valid respondents, 99 representing 70.71% play a role as contractors' team member (Project engineer, Project manager, Site engineer, etc.), 17, representing 12.14% as consultant's team member, 16, representing 11.43% as Client's team member while 8 representing 5. 75% did not provide any detail regarding the role they play in the case study project. About 132 (94.29%) of the respondents involved in infrastructure related works such as earthworks, demolishing works, concrete/masonry works, track laying and steel works while 6 (4.29%) and 2 (1.42%) involved in utility diversions and administrative support works respectively. A majority of 71 (50.71%) respondents worked on ETNP between 3-5 years, 60 representing 42.86% for 1-2 years, 4 representing 2.86% for less than a year while 5 respondents representing 3.57% worked on the ETNP for more 5 years.

Table 5.3: Summary of Descriptive Results and Analysis for the Questionnaire Survey

Parameter	Frequency	Percentage	Cumulative
Company Designation			
Client	00	0.00	0.00
Consultant	18	12.86	12.86
Main Contractor	98	70.00	82.86
Other	24	17.14	100.00
Role in the project			
Client’s team member	16	11.43	11.43
Consultant’s team member	17	12.14	23.57
Contractor’s team member	99	70.71	94.28
Other	8	5.72	100.00
Type of works			
Infrastructure	132	94.29	94.29
Utility diversion	6	4.29	98.58
Others (Administrative support)	2	1.42	100.00
Years Worked on the project			
Less than 1 year	4	2.86	2.86
1-2 years	60	42.86	45.72
3-5 years	71	50.71	96.43
More than 5 years	5	3.57	100.00
Procurement Approach			
Traditional lump sum competitive tendering	6	4.29	4.29
Partnering	11	7.86	12.15
Management contracting	72	51.43	63.58
Construction Management	48	34.29	97.87
Other (Tri-Party Agreement with *CEC)	3	2.14	100.00

* refers to the City of Edinburgh Council

Further indications on Table 5.3 revealed that companies involved in ETNP adopted various procurement approaches for several work packages within the project. A significant number (51.43%) adopted management contracting; 34.29% revealed construction management; 7.86% reported partnering; 4.29% for traditional lump sum competitive tendering and 2.14% indicated tri-party agreement approach with the City of Edinburgh Council for the utility diversion works. All of this information summarised in Table 5.3 indicates that respondents were competent enough and capable of participating in the survey. A plausible conclusion therefore is that the respondents are sufficiently well vested in the construction of the case study project (ETNP) to provide data which is credible.

5.2.2.2. Standardised Quantitative Results and Analysis

As part of the data collection, it was deemed necessary to establish from the respondents what their perception was on project performance for Edinburgh Tram Network Project and the level of impact of social; technical; economic; Environmental and political (STEEP) risks on project cost, time and quality. It was considered that knowledge of this kind would provide some basis to have an insight into how the respondents view the performance of ETNP with regard to risk effects in the current construction climate in the UK. Subsequently the respondents were asked to rate the level of STEEP risks impact on project cost, time and quality from very low to very high, where 1 represents very low; 2 = low; 3 = average or moderate; 4 = High and 5 = very high so that their opinions can be standardized to provide a fair idea of what could be the perceived levels of risk impacts on the objectives of ETNP.

- **Adjustments of Participants' Opinions**

To standardize the results gained from each participant of the questionnaire survey, STEEP risks and their respective potential risk variables were tabulated, coded and summarized into clusters and risk type. With the help of a Weighted Quantitative Score (WQS) method, Respondent's Mean Scores of Importance (RMSI) were calculated and the results summarised into a manageable form to aid the Analytical Network Process (ANP) pairwise calculations. The RMSI calculations were significantly distinguished based on participant's experience, background and as well as their information in regard to the case study. (See Appendix C for detailed results on how the RMSI was performed for potential STEEP risks). The steps for performing the RMSI for risk variables are the same as the steps involved for the potential STEEP risks and as a result, were not included in this appendix due to the large volume). In this regard, the results achieved by WQS are derived by the following equation:

$$MV = \frac{1}{n}\left(\sum_{i=1}^{n} E_{i(C,T,Q)}\right)$$

Where

MV - Indicates the value of mean scores of importance for each criteria/sub-criteria calculated by WQS

E - Refers to the experimental WQS for each sub/criteria expressed as a percentage year of experience multiplied by each participant's score of importance

i_c - Is the participant's score of importance for each sub/criteria with respect to cost

i_t - Is the participant's score of importance for each sub/criteria with respect to time

i_q - Is the participant's score of importance for each sub/criteria with respect to quality

n - Is the total number of participants in this research (n = 140)

Table 5.4: Summary of Respondent's Mean Scores of Importance for Project Objectives

Project objectives (P_o)	®Mean Values $(MVpo) = \frac{1}{n}\left(\sum_{i=1}^{n} E_{i(C,T,Q)}\right)$				
	P_o Formulae	Cost $\frac{1}{n}\left(\sum_{i=1}^{n} E_{i(C)}\right)$	Time $\frac{1}{n}\left(\sum_{i=1}^{n} E_{i(T)}\right)$	Quality $\frac{1}{n}\left(\sum_{i=1}^{n} E_{i(Q)}\right)$	Rounded MVs
C: Cost	$MVp_{0(C)}$ =	4.9			5
T: Time	$MVp_{0(T)}$ =		4.8		5
Q: Quality	$MVp_{0(Q)}$=			5.0	5

®Refer to Appendix (C) for detailed results

Table 5.5: Summary of Respondent's Mean Scores of Importance for Risk Clusters

Risk Cluster (P_R)	®Mean Values (MV_{RC}) = $\frac{1}{n}\left(\sum_{i=1}^{n} E_{i(C,T,Q)}\right)$						
	P_o	Cost	Time	Quality	Rounded MVs		
	Formulae	$\frac{1}{n}\left(\sum_{i=1}^{n} E_{i(C)}\right)$	$\frac{1}{n}\left(\sum_{i=1}^{n} E_{i(T)}\right)$	$\frac{1}{n}\left(\sum_{i=1}^{n} E_{i(Q)}\right)$	Cost	Time	Quality
P_{R1}:Social risks	MV_{PR1} =	4.2	3.6	2.4	4	4	2
P_{R2}:Technical risks	MV_{PR2} =	4.7	4.7	4.6	5	5	5
P_{R3}:Economic risks	MV_{PR3} =	4.7	4.6	4.4	5	5	4
P_{R4}:Environmental risks	MV_{PR4} =	4.1	4.1	4.0	4	4	4
P_{R5}:Political risks	MV_{PR5} =	4.5	4.0	3.4	5	4	3

®Refer to Appendix (C) for detailed results

Table 5.6: Summary of Respondent’s Mean Scores of Importance for Risk Variables

Risk Cluster	Type of risks under each Cluster		®Mean Values (MV_{Risks}) $= \frac{1}{n}\left(\sum_{i=1}^{n} E_{i(C,T,Q)}\right)$						
			P_o Formulae	Cost	Time	Quality	Rounded **MVs**		
				$\frac{1}{n}\left(\sum_{i=1}^{n} E_{i(C)}\right)$	$\frac{1}{n}\left(\sum_{i=1}^{n} E_{i(T)}\right)$	$\frac{1}{n}\left(\sum_{i=1}^{n} E_{i(Q)}\right)$	Cost	Time	Quality
P_{R1}: Social risks	S_{V1}:	Social grievances	$MV_{SV1} =$	5.42	4.51	2.69	5	5	3
	S_{V2}:	Multi -level decision making bodies	$MV_{SV2} =$	9.14	7.88	5.51	9	8	6
	S_{V3}:	Disputes	$MV_{SV3} =$	9.04	7.81	6.10	9	8	7
	S_{V4}:	Legal Actions	$MV_{SV4} =$	8.84	7.77	5.85	9	8	6
	S_{V5}:	Stakeholder's pressure	$MV_{SV5} =$	7.50	6.13	3.81	8	6	4
	S_{V6}:	Treats to person & asset security	$MV_{SV6} =$	4.35	2.92	2.77	4	3	3
	S_{V7}:	Social Issues	$MV_{SV7} =$	2.76	2.35	2.43	3	2	3
P_{R2}: Technical risks	T_{V1}:	Ambiguity of project scope/ Scope change	$MV_{TV1} =$	8.22	7.33	4.27	8	7	4
	T_{V2}:	Ground conditions on given project sites	$MV_{TV2} =$	7.15	6.50	2.80	7	7	3
	T_{V3}:	Inadequate project complexity analysis	$MV_{TV3} =$	8.91	7.52	5.15	9	8	5
	T_{V4}:	Unforeseen modification to project	$MV_{TV4} =$	7.73	6.86	4.25	8	7	4
	T_{V5}:	Inaccurate project cost estimate	$MV_{TV5} =$	8.84	6.92	4.44	9	7	4
	T_{V6}:	Failure to meet specified standards	$MV_{TV6} =$	8.97	7.03	7.95	9	7	8
	T_{V7}:	Technical difficulties in utilities diversions	$MV_{TV7} =$	9.08	8.51	3.97	9	9	4
	T_{V8}:	Engineering and design change	$MV_{TV8} =$	6.32	5.68	3.35	6	6	3
	T_{V9}:	Supply chain breakdown	$MV_{TV9} =$	5.09	7.13	2.46	5	7	2
	T_{V10}:	Project time overruns	$MV_{TV10} =$	9.25	8.18	4.62	9	8	5
	T_{V11}:	Project cost overruns	$MV_{TV11} =$	9.03	7.34	4.53	9	7	5
	T_{V12}:	Inadequate site investigation	$MV_{TV12} =$	8.91	8.22	5.55	9	8	6

®Refer to Appendix (C) for detailed results

Table 5.6: Summary of Respondent’s Mean Scores of Importance for Risk Variables (Continued)

Risk Cluster	Type of risks under each Cluster		®Mean Values (MV_{Risks}) $= \frac{1}{n}\left(\sum_{i=1}^{n} E_{i(C,T,Q)}\right)$						
			P_o Formulae	Cost	Time	Quality	Rounded **MVs**		
				$\frac{1}{n}\left(\sum_{i=1}^{n} E_{i(C)}\right)$	$\frac{1}{n}\left(\sum_{i=1}^{n} E_{i(T)}\right)$	$\frac{1}{n}\left(\sum_{i=1}^{n} E_{i(Q)}\right)$	Cost	Time	Quality
P_{R3}: Economic risks	E_{V1}:	Change in government funding policy;	MV_{EV1} =	8.51	7.18	6.31	9	7	6
	E_{V2}:	Taxation changes;	MV_{EV2} =	3.90	2.41	2.42	4	2	2
	E_{V3}:	Change in government;	MV_{EV3} =	7.01	6.81	5.84	7	7	6
	E_{V4}:	Wage inflation;	MV_{EV4} =	3.38	2.34	2.35	3	2	2
	E_{V5}:	Local inflation change;	MV_{EV5} =	2.91	2.08	2.03	3	2	2
	E_{V6}:	Foreign exchange rate;	MV_{EV6} =	2.81	2.25	2.17	3	2	2
	E_{V7}:	Material price changes;	MV_{EV7} =	6.65	4.59	4.58	7	5	5
	E_{V8}:	Economic recession;	MV_{EV8}=	5.34	3.44	3.02	5	3	3
	E_{V9}:	Energy price changes;	MV_{EV9} =	5.70	3.42	2.90	6	4	3
	E_{V10}:	Catastrophic environmental effects;	MV_{EV10}=	7.12	6.82	5.57	7	7	6
	E_{V11}:	Project technical difficulties	MV_{EV11}=	8.00	7.34	5.50	8	7	6
	E_{V12}	Project delays of all forms	MV_{EV12}=	8.50	7.64	5.59	9	8	6
P_{R4}: Environmental risks	E_{NV1}:	Environmental issues from works (Pollution)	MV_{ENV1}=	4.66	4.05	2.63	5	4	3
	$E_{NV\,2}$:	Unfavourable climate conditions (Snow, rain, wind etc.)	MV_{ENV2}=	8.78	7.27	6.13	9	7	6
P_{R5}: Political risks	P_{V1}:	Change in government funding policy;	MV_{PV1} =	8.56	7.12	6.01	9	7	6
	P_{V2}:	Political opposition;	MV_{PV2} =	7.49	6.03	4.03	7	6	4
	P_{V3}:	Government discontinuity;	MV_{PV3}=	7.50	7.04	5.77	8	7	6
	P_{V4}:	Lack of political support;	MV_{PV4} =	8.17	7.27	5.49	8	7	5
	P_{V5}:	Political indecision;	MV_{PV5}=	8.76	7.99	6.01	9	8	6
	P_{V6}:	Project termination;	MV_{PV6}=	5.99	5.59	4.17	6	6	4
	P_{V7}:	Delay in obtaining consent/Approval;	MV_{PV7} =	6.41	6.29	3.25	6	6	3
	P_{V8}:	Legislative/regulatory changes;	MV_{PV8} =	5.80	4.35	2.66	6	4	3
	P_{V9}:	Protectionism	MV_{PV9}=	3.20	3.57	2.48	3	4	3
	$P_{V10:}$	Delay in obtaining temporary Traffic Regulation Orders (TROs)	MV_{PV10} =	6.36	6.22	2.93	6	6	3

Apart from the values of the respondent’s Mean Scores of Importance, Tables 5.4 to 5.6 further indicate approximation (Rounded MVs) of the experimental Weighted Quantitative Scores (WQS) percentages to be input into the ANP calculation. This was done in order to accomplish ANP pairwise and super-matrix comparison of each node.

5.3. Summary

This chapter has presented the preliminary analysis of the data. The analysis undertaken included descriptive statistics on the demographic data and the standardised quantitative analysis with a Weighted Quantitative Score (WQS) method to calculate Respondent’s Mean Scores of Importance (RMSI). The demographic results suggest that the respondents have reasonable experience in the construction phase of the case study project, which should give credence to the data collected. Thereafter, the RMSI was performed so that respondents’ opinion on the level of impact of the risk on project performance is reduced to a manageable size for ANP pairwise comparison calculation.

In the next chapter, the development of the ANP models for STEEP risks will be described. The rounded mean values of the Respondent’s Mean Scores of Importance (RMSI) calculated by the Weighted Quantitative Score (WQS) method would further be used to generate a single value called Risk Priority Index (RPI) for each potential risk variables for further analysis in this report.

CHAPTER SIX: ANP MODEL

6.1. Introduction

Following the preliminary analysis presented in chapter five, this chapter now addresses the development of the substantive ANP models for the potential risks considered in this research. As already explained in chapter three of this thesis, the ANP model is developed for the "construction phase" of the megaproject lifecycle.

Drawing from the Quantitative Weighted Score (QWS) analysis, mean values were derived for the level of risk impact on project cost, time and quality for risk clusters and potential risk variables. This was necessary to help provide a basis for converting the broad range of respondents' scores for each risk variable into a single score so that the requirements of ANP to prioritize risks through construction of hierarchical risk structures for elements affecting management decisions and pairwise comparison analysis can be met. Saaty (2005a) emphasized the fact that a hierarchic structure is beneficial to a decision maker. It provides an overall view of the complex relationships inherent in a situation and in a judgment process and also allows the decision maker to assess whether he or she is comparing issues of the same order of magnitude.

The chapter concludes with the Risk Priority Index (RPI) calculation as a project ranking method for all risks and a summary of the relevancies of using the ANP for risk prioritization in the research.

6.2. Risk Prioritization

6.2.1. Network Model Construction

In this section, a network structure on ETNP was first constructed to create influence among project objectives, risk clusters and variables. The framework of ANP network process for all risks is shown in Figure 6.1. As indicated in Figure 6.1, there is an outer dependency between different clusters and an inner dependency within each member cluster of risks in the risk prioritization structure. Indirect dominance comparison of variables in set $S_{V1\text{-}7}$, $T_{V1\text{-}12}$, $E_{V1\text{-}12}$, $E_{NV1\text{-}2}$, and $P_{V1\text{-}10}$ was carried out according to their influence on project cost, time and quality respectively. P_{R1}, P_{R2}, P_{R3}, P_{R4} and P_{R5} were considered as primary standards while sub variables $S_{V1\text{-}7}$, $T_{V1\text{-}12}$, $E_{V1\text{-}12}$, $E_{NV1\text{-}2}$, and $P_{V1\text{-}10}$ as secondary standards to construct judgment matrices.

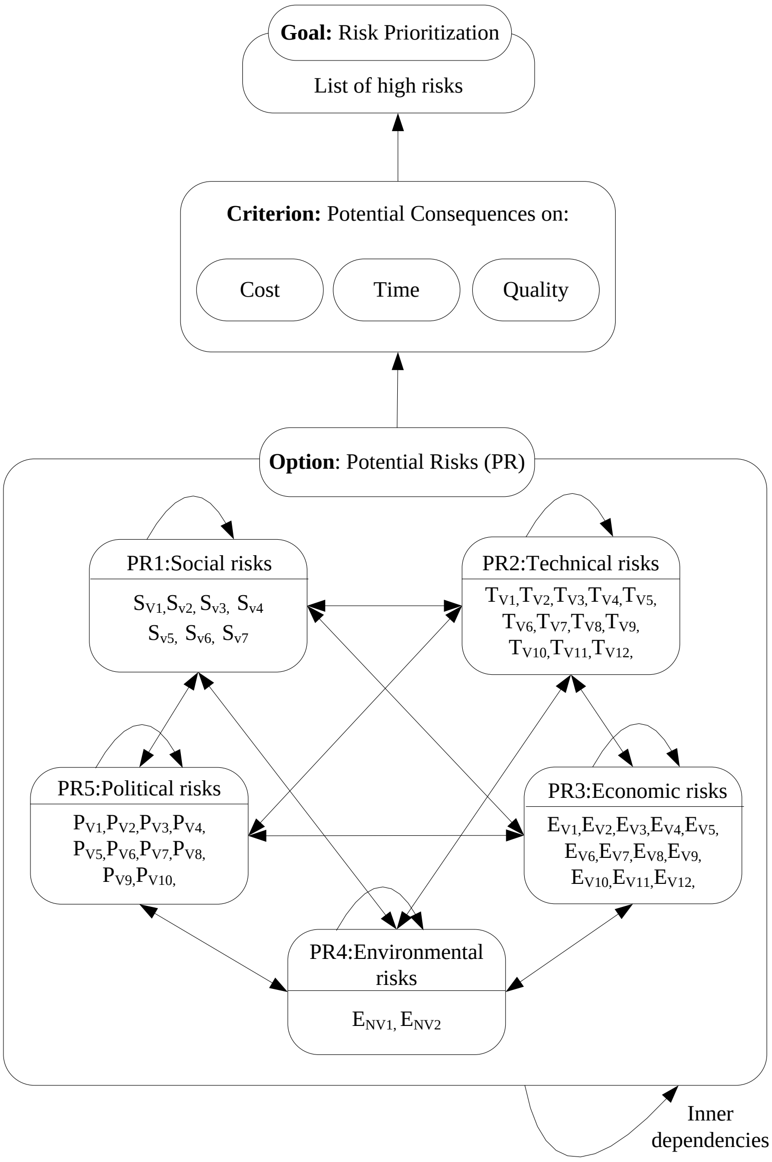
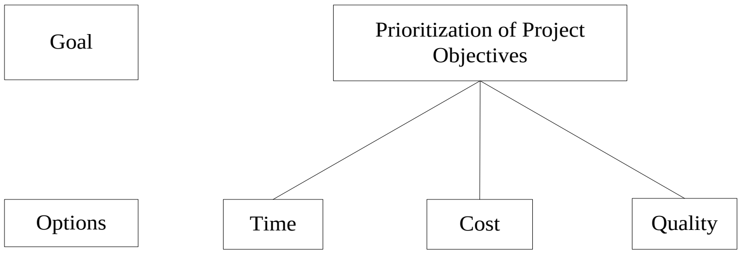
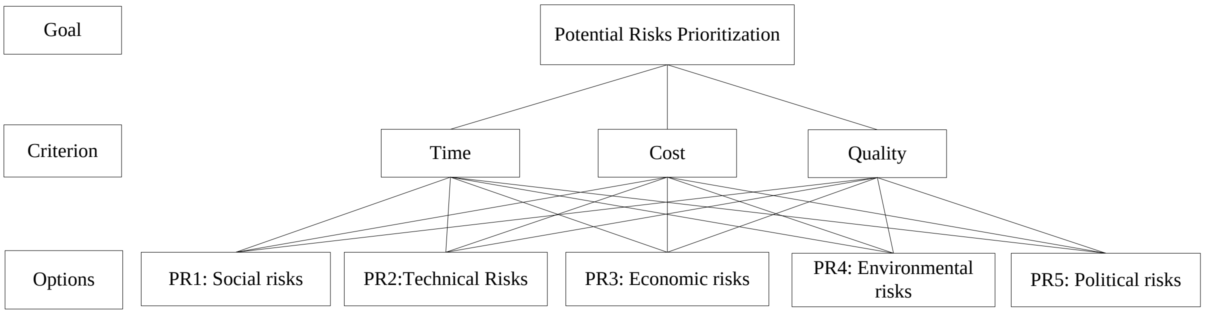


Figure 6.1: The Overall ANP Network Model for Risk Prioritization

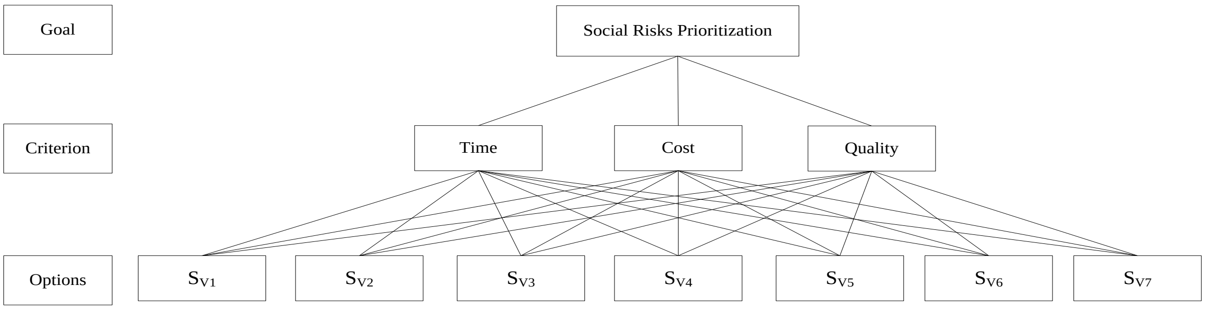
Subsequently, the overall network model was decomposed into sub network models as indicated in Figure 6.2. These include ANP Network models for (a) Project Objectives, (b) STEEP clusters (c) Social risk cluster, (d) Technical risk cluster, (e) Economic risk cluster, (f) Environmental risk cluster and (g) Political risk cluster. These network structures illustrate how the project objectives (Criterion) and the potential risks (Options) fed up through the system to give synthesized priority values in section 6.2.2.



(a) ANP Network Model for Project Objectives

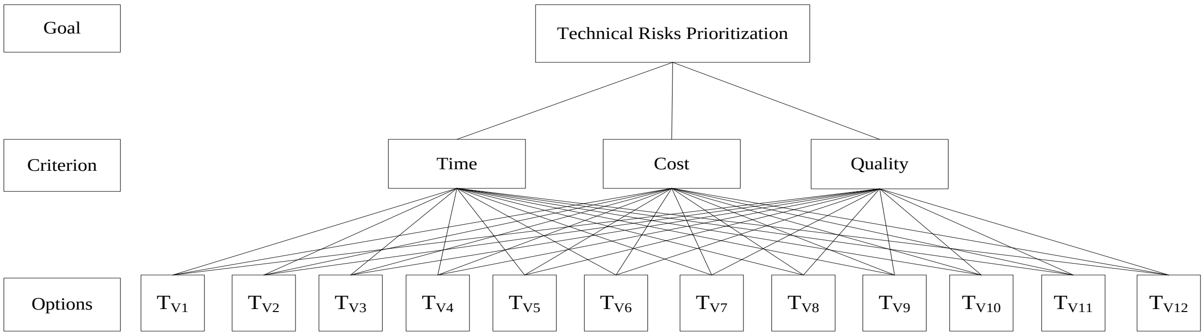


(b) ANP Network Model for STEEP Clusters

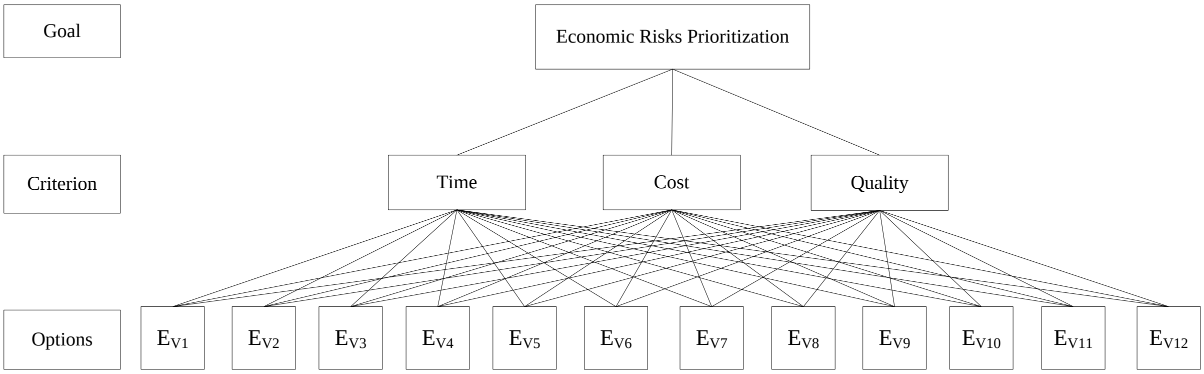


(c) ANP Network Model for Social Risks Prioritization

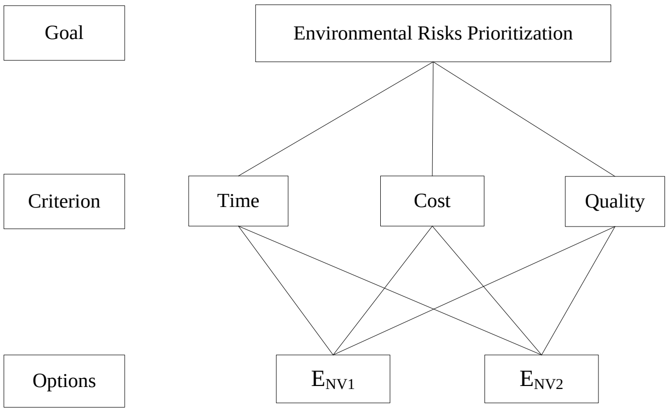
Figure 6.2 ANP Sub Network Prioritization Models



(d) ANP Network Model for Technical Risks Prioritization

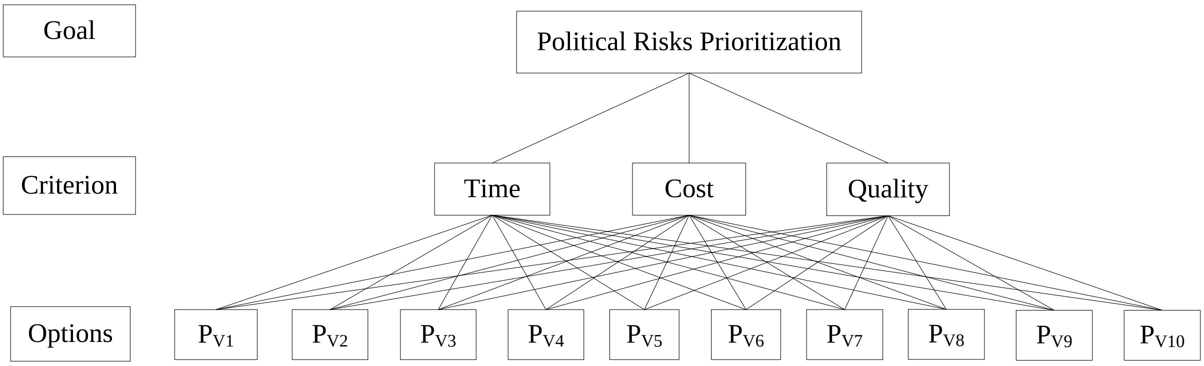


(e) ANP Network Model for Economic Risks Prioritization



(f) ANP Network Model for Environmental Risks Prioritization

Figure 6.2 ANP Sub Network Prioritization Models (Continued)



(g) ANP Network Model for Political Risks Prioritization

Figure 6.2 ANP Sub Network Prioritization Models (Continued)

6.2.2. Pairwise Comparison Matrices

Once the ANP hierarchy is built, its various elements were evaluated systematically and compared to one another in pairs. In making the comparisons, the rounded mean values derived from the QWS in chapter five were used against the ANP fundamental pairwise judgment scale in Table 6.1 for judgments about the elements' relative meaning and importance. It is the essence of the ANP that human judgments, and not just the underlying information, can be used in performing the assessments. The ANP converts these evaluations to numerical values that can be processed and compared over the entire range of the problem.

The new values were then inserted into multi criteria decision software called the Super Decision to evaluate relationships among criterion and option. A numerical weight or priority is derived for each element of the hierarchy, allowing diverse and often incommensurable elements to be compared to one another in a rational and consistent way. This capability distinguishes the ANP from other decision making techniques. In the final step of the process, numerical priorities were derived for each of the decision alternatives. To reflect the interdependencies on the ANP Network Models in Figure 6.1, pairwise comparisons for project objectives and potential risks were performed. The comparison matrices and their results are represented in sections 6.2.2.1to 6.2.2.7.

Table 6.1: Fundamental Scale of Pairwise Judgment and Pairwiser Criteria

Scales of Pairwise Judgment [a]	Comparisons of Pair Indicator Scores [b]
1 = equal	1:1
2 = equally to moderately dominant	2:1, 3:2, 4:3, 5:4, 6:5, 7:6, 8:7, 9:8
3 = moderately dominant	3:1, 4:2, 5:3, 6:4, 7:5, 8:6, 9:7
4 = moderately to strongly dominant	4:1, 5:2, 6:3, 7:4, 8:5, 9:6
5 = strongly dominant	5:1, 6:2, 7:3, 8:4, 9:5
6 = strongly to very strongly dominant	6:1, 7:2, 8:3, 9:4
7 = very strongly dominant	7:1, 8:2, 9:3
8 = very strongly to extremely dominant	8:1, 9:2
9 = Extremely dominant	9:1

[a] Saaty, 1996.

[b] Scores of indicators used to judge the relative meaning and importance of risk variables

6.2.2.1. Pairwise Comparison Matrix for Project Objectives

Table 6.2 represents the priority matrix for the project objectives (P_O) of the case study project. It was created using equation 6.1 where the element $p_{o(ij)}$ represents the relative importance of the *i*th option of the matrix with respect to the *j*th option. $1/p_{o(ji)}$, $1/p_{o(13)}$ and $1/p_{o(23)}$ represent the inverse of $p_{o(ij)}$ and are symmetrical with respect to the diagonal to the matrix (P_O); (*i*) and (*j*) = 1, 2…..*n*. Where *'n'* = the number of options.

$$P_O = \begin{vmatrix} 1 & p_{o(ij)} & p_{o(13)} \\ 1/p_{o(ji)} & 1 & p_{o(23)} \\ 1/p_{o(13)} & 1/p_{o(23)} & 1 \end{vmatrix} \qquad (6.1)$$

Table 6.2: Matrix for Project Objectives with respect to Decision Goal

Pairwise Comparison of Project Objective Criterion	MV	$p_{o(C)}$	$p_{o(T)}$	$p_{o(Q)}$	TPV	NPV	IPV	Ranking	The consistency test
$p_{o(C)}$: Cost	5	1	1	1	0.33	0.333	1.00	2	$\lambda_{max} = 3.00$
$p_{o(T)}$: Time	5	1	1	1	0.33	0.333	1.00	3	CI = 0.00
$p_{o(Q)}$: Quality	5	1	1	1	0.33	0.333	1.00	1	RI = 0.52
									CR = 0.00
$\sum_{j=1}^{n} \mathbf{w}_{(\mathbf{po})}$		=				0.999			

Legend: ***TPV*** *= Total priority value,* ***NPV*** *= Normal priority value,* ***IPV*** *= Ideal priority value*

Inconsistency = 0.00

Based on the rounded mean scores of importance, the pairwise comparison in each option was performed with the Supper Decisions software to derive the eigenvectors or the normalised priority value (NPV), total priority value (TPV) and the ideal priority value (IPV). It can be observed from the pairwise comparisons results that cost, time and quality indicate equal synthesized priority weights of {$P_o = (p_{o(C)}, p_{o(T)}, p_{o(Q)}) = (0.33, 0.33, 0.33)$} per the ANP computation. This suggests that they are the appropriate project objectives according to respondents' view for the development of the case study project. Further analysis of the results suggests that respondent's answers to the prioritization on project objectives during the survey are consistent. Otherwise, the evaluation could have been re-considered by an expert team. It can therefore be concluded that the project cost, time and quality are the appropriate project objectives for the specific development.

6.2.2.2. Consistency Test

The Consistency Ratio (CR) is a widely used consistency test method in both AHP and ANP. The CR is used to check the consistencies of the values obtained according to the pairwise comparison. In the ANP method, survey participants and decision makers or experts who make judgments or preferences must go through the consistency test. Reasons are because the final risk assessment and decision analysis could be inaccurate if the priority values are calculated from the inconsistent comparison matrix. Therefore, the consistency of each comparison matrix has to be tested before the comparison matrices are used to assess risk and analyse a decision. If the consistency test for the comparison matrix failed, the inconsistent elements in the comparison matrix have to be identified and revised; otherwise, the result of risk assessment and decision analysis would be unreliable.

To determine the consistency of respondents' judgment on the level of STEEP risk impacts on Edinburgh Tram Network Project, a consistency ratio (*CR*) of the comparison matrices are calculated using the process in Figure 6.3.

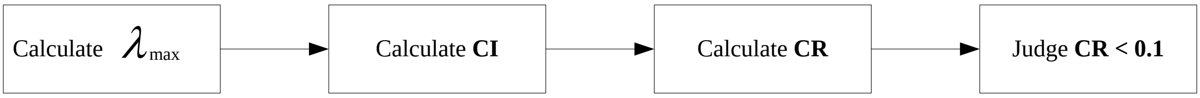


Figure 6.3: Calculation Process for the CR Method

Step 1: Calculate the maximum eigenvalue ($\lambda_{\mathrm{max.}}$) of one comparison matrix.
Step 2: Calculate the value of Consistency Index (*CI)*
Step 3: Calculate the CR using the formula $CR = CI/RI$ and Table 6.3.
Step 4: Compare the value of CR with the consistency threshold 0.1 to judge whether the comparison is consistent.

***Step 1:** Calculate the maximum eigenvalue ($\lambda_{max.}$) of one comparison matrix*.

After a comparison matrix has been formed, the normalized priority of the element can be compared by the computation of eigenvalue and eigenvectors with the Equation 2.

$$\sum_{j=1}^{n} a_{ij} w_i = \lambda_{max} w_i \qquad (2)$$

Where *A* is the matrix of pair-wise comparison,
w is the eigenvector, and
λ_{max} is the maximum eigenvalue of [A]

By substitution, the maximum eigenvalue ($\lambda_{\max}$) is calculated to derive a new matrix (W) by multiplying comparison matrix (A) with (w_i). Finally, the ($\lambda_{\max}$) can be obtained by averaging the value. Computations of the process are listed in Equation (3) and Equation (4) respectively.

$$\begin{vmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & a_{23} & a_{2n} \\ \vdots & 1/a_{23} & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{vmatrix} \text{x} \begin{vmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{vmatrix} = \begin{vmatrix} W_1 \\ W_2 \\ \vdots \\ W_n \end{vmatrix} \tag{3}$$

$$\lambda_{max} = \frac{1}{n}\left(\frac{W_1}{w_1} + \frac{W_2}{w_2} + \ldots\ldots + \frac{W_n}{w_n}\right) \tag{4}$$

Step 2: *Calculating the value of CI*

In order to determine the consistencies of respondents' judgments, the consistency ratios (*CR*) of the comparison matrices are calculated using the formula:

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{5}$$

Where *CI* = Consistency Index

λ_{max} = the maximum eigenvalue

n = the order of matrix [A].

If *CI* = 0, means respondents' judgments satisfy the consistency.

If *CI* > 0, means the experts have conflicting judgments.

If *CI* ≤ 0.1, means there is reasonable level of consistency.

Step 3: *Calculating the Consistency Ratio (CR)*

CR is the most widely used consistency index when conducting traditional consistency test. Based on various matrix sizes, the CR for each matrix was calculated using the formula:

$$CR = \frac{CI}{RI} \tag{6}$$

Where RI is a random index as shown in Table 6.3

When $CR \leq 0.1$, it means the evaluation process satisfies the consistency

Table 6.3: The Average Random Index

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.4	1.45	1.49	1.52	1.54	1.56	1.58	1.59

Step 4: *Judging the consistency*

This is done by comparing the value of CR with the consistency threshold of 0.1 to judge whether the comparison is consistent. If $CR \leq 0$, it means respondents' judgments satisfy the consistency. If not, then that means the experts have conflicting judgments. The inconsistent elements in the comparison matrix have to be identified and revised; otherwise, the result of risk assessment and decision analysis is unreliable. If $CR \leq 0.1$, means there is reasonable level of consistency.

6.2.2.3. Inner Dependency Matrix for Cluster 'Potential Risks'

There are five scenarios of pairwise comparison in this cluster. One scenario is with respect to clusters "Potential consequences on cost, time and quality" and "Goal", while the rest are with respect to the element in the cluster "Potential risks". For example, with respect to "Goal: risk prioritization", what element in cluster "Potential risks" is more risky than the others? Table 6.4 summarizes the results of the pairwise comparison. As indicated in Table 6.4a, potential risks listed in column 3 were compared with each other listed in the row on top as to which one has more impact on project cost, time and quality to select the most risky one. Thereafter, the priorities for each of these potential risks are calculated from the matrix of comparisons for cost, time and quality with the rankings given against them.

As shown in the Table 6.4a, for example, Technical risks (25%), Economic risks (25%) and Political Risks (25%) are judged to be more risky and therefore have higher level of impact on project cost than the Social risks (13%) and the Environmental Risks (13%).

Table 6.4: Pairwise Comparison Matrices for Potential Risks

Table 6.4a: Comparison Matrices with respect to Cost, Time and Quality

Project objective	MV_R	Potential Risks	P_{R1}	P_{R2}	P_{R3}	P_{R4}	P_{R5}	TPV	Priorities	R
Cost	4	P_{R1}	1	1/2	1/2	1	1/2	0.13	0.13	4
$\lambda_{max} = 5.00$	5	P_{R2}	2	1	1	2	1	0.25	0.25	1
CI = 0.00	5	P_{R3}	2	1	1	2	1	0.25	0.25	1
RI = 1.11	4	P_{R4}	1	1/2	1/2	1	1/2	0.13	0.13	5
CR = 0.00	5	P_{R5}	2	1	1	2	1	0.25	0.25	1
Total priority weights with respect to cost ($\sum_{j=1}^{n} w_{RC(c)}$)								1.01	1.01	
Time	4	P_{R1}	1	1/2	1/2	1	1	0.14	0.14	3
$\lambda_{max} = 5.00$	5	P_{R2}	2	1	1	2	2	0.29	0.29	1
CI = 0.00	5	P_{R3}	2	1	1	2	2	0.29	0.29	1
RI = 1.11	4	P_{R4}	1	1/2	1/2	1	1	0.14	0.14	3
CR = 0.00	4	P_{R5}	1	1/2	1/2	1	1	0.14	0.14	3
Total priority weights with respect to time ($\sum_{j=1}^{n} w_{RC(T)}$)								1.00	1.00	
Quality	3	P_{R1}	1	1/3	1/2	1/2	1	0.11	0.11	4
$\lambda_{max} = 5.08$	5	P_{R2}	3	1	2	2	3	0.37	0.37	1
CI = 0.02	4	P_{R3}	2	1/2	1	1	2	0.21	0.21	2
RI = 1.11	4	P_{R4}	2	1/2	1	1	2	0.21	0.21	2
CR = 0.02	3	P_{R5}	1	1/3	1/2	1/2	1	0.11	0.11	4
Total priority weights with respect to quality ($\sum_{j=1}^{n} w_{RC(Q)}$)								1.01	1.01	

Legend: λ_{max} = maximum eigenvalue, *CI = Consistency Index, RI = Random Index, CR = Consistency ratio, TPV = Total priority value, NPV = Normal priority value, IPV = Ideal priority value R = Ranking*

Similarly, priorities with respect to project time indicate that, Technical risks (29%) and Economic risks (29%) are judged to have high level of impact on project time than the Social risks (14%), the Environmental Risks (14%) and the Political risks (14%). With respect to project quality, Technical risks (37%) are judged as the most risky, followed by Economic risks (21%) and the Environmental risks (21%) with the least being the Social and Political risks with values of 11% each.

6.2.2.4. The Super Matrix Calculation

After completing the pairwise comparisons, the next step is to build the supermatrix. As discussed in section 3.4.4.2.3 of chapter 3, the super matrices are computed in three steps. In the first step the unweighted supermatrix is created directly from all local priorities of the potential risks as indicated in Table 6.4b. In the second step, the weighted supermatrix (See Table 6.4c) is calculated by weighing the local priority indexes or the unweighted supermatrix with their affiliated priorities for project cost, time and quality as their parent criterion to obtain the global priority indexes.

Table 6.4b: Unweighted Super Matrix for Potential Risks

		Project Objective				Potential Risks				
		Goal	Cost	Time	Quality	P_{R1}	P_{R2}	P_{R3}	P_{R4}	P_{R5}
	Goal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Project	Cost	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Objective	Time	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Quality	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Potential	P_{R1}	0.00	0.13	0.14	0.11	0.00	0.00	0.00	0.00	0.00
Risks	P_{R2}	0.00	0.25	0.29	0.37	0.00	0.00	0.00	0.00	0.00
	P_{R3}	0.00	0.25	0.29	0.21	0.00	0.00	0.00	0.00	0.00
	P_{R4}	0.00	0.13	0.14	0.21	0.00	0.00	0.00	0.00	0.00
	P_{R5}	0.00	0.25	0.14	0.11	0.00	0.00	0.00	0.00	0.00

Table 6.4c: Weighted Super Matrix for Potential Risks

		Project Objective				Potential Risks				
		Goal	Cost	Time	Quality	P_{R1}	P_{R2}	P_{R3}	P_{R4}	P_{R5}
	Goal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Project	Cost	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Objective	Time	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Quality	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Potential	P_{R1}	0.00	0.13	0.14	0.11	0.00	0.00	0.00	0.00	0.00
Risks	P_{R2}	0.00	0.25	0.29	0.37	0.00	0.00	0.00	0.00	0.00
	P_{R3}	0.00	0.25	0.29	0.21	0.00	0.00	0.00	0.00	0.00
	P_{R4}	0.00	0.13	0.14	0.21	0.00	0.00	0.00	0.00	0.00
	P_{R5}	0.00	0.25	0.14	0.11	0.00	0.00	0.00	0.00	0.00

Finally, the weighted supermatrix is raised to a limiting power in order to converge and to obtain a stable set of weights that represents the final priority vector. Stabilization is achieved when all the columns in the supermatrix corresponding to any node have the same values. In this report, the Limit Supermatrix of the risk hierarchies will show same result as the hierarchic composition. A summary of the final modes decision making priorities for the potential risks are further explained and represented in Table 6.4d.

Table 6.4d**:** Results of Final Mode ANP Decision Making Priorities for Potential Risks

Potential Risks	**Priorities for Potential Risks**						**Final Priorities**		
	Local risk priority index (RPI_L)			Global risks priority index (RPI_G)			Synthesized results		
	Cost (0.33)	Time (0.33)	Quality(0.33)	Cost	Time	Quality	TRPI	IRPI	R
P_{R1}:Social	0.13	0.14	0.11	0.04	0.05	0.04	0.13	0.43	5
P_{R2}:Technical	0.25	0.29	0.37	0.08	0.10	0.12	0.30	1.00	1
P_{R3}: Economic	0.25	0.29	0.21	0.08	0.10	0.07	0.25	0.83	2
P_{R4}: Environmental	0.13	0.14	0.21	0.04	0.05	0.07	0.16	0.53	4
P_{R5}:Political	0.25	0.14	0.11	0.08	0.05	0.04	0.17	0.56	3
Total	1.01	1.00	1.01		1.00		1.01		

Legend: TRPI = Total risk priority index, IRPV = Ideal risk priority indexes and R = Ranking

As indicated in Table 6.4d, the globalized priorities under each objective in each row were then summed up to obtain synthesised results; in this case, the total risk priority indexes (TRPI). Finally, the TRPIs were expressed in ideal forms known as Ideal Risk Priority Indexes (IRPIs) by dividing each TRPI by the largest value. For example, in Table 6.4b, the IRPI for potential risk P_{R1} will be as follows:

$$IRPI_{PR1} = TRPI_{PR1} \div TRPI_{max}$$

$$\text{That is } IRPI_{PR1} = 0.13 \div 0.30$$

$$= 0.43 \text{ (in approximation)}$$

Where $IRPI_{PR1}$ is the Ideal Risk Priority Index for Social Risks (0.43) and represented by a code (P_{P1}); $TRPI_{PR1}$ is the Total Risk Priority Index for Social Risks (0.13) while $TRPI_{max}$ representing the maximum value (0.30) among the Total Risk Priority Indexes for the potential risks. The effect of this normalisation is to make each potential risk the ideal one with others in proportionate value. A decision maker may then interpret the results to mean that the impacts of social risks, economic risks, environmental risks and political risks on the objectives of Edinburgh Tram Network Project (ETNP) are about 43%, 83%, 53% and 56% respectively as risky as that of technical risks.

6.2.2.5. Risk Ratings Mode

In this section, rating categories for each potential risk were established and prioritized by pairwise comparing them for preference. Potential risks as alternatives were evaluated by selecting the appropriate rating category on their level of impacts on each criterion (objectives) as Very high (5), High (4), Medium or Moderate (3), Low (2) and Very low (1). They were compared for preference using a pairwise comparison matrix in the usual way as given in Table 6.4a to obtain the idealised priorities. These priorities are further normalised by dividing each priority by the largest of the priorities. The idealised priorities are therefore used in range for risks rating. For example, a priority value greater than 0.62 is classified as having a very high risk impact on the project objectives and so on. The rating categories for the five scales are established in Table 6.5a. Finally, Table 6.5b provides the verbal ratings of how the five potential risks as alternatives on each covering criterion and their corresponding numerical ratings from Table 6.4b were rated.

Table 6.5: Risks Rating Priority Calculation

Table 6.5a: Deriving Priorities for Risks Ratings

Risks rating for megaproject construction		**VH**	**H**	**M**	**L**	**VL**	**Normalised priorities**	**Idealised priorities**	**Numerical risks rating (%)**
Very High	VH	1	2	3	4	5	0.42	1.00	> 62
High	H	1/2	1	2	3	4	0.26	0.62	38-61
Moderate	M	1/3	1/2	1	2	3	0.16	0.38	24-37
Low	L	1/4	1/3	½	1	2	0.10	0.24	14-23
Very Low	VL	1/5	1/4	1/3	1/2	1	0.06	0.14	< 14
Total priorities							1.00		

Table 6.5b: Verbal Ratings for Potential Risks

Potential Risks	Ideal Synthesized risk priority indexes (IRPI %)	Verbal ratings
P_{R1}:Social	43	High
P_{R2}:Technical	100	Very high
P_{R3}: Economic	83	Very high
P_{R4}: Environmental	53	High
P_{R5}:Political	56	High

Risk ratings: Very high = (>62%), High = (38%-61%), Medium = (24%-37%), Low = (14%-37%) and Very low = (<14%)

6.2.2.6. Pairwise Comparison Matrices for Variables in the Potential Risks Cluster

Based on the individual ANP Network Models for the social, technical, economic, environmental and political risks prioritization indicated in Figure 6.2, pairwise comparison matrices were produced for elements under each potential risks with respect to their impact on project objectives (cost, time and quality). The total priority value (TPV), Normalized priority value (NPV), Idealized priority value (IPV) and the risk rankings were all derived from the super decisions software.

By using the same procedure described in section 6.2.2.3, final modes ANP Decision Making Matrices were also produced for the Variables in the Potential Risks Cluster. The values obtained represent risk impact priority indexes (RPIs) that Project Managers and risk analysts may need in identifying which risk variables to tackle urgently during the decision making process. Finally, ratings are performed for the priority values as in section 6.2.2.3.

Table 6.6: Pairwise Matrix for Social Risks

Table 6.6a: Pairwise Comparison for Social Risk Variables

Pairwise comparison against Project objectives	MV_R	Risk Code	S_{V1}	S_{V2}	S_{V3}	S_{V4}	S_{V5}	S_{V6}	S_{V7}	TPV	NPV	IPV	R
Cost	5	S_{V1}:	1	1/5	1/5	1/5	1/4	2	3	0.06	0.06	0.24	5
λ_{max} *= 7.10*	9	S_{V2}:	5	1	1	1	2	6	7	0.24	0.24	1.00	1
CI = 0.02	9	S_{V3}:	5	1	1	1	2	6	7	0.24	0.24	1.00	1
RI = 1.35	9	S_{V4}:	5	1	1	1	2	6	7	0.24	0.24	1.00	1
CR = 0.01	8	S_{V5}:	4	1/2	1/2	1/2	1	5	6	0.15	0.15	0.63	4
(Inconsistency	4	S_{V6}:	1/2	1/6	1/6	1/6	1/5	1	2	0.04	0.04	0.16	6
= 0.000)	3	S_{V7}:	1/3	1/7	1/7	1/7	1/6	1/2	1	0.03	0.03	0.11	7
Total = $\sum_{j=1}^{n} \mathbf{w}_{\cdot(\text{cost})}$ =										1.00	1.00	4.14	
Time	5	S_{V1}:	1	1/4	1/4	1/4	1/2	3	3	0.07	0.07	0.29	5
λ_{max} *= 7.20*	8	S_{V2}:	4	1	1	1	3	6	7	0.25	0.25	1.00	1
CI = 0.03	8	S_{V3}:	4	1	1	1	3	6	7	0.25	0.25	1.00	1
RI = 1.35	8	S_{V4}:	4	1	1	1	3	6	7	0.25	0.25	1.00	1
CR = 0.02	6	S_{V5}:	2	1/3	1/3	1/3	1	4	5	0.11	0.11	0.44	4
(Inconsistency	3	S_{V6}:	1/3	1/6	1/6	1/6	1/4	1	2	0.04	0.04	0.15	6
= 0.002)	2	S_{V7}:	1/3	1/7	1/7	1/7	1/5	1/2	1	0.03	0.03	0.11	7
Total = $\sum_{j=1}^{n} \mathbf{w}_{\cdot(\text{time})}$ =										1.00	1.00	3.99	
Quality	3	S_{V1}:	1	1/4	1/5	1/4	1/2	1	1	0.05	0.05	0.16	5
λ_{max} *= 7.08*	6	S_{V2}:	4	1	1/2	1	3	4	4	0.21	0.21	0.64	2
CI = 0.01	7	S_{V3}:	5	2	1	2	4	5	5	0.33	0.33	1.00	1
RI = 1.35	6	S_{V4}:	4	1	1/2	1	3	4	4	0.21	0.21	0.64	2
CR = 0.00	4	S_{V5}:	2	1/3	1/4	1/3	1	2	2	0.09	0.09	0.27	4
(Inconsistency	3	S_{V6}:	1	1/4	1/5	1/4	1/2	1	1	0.05	0.05	0.16	5
= 0.001)	3	S_{V7}:	1	1/4	1/5	1/4	1/2	1	1	0.05	0.05	0.16	5
Total = $\sum_{j=1}^{n} \mathbf{w}_{\cdot(\text{quality})}$ =										0.99	0.99	3.03	

Legend: λ_{max} *= maximum eigenvalue, CI = Consistency Index, RI = Random Index, CR = Consistency ratio, TPV = Total priority value, NPV = Normal priority value, IPV = Ideal priority value R = Ranking,* $MV_{R=}$ *Rounded mean value.*

Table 6.6b: Results of Final Mode ANP Decision Making Priorities for Social Risk Variables

Risk Code	Priorities for Social Risk Variables						Final priorities		
	Local risk priority index (RPI_L)			Global risks priority index (RPI_G)			Synthesized results		
	Cost (0.33)	Time (0.33)	Quality (0.33)	Cost	Time	Quality	TRPI	IRPI	R
S_{V1}:	0.06	0.07	0.05	0.02	0.02	0.02	0.06	0.20	5
S_{V2}:	0.24	0.25	0.21	0.08	0.08	0.07	0.23	0.85	2
S_{V3}:	0.24	0.25	0.33	0.08	0.08	0.11	0.27	1.00	1
S_{V4}:	0.24	0.25	0.21	0.08	0.08	0.07	0.23	0.85	2
S_{V5}:	0.15	0.11	0.09	0.05	0.04	0.03	0.12	0.40	4
S_{V6}:	0.04	0.04	0.05	0.01	0.01	0.02	0.04	0.15	6
S_{V7}:	0.03	0.03	0.05	0.01	0.01	0.02	0.04	0.15	6
Total	1.00	1.00	1.01		1.00		0.99		

Legend: TRPI = Total risk priority index, IRPV = Ideal risk priority indexes and R = Ranking

Table 6.6c: Verbal Ratings for Social Risk Variables

Risk Code	Social risk variables	Ideal Synthesized risk priority indexes (IRPI %)	Verbal ratings
S_{V1}:	Social grievances	20	Low
S_{V2}:	Multi -level decision making bodies	85	Very high
S_{V3}:	Disputes	100	Very high
S_{V4}:	Legal Actions	85	Very high
S_{V5}:	Stakeholder's pressure	40	High
S_{V6}:	Treats to person & asset security	15	Low
S_{V7}:	Social Issues	15	Low

Risk ratings: Very high = (>62%), High = (38%-61%), Medium = (24%-37%), Low = (14%-37%) and Very low = (<14%)

Table 6.7: Pairwise Matrix for Technical Risks

Table 6.7a: Pairwise Comparison for Technical Risk Variables

Project Objective	**MV_R**	**Risk Code**	**T_{V1}**	**T_{V2}**	**T_{V3}**	**T_{V4}**	**T_{V5}**	**T_{V6}**	**T_{V7}**	**T_{V8}**	**T_{V9}**	**T_{V10}**	**T_{V11}**	**T_{V12}**	**Priorities**	**Ranking**
Cost	8	T_{V1}	1	2	1/2	1	1/2	1/2	1/2	3	4	1/2	1/2	1/2	0.06	8
	7	T_{V2}	1/2	1	1/3	1/2	1/3	1/3	1/3	2	3	1/3	1/3	1/3	0.04	10
λ_{max} =12.11	9	T_{V3}	2	3	1	2	1	1	1	4	5	1	1	1	0.11	1
CI = 0.01	8	T_{V4}	1	2	1/2	1	1/2	1/2	1/2	3	4	1/2	1/2	1/2	0.06	8
RI = 1.54	9	T_{V5}	2	3	1	2	1	1	1	4	5	1	1	1	0.11	1
CR = 0.01	9	T_{V6}	2	3	1	2	1	1	1	4	5	1	1	1	0.11	1
(Inconsistency	9	T_{V7}	2	3	1	2	1	1	1	4	5	1	1	1	0.11	1
= 0.00)	6	T_{V8}	1/3	1/2	1/4	1/3	1/4	1/4	1/4	1	2	1/4	1/4	1/4	0.03	11
	5	T_{V9}	1/4	1/3	1/5	1/4	1/5	1/5	1/5	1/2	1	1/5	1/5	1/5	0.02	12
	9	T_{V10}	2	3	1	2	1	1	1	4	5	1	1	1	0.11	1
	9	T_{V11}	2	3	1	2	1	1	1	4	5	1	1	1	0.11	1
	9	T_{V12}	2	3	1	2	1	1	1	4	5	1	1	1	0.11	1
Total = $\sum_{j=1}^{n} \mathbf{w}_{\cdot(\text{cost})}$ =															0.98	
Time	7	T_{V1}	1	1	1/2	1	1	1	1/3	2	1	1/2	1	1/2	0.06	5
	7	T_{V2}	1	1	1/2	1	1	1	1/3	2	1	1/2	1	1/2	0.06	5
λ_{max} = 12.07	8	T_{V3}	2	2	1	2	2	2	1/2	3	2	1	2	1	0.12	2
CI = 0.01	7	T_{V4}	1	1	1/2	1	1	1	1/3	2	1	1/2	1	1/2	0.06	5
RI =1.54	7	T_{V5}	1	1	1/2	1	1	1	1/3	2	1	1/2	1	1/2	0.06	5
CR = 0.00	7	T_{V6}	1	1	1/2	1	1	1	1/3	2	1	1/2	1	1/2	0.06	5
(Inconsistency	9	T_{V7}	3	3	2	3	3	3	1	4	3	2	3	2	0.19	1
= 0.001)	6	T_{V8}	1/2	1/2	1/3	1/2	1/2	1/2	1/4	1	1/2	1/3	1/2	1/3	0.04	12
	7	T_{V9}	1	1	1/2	1	1	1	1/3	2	1	1/2	1	1/2	0.06	5
	8	T_{V10}	2	2	1	2	2	2	1/2	3	2	1	2	1	0.12	2
	7	T_{V11}	1	1	1/2	1	1	1	1/3	2	1	1/2	1	1/2	0.06	5
	8	T_{V12}	2	2	1	2	2	2	1/2	3	2	1	2	1	0.12	2
Total = $\sum_{j=1}^{n} \mathbf{w}_{\cdot(\text{time})}$ =															1.01	

Legend: λ_{max} = maximum eigenvalue, *CI = Consistency Index, RI = Random Index, CR = Consistency ratio*

Table 6.7a: Pairwise Comparison for Technical Risk Variables (Continued)

Project Objective	**MV_R**	**Risk Code**	**T_{V1}**	**T_{V2}**	**T_{V3}**	**T_{V4}**	**T_{V5}**	**T_{V6}**	**T_{V7}**	**T_{V8}**	**T_{V9}**	**T_{V10}**	**T_{V11}**	**T_{V12}**	**Priorities**	**Ranking**
Quality	4	T_{V1}	1	2	1/2	2	2	1/5	1	2	3	1/2	1/2	1/3	0.06	6
	3	T_{V2}	1/2	1	1/3	1/2	1/2	1/6	1/2	1	2	1/2	1/2	1/4	0.03	10
$\lambda_{max} = 12.23$	5	T_{V3}	2	3	1	2	2	1/4	2	3	4	1	1	1/2	0.09	3
CI = 0.02	4	T_{V4}	1/2	2	1/2	1	1	1/5	1	2	3	1/2	1/2	1/3	0.05	7
RI = 1.54	4	T_{V5}	1/2	2	1/2	1	1	1/5	1	2	3	1/2	1/2	1/3	0.05	7
CR = 0.01	8	T_{V6}	5	6	4	5	5	1	5	6	7	4	4	3	0.28	1
(Inconsistency	4	T_{V7}	1	2	1/2	1	1	1/5	1	2	3	1/2	1/2	1/3	0.05	7
= 0.00)	3	T_{V8}	1/2	1	1/3	1/2	1/2	1/6	1/2	1	2	1/3	1/3	1/4	0.03	10
	2	T_{V9}	1/3	1/2	1/4	1/3	1/3	1/7	1/3	1/2	1	1/4	1/4	1/5	0.02	12
	5	T_{V10}	2	2	1	2	2	1/4	2	3	4	1	1	1/2	0.09	3
	5	T_{V11}	2	2	1	2	2	1/4	2	3	4	1	1	1/2	0.09	3
	6	T_{V12}	3	4	2	4	3	1/3	3	4	5	2	2	1	0.15	2
Total = $\sum_{j=1}^{n} w_{\cdot(Quality)}$ =															0.99	

Legend: λ_{max} = maximum eigenvalue, *CI = Consistency Index, RI = Random Index, CR = Consistency ratio*

Table 6.7b: Results of Final Mode ANP Decision Making Priorities for Technical Risk Variables

Risk Code	**Priorities for Technical Risk Variables**						**Final priorities**		
	Local risk priority index (RPI_L)			Global risks priority index (RPI_G)			Synthesized results		
	Cost (0.33)	Time (0.33)	Quality (0.33)	Cost	Time	Quality	TRPI	IRPI	R
T_{V1}	0.06	0.06	0.06	0.02	0.02	0.02	0.06	0.40	8
T_{V2}	0.04	0.06	0.03	0.01	0.02	0.01	0.04	0.27	10
T_{V3}	0.11	0.12	0.09	0.04	0.04	0.03	0.11	0.73	4
T_{V4}	0.06	0.06	0.05	0.02	0.02	0.02	0.06	0.40	8
T_{V5}	0.11	0.06	0.05	0.04	0.02	0.02	0.08	0.53	7
T_{V6}	0.11	0.06	0.28	0.04	0.02	0.09	0.15	1.00	1
T_{V7}	0.11	0.19	0.05	0.04	0.06	0.02	0.12	0.80	3
T_{V8}	0.03	0.04	0.03	0.01	0.01	0.01	0.03	0.20	12
T_{V9}	0.02	0.06	0.02	0.01	0.02	0.01	0.04	0.27	10
T_{V10}	0.11	0.12	0.09	0.04	0.04	0.03	0.11	0.73	4
T_{V11}	0.11	0.06	0.09	0.04	0.02	0.03	0.09	0.60	6
T_{V12}	0.11	0.12	0.15	0.04	0.04	0.05	0.13	0.87	2
Total	1.00	1.00	0.99				1.02		

Legend: TRPI = Total risk priority index, IRPV = Ideal risk priority indexes and R = Ranking

Table 6.7c: Verbal Ratings for Technical Risk Variables

Risk code	**Technical Risk Variables**	**Ideal Synthesized risk priority indexes (IRPI %)**	**Verbal ratings**
T_{V1}	Ambiguity of project scope/ Scope change	40	High
T_{V2}	Ground conditions on given project sites	27	Medium
T_{V3}	Inadequate project complexity analysis	73	Very high
T_{V4}	Unforeseen modification to project	40	High
T_{V5}	Inaccurate project cost estimate	53	High
T_{V6}	Failure to meet specified standards	100	Very high
T_{V7}	Technical difficulties in utilities diversions	80	Very high
T_{V8}	Engineering and design change	20	Low
T_{V9}	Supply chain breakdown	27	High
T_{V10}	Project time overruns	73	Very high
T_{V11}	Project cost overruns	60	High
T_{V12}	Project delays of all forms	87	Very high

Risk ratings: Very high = (>62%), High = (38%-61%), Medium = (24%-37%), Low = (14%-37%) and Very low = (<14%)

Table 6.8: Pairwise Matrix for Economic Risks

Table 6.8a: Pairwise Comparison for Economic Risk Variables

Project Objective	MV_R	Risk Code	E_{V1}	E_{V2}	E_{V3}	E_{V4}	E_{V5}	E_{V6}	E_{V7}	E_{V8}	E_{V9}	E_{V10}	E_{V11}	E_{V12}	Priorities	Ranking
Cost	9	E_{V1}	1	6	3	7	7	7	3	5	4	3	2	1	0.20	1
	4	E_{V2}	1/6	1	1/4	2	2	2	1/4	1/2	1/3	1/4	1/5	1/6	0.03	9
λ_{max} = 12.49	7	E_{V3}	1/3	4	1	5	5	5	1	3	2	1	1/2	1/3	0.09	4
CI = 0.04	3	E_{V4}	1/7	1/2	1/5	1	1	1	1/5	1/3	1/4	1/5	1/6	1/7	0.02	10
RI = 1.54	3	E_{V5}	1/7	1/2	1/5	1	1	1	1/5	1/3	1/4	1/5	1/6	1/7	0.02	10
CR = 0.03	3	E_{V6}	1/7	1/2	1/5	1	1	1	1/5	1/3	1/4	1/5	1/6	1/7	0.02	10
(Inconsistency	7	E_{V7}	1/3	4	4	5	5	5	1	3	2	1	1/2	1/3	0.09	4
= 0.00)	5	E_{V8}	1/5	2	2	3	3	3	1/3	1	1/2	1/3	1/4	1/5	0.04	8
	6	E_{V9}	1/4	3	3	4	4	4	1/2	2	1	1/2	1/3	1/4	0.06	7
	7	E_{V10}	1/3	4	4	5	5	5	1	3	2	1	1/2	1/3	0.09	4
	8	E_{V11}	1/2	5	5	6	6	6	2	4	3	2	1	1/2	0.14	3
	9	E_{V12}	1	6	6	7	7	7	3	5	4	3	2	1	0.20	1
Total = $\sum_{j=1}^{n} \mathbf{w}_{\cdot(\mathbf{cost})}$ =															1.00	
Time	7	E_{V1}	1	6	1	6	6	6	3	5	4	1	1	1/2	0.14	4
	2	E_{V2}	1/6	1	1/6	1	1	1	1/4	1/2	1/3	1/6	1/6	1/7	0.02	9
λ_{max} = 12.35	7	E_{V3}	1	6	1	6	6	6	3	5	4	1	1	1/2	0.14	4
CI = 0.03	2	E_{V4}	1/6	1	1/6	1	1	1	1/4	1/2	1/3	1/6	1/6	1/7	0.02	9
RI = 1.54	2	E_{V5}	1/6	1	1/6	1	1	1	1/4	1/2	1/3	1/6	1/6	1/7	0.02	9
CR = 0.02	2	E_{V6}	1/6	1	1/6	1	1	1	1/4	1/2	1/3	1/6	1/6	1/7	0.02	9
(Inconsistency	5	E_{V7}	1/3	4	1/6	4	4	4	1	3	2	1/5	1/5	1/4	0.06	6
= 0.00)	3	E_{V8}	1/5	2	1/5	2	2	2	1/3	1	1/2	1/5	1/5	1/6	0.03	8
	4	E_{V9}	1/4	3	1/4	3	3	3	1/2	2	1	1/4	1/4	1/5	0.05	7
	7	E_{V10}	1	6	1	6	6	6	5	5	4	1	1	1/2	0.15	2
	7	E_{V11}	1	6	1	6	6	6	5	5	4	1	1	1/2	0.15	2
	8	E_{V12}	2	7	2	7	7	7	4	6	5	2	2	1	0.21	1
Total = $\sum_{j=1}^{n} \mathbf{w}_{\cdot(\mathbf{time})}$ =															1.01	

Legend: λ_{max} = maximum eigenvalue, *CI = Consistency Index, RI = Random Index, CR = Consistency ratio*

Table 6.8a: Pairwise Comparison for Economic Risk Variables (Continued)

Project Objective	MV_R	Risks Code	E_{V1}	E_{V2}	E_{V3}	E_{V4}	E_{V5}	E_{V6}	E_{V7}	E_{V8}	E_{V9}	E_{V10}	E_{V11}	E_{V12}	Priorities	Ranking
Quality	6	E_{V1}	1	5	1	5	5	5	2	4	4	1	1	1	0.14	1
	2	E_{V2}	1/5	1	1/5	1	1	1	1/4	1/2	1/2	1/5	1/5	1/5	0.03	9
λ_{max} = 12.20	6	E_{V3}	1	5	1	5	5	5	2	4	4	1	1	1	0.14	1
CI = 0.02	2	E_{V4}	1/5	1	1/5	1	1	1	1/4	1/2	1/2	1/5	1/5	1/5	0.03	9
RI = 1.54	2	E_{V5}	1/5	1	1/5	1	1	1	1/4	1/2	1/2	1/5	1/5	1/5	0.03	9
CR = 0.01	2	E_{V6}	1/5	1	1/5	1	1	1	1/4	1/2	1/2	1/5	1/5	1/5	0.03	9
(Inconsistency	5	E_{V7}	1/2	4	1/2	4	4	4	1	3	3	1/2	1/2	1/2	0.09	6
= 0.00)	3	E_{V8}	1/4	2	1/4	2	2	2	1/3	1	1	1/4	1/4	1/4	0.04	7
	3	E_{V9}	1/4	2	1/4	2	2	2	1/3	1	1	1/4	1/4	1/4	0.04	7
	6	E_{V10}	1	5	1	5	5	5	2	4	4	1	1	1	0.14	1
	6	E_{V11}	1	5	1	5	5	5	2	4	4	1	1	1	0.14	1
	6	E_{V12}	1	5	1	5	5	5	2	4	4	1	1	1	0.14	1
Total = $\sum_{j=1}^{n} \mathbf{w}_{\cdot(\mathbf{Quality})}$ =															0.99	

Legend: λ_{max} = maximum eigenvalue, *CI = Consistency Index, RI = Random Index, CR = Consistency ratio R* = Ranking

Table 6.8b: Results of Final Mode ANP decision Making Priorities for Economic Risks Variables

Risk Code	Priorities for Economic Risk Variables						Final priorities		
	Local risk priority index (RPI_L)			Global risks priority index (RPI_G)			Synthesized results		
	Cost (0.33)	Time (0.33)	Quality (0.33)	Cost	Time	Quality	TRPI	IRPI	R
E_{V1}	0.20	0.14	0.14	0.07	0.05	0.05	0.17	1.00	1
E_{V2}	0.03	0.02	0.03	0.01	0.01	0.01	0.03	0.18	8
E_{V3}	0.09	0.14	0.14	0.03	0.05	0.05	0.13	0.76	4
E_{V4}	0.02	0.02	0.03	0.01	0.01	0.01	0.03	0.18	8
E_{V5}	0.02	0.02	0.03	0.01	0.01	0.01	0.03	0.18	8
E_{V6}	0.02	0.02	0.03	0.01	0.01	0.01	0.03	0.18	8
E_{V7}	0.09	0.06	0.09	0.03	0.02	0.03	0.08	0.47	6
E_{V8}	0.04	0.03	0.04	0.01	0.01	0.01	0.03	0.18	8
E_{V9}	0.06	0.05	0.04	0.02	0.02	0.01	0.05	0.29	7
E_{V10}	0.09	0.15	0.14	0.03	0.05	0.05	0.13	0.76	4
E_{V11}	0.14	0.15	0.14	0.05	0.05	0.05	0.15	0.88	3
E_{V12}	0.20	0.21	0.14	0.07	0.07	0.05	0.19	1.00	1
Total	1.00	1.01	0.99				1.05		

Legend: TRPI = Total risk priority index, IRPV = Ideal risk priority indexes and R = Ranking

Table 6.8c: Verbal Ratings for Economic Risk Variables

Risk code	Risks	Ideal Synthesized risk priority indexes (IRPI %)	Verbal ratings
E_{V1}	Change in government funding policy;	100	Very high
E_{V2}	Taxation changes;	018	Low
E_{V3}	Change in government;	076	Very high
E_{V4}	Wage inflation;	018	Low
E_{V5}	Local inflation change;	018	Low
E_{V6}	Foreign exchange rate;	018	Low
E_{V7}	Material price changes;	047	High
E_{V8}	Economic recession;	018	Low
E_{V9}	Energy price changes;	029	Medium
E_{V10}	Catastrophic environmental effects;	076	Very high
E_{V11}	Project technical difficulties	088	Very high
E_{V12}	Project delays of all forms	100	Very high

Risk ratings: Very high = (>62%), High = (38%-61%), Medium = (24%-37%), Low = (14%-37%) and Very low = (<14%)

Table 6.9: Pairwise Matrix for Environmental Risks

Table 6.9a: Pairwise Comparison for Environmental Risk Variables

Project Objective	MV_R	Risk Code	E_{NV1}	E_{NV2}	Priorities	Ranking	The consistency test
Cost	5	E_{NV1}	1	1/5	0.17	2	$\lambda_{max} = 2.00$
	9	E_{NV2}	5	1	0.83	1	CI = 0.00
							RI = 0.00
Total = $\sum_{j=1}^{n} w_{\cdot(Cost)}$					1.00		CR = 0.00
Time	4	E_{NV1}	1	1/4	0.20	2	$\lambda_{max} = 2.00$
	7	E_{NV2}	4	1	0.80	1	CI = 0.00
							RI = 0.00
Total = $\sum_{j=1}^{n} w_{\cdot(Time)}$					1.00		CR = 0.00
Quality	3	E_{NV1}	1	1/4	0.20	2	$\lambda_{max} = 2.00$
	6	E_{NV2}	4	1	0.80	1	CI = 0.00
							RI = 0.00
Total = $\sum_{j=1}^{n} w_{\cdot(Quality)}$					1.00		CR = 0.00

Legend: λ_{max} = maximum eigenvalue, *CI = Consistency Index, RI = Random Index, CR = Consistency ratio*

Table 6.9b: Results of final mode ANP decision making priorities for Environmental Risk Variables

Risk Code	Priorities for ETNP Objectives						Final priorities		
	Local risk priority index (RPI_L)			Global risks priority index (RPI_G)			Synthesized results		
	Cost (0.33)	Time (0.33)	Quality (0.33)	Cost	Time	Quality	TRPI	IRPI	R
E_{NV1}	0.17	0.20	0.20	0.06	0.07	0.07	0.20	0.25	2
E_{NV2}	0.83	0.80	0.80	0.27	0.26	0.26	0.79	1.00	1
Total	1.00	1.00	1.00				0.99		

Legend: TRPI = Total risk priority index, IRPV = Ideal risk priority indexes and R = Ranking

Table 6.9c: Verbal Ratings for Environmental Risk Variables

Risk code	Environmental Risk Variables	Ideal Synthesized risk priority indexes (IRPI %)	Verbal ratings
E_{NV1}	Environmental issues from works (Pollution)	025	Medium
E_{NV2}	Unfavourable climate conditions (Snow, rain, etc.)	100	Very high

Risk ratings: Very high = (>62%), High = (38%-61%), Medium = (24%-37%), Low = (14%-37%) and Very low = (<14%)

Table 6.10: Pairwise Matrix for Political Risks

Table 6.10a: Pairwise Comparison for Political Risk Variables

Project Objective	MV_R	Risk Code	P_{V1}	P_{V2}	P_{V3}	P_{V4}	P_{V5}	P_{V6}	P_{V6}	P_{V8}	P_{V9}	P_{V10}	Priorities	Ranking
Cost	9	P_{V1}	1	3	2	2	1	4	4	4	7	4	0.21	1
	7	P_{V2}	1/3	1	1/2	1/2	1/3	2	2	2	5	2	0.08	5
$\lambda_{max} = 10.19$	8	P_{V3}	1/2	2	1	1	1/2	3	3	3	6	3	0.13	3
CI = 0.02	8	P_{V4}	1/2	2	1	1	1/2	3	3	3	6	3	0.13	3
RI = 1.49	9	P_{V5}	1	3	2	2	1	4	4	4	7	4	0.21	1
CR = 0.01	6	P_{V6}	1/4	1/2	1/3	1/3	1/4	1	1	1	4	1	0.05	6
(Inconsistency	6	P_{V7}	1/4	1/2	1/3	1/3	1/4	1	1	1	4	1	0.05	6
= 0.00)	6	P_{V8}	1/4	1/2	1/3	1/3	1/4	1	1	1	4	1	0.05	6
	3	P_{V9}	1/7	1/5	1/6	1/6	1/7	1/4	1/4	1/4	1	1/4	0.02	10
	6	P_{V10}	1/4	1/2	1/3	1/3	1/4	1	1	1	4	1	0.05	6
Total = $\sum_{j=1}^{n} \mathbf{w}_{\textbf{Political risk factors}_{(\textbf{cost})}}$ =													0.98	
Time	7	P_{V1}	1	2	1	1	1/2	1	1	4	4	2	0.12	4
	6	P_{V2}	1/2	1	1/2	1/2	1/3	1	1	3	3	1	0.08	5
$\lambda_{max} = 10.00$	7	P_{V3}	1	2	1	1	1/2	2	2	4	4	2	0.14	2
CI = 0.00	7	P_{V4}	1	2	1	1	1/2	2	2	4	4	2	0.14	2
RI = 1.49	8	P_{V5}	2	3	2	2	1	3	3	5	5	3	0.22	1
CR = 0.00	6	P_{V6}	1	1	1/2	1/2	1/3	1	1	3	3	1	0.08	5
(Inconsistency	6	P_{V7}	1	1	1/2	1/2	1/3	1	1	3	3	1	0.08	5
= 0.00)	4	P_{V8}	1/4	1/3	1/4	1/4	1/5	1/3	1/3	1	1	1/3	0.03	9
	4	P_{V9}	1/4	1/3	1/4	1/4	1/5	1/3	1/3	1	1	1/3	0.03	9
	6	P_{V10}	1/2	1	1/2	1/2	1/3	1	1	3	3	1	0.08	5
Total = $\sum_{j=1}^{n} \mathbf{w}_{\textbf{Political risk factors}_{(\textbf{time})}}$ =													1.00	

Legend: λ_{max} = maximum eigenvalue, *CI = Consistency Index, RI = Random Index, CR = Consistency ratio*

Table 6.10a: Pairwise Comparison for Political Risk Variables (Continued)

Project objectives	MV_R	Risk Code	P_{V1}	P_{V2}	P_{V3}	P_{V4}	P_{V5}	P_{V6}	P_{V6}	P_{V8}	P_{V9}	P_{V10}	Priorities	Ranking
Quality	6	P_{V1}	1	3	1	2	1	3	4	4	4	4	0.19	1
	4	P_{V2}	1/3	1	1/3	1/2	1/3	1	2	2	2	2	0.07	5
$\lambda_{max} = 10.08$	6	P_{V3}	1	3	1	2	1	3	4	4	4	4	0.19	1
CI = 0.01	5	P_{V4}	1/2	2	½	1	1/2	2	3	3	3	3	0.12	4
RI = 1.49	6	P_{V5}	1	3	1	2	1	3	4	4	4	4	0.19	1
CR = 0.01	4	P_{V6}	1/3	1	1/3	1/2	1/3	1	2	2	2	2	0.07	5
(Inconsistency =	3	P_{V7}	1/4	1/2	¼	1/3	1/4	1/2	1	1	1	1	0.04	7
0.00)	3	P_{V8}	1/4	1/2	¼	1/3	1/4	1/2	1	1	1	1	0.04	7
	3	P_{V9}	1/4	1/2	¼	1/3	1/4	1/2	1	1	1	1	0.04	7
	3	P_{V10}	1/4	1/2	¼	1/3	1/4	1/2	1	1	1	1	0.04	7
Total = $\sum_{j=1}^{n} \mathbf{w}_{\textbf{Political risk factors}_{(\textbf{Quality})}}$ =													0.99	

Legend: λ_{max} = maximum eigenvalue, *CI = Consistency Index, RI = Random Index, CR = Consistency ratio*

Table 6.10b: Results of Final Mode ANP Decision Making Priorities for Political Risk Variables

Risk Code	Priorities for Political Risk Variables						Final priorities		
	Local risk priority index (RPI_L)			Global risks priority index (RPI_G)			Synthesized results		
	Cost (0.33)	Time (0.33)	Quality (0.33)	Cost	Time	Quality	TRPI	IRPI	R
P_{V1}	0.21	0.12	0.19	0.07	0.04	0.06	0.17	0.81	2
P_{V2}	0.08	0.08	0.07	0.03	0.03	0.02	0.08	0.38	5
P_{V3}	0.13	0.14	0.19	0.04	0.05	0.06	0.15	0.71	3
P_{V4}	0.13	0.14	0.12	0.04	0.05	0.04	0.13	0.62	4
P_{V5}	0.21	0.22	0.19	0.07	0.07	0.06	0.21	1.00	1
P_{V6}	0.05	0.08	0.07	0.02	0.03	0.02	0.07	0.33	6
P_{V7}	0.05	0.08	0.04	0.02	0.03	0.01	0.06	0.29	7
P_{V8}	0.05	0.03	0.04	0.02	0.01	0.01	0.04	0.19	9
P_{V9}	0.02	0.03	0.04	0.01	0.01	0.01	0.03	0.14	10
P_{V10}	0.05	0.08	0.04	0.02	0.03	0.01	0.06	0.29	7
Total	1.00	1.01	0.99				1.00		

Legend: TRPI = Total risk priority index, IRPV = Ideal risk priority indexes and R = Ranking

Table 6.10c: Verbal ratings for Political Risk Variables

Risk code	Political Risk Variables	Ideal Synthesized risk priority indexes (IRPI %)	Verbal ratings
P_{V1}	Change in government funding policy	81	Very high
P_{V2}	Political opposition	38	High
P_{V3}	Government discontinuity	71	Very high
P_{V4}	Lack of political support	62	Very high
P_{V5}	Political indecision	100	Very high
P_{V6}	Project termination	33	Medium
P_{V7}	Delay in obtaining consent/Approval	29	Medium
P_{V8}	Legislative/regulatory changes	19	Low
P_{V9}	Protectionism	14	Low
P_{V10}	Delay in obtaining temporary Traffic Regulation Orders (TROs)	29	Medium

Risk ratings: Very high = (>62%), High = (38%-61%), Medium = (24%-37%), Low = (14%-37%) and Very low = (<14%)

6.2.2.7. Risk Priority Index (RPI) as a Project Ranking Method for all Risks

The developed RPIs can be used to prioritize transportation megaprojects from a risk perspective during construction. For example, if STEEP risks are considered as risks that a developer is to assess with respect to project time, cost and quality, the RPI will provide a value to prioritize them. The higher the RPI, the higher the rank of the risks associated with the project.

Table 6.11: Summary of Final ANP Decision Making Priority Results for all Risks

Potential Risk	Cluster priorities (W)	Risk Code	Risk priorities							Ranking
			Local			Synthesized				
			Cost	Time	Quality	Cost	Time	Quality	Total	
			(0.33)	(0.33)	(0.33)	($w_{(C)}$)	($w_{(T)}$)	($w_{(Q)}$)	(T)	
	$W_{(PR_i)}$		$w_{(c)}$	$w_{(t)}$	$w_{(q)}$	0.33* $w_{(c)}$	0.33* $w_{(t)}$	0.33* $w_{(q)}$	$\sum w_{(C,T,Q)ij}$	
P_{R1}: Social	0.13	S_{V1}	0.06	0.07	0.05	0.02	0.02	0.02	0.06	5
		S_{V2}	0.24	0.25	0.21	0.08	0.08	0.07	0.23	2
		S_{V3}	0.24	0.25	0.33	0.08	0.08	0.11	0.27	1
		S_{V4}	0.24	0.25	0.21	0.08	0.08	0.07	0.23	2
		S_{V5}	0.15	0.11	0.09	0.05	0.04	0.03	0.12	4
		S_{V6}	0.04	0.04	0.05	0.01	0.01	0.02	0.04	6
		S_{V7}	0.03	0.03	0.05	0.01	0.01	0.02	0.04	6
P_{R2}: Technical	0.30	T_{V1}	0.06	0.06	0.06	0.02	0.02	0.02	0.06	8
		T_{V2}	0.04	0.06	0.03	0.01	0.02	0.01	0.04	10
		T_{V3}	0.11	0.12	0.09	0.04	0.04	0.03	0.11	4
		T_{V4}	0.06	0.06	0.05	0.02	0.02	0.02	0.06	8
		T_{V5}	0.11	0.06	0.05	0.04	0.02	0.02	0.08	7
		T_{V6}	0.11	0.06	0.28	0.04	0.02	0.09	0.15	1
		T_{V7}	0.11	0.19	0.05	0.04	0.06	0.02	0.12	3
		T_{V8}	0.03	0.04	0.03	0.01	0.01	0.01	0.03	12
		T_{V9}	0.02	0.06	0.02	0.01	0.02	0.01	0.04	10
		T_{V10}	0.11	0.12	0.09	0.04	0.04	0.03	0.11	4
		T_{V11}	0.11	0.06	0.09	0.04	0.02	0.03	0.09	6
		T_{V12}	0.11	0.12	0.15	0.04	0.04	0.05	0.13	2
P_{R3}: Economic	0.25	E_{V1}	0.20	0.14	0.14	0.07	0.05	0.05	0.17	1
		E_{V2}	0.03	0.02	0.03	0.01	0.01	0.01	0.03	8
		E_{V3}	0.09	0.14	0.14	0.03	0.05	0.05	0.13	4
		E_{V4}	0.02	0.02	0.03	0.01	0.01	0.01	0.03	8
		E_{V5}	0.02	0.02	0.03	0.01	0.01	0.01	0.03	8
		E_{V6}	0.02	0.02	0.03	0.01	0.01	0.01	0.03	8
		E_{V7}	0.09	0.06	0.09	0.03	0.02	0.03	0.08	6
		E_{V8}	0.04	0.03	0.04	0.01	0.01	0.01	0.03	8
		E_{V9}	0.06	0.05	0.04	0.02	0.02	0.01	0.05	7
		E_{V10}	0.09	0.15	0.14	0.03	0.05	0.05	0.13	4
		E_{V11}	0.14	0.15	0.14	0.05	0.05	0.05	0.15	3
		E_{V12}	0.20	0.21	0.14	0.07	0.07	0.05	0.19	1
P_{R4}: Environmental	0.16	E_{NV1}	0.17	0.20	0.20	0.06	0.07	0.07	0.20	2
		E_{NV2}	0.83	0.80	0.80	0.27	0.26	0.26	0.79	1
P_{R5}: Political	0.17	P_{V1}	0.21	0.12	0.19	0.07	0.04	0.06	0.17	2
		P_{V2}	0.08	0.08	0.07	0.03	0.03	0.02	0.08	5
		P_{V3}	0.13	0.14	0.19	0.04	0.05	0.06	0.15	3
		P_{V4}	0.13	0.14	0.12	0.04	0.05	0.04	0.13	4
		P_{V5}	0.21	0.22	0.19	0.07	0.07	0.06	0.21	1
		P_{V6}	0.05	0.08	0.07	0.02	0.03	0.02	0.07	6
		P_{V7}	0.05	0.08	0.04	0.02	0.03	0.01	0.06	7
		P_{V8}	0.05	0.03	0.04	0.02	0.01	0.01	0.04	9
		P_{V9}	0.02	0.03	0.04	0.01	0.01	0.01	0.03	10
		P_{V10}	0.05	0.08	0.04	0.02	0.03	0.01	0.06	7

Therefore, technical risk has the first priority because it has the highest RPI (30%) as shown in table 27. STEEP risks effects on project cost, time and quality can be assessed in order, based on the level of impacts as follows: technical risks, economic risks, political risks, environmental risks and social risks because they have RPIs of 30%, 25%, 17%, 16% and 13% respectively.

Consequently, the transportation megaproject developer has the flexibility to re-categorize and select the appropriate risks under each risk cluster based on the situation in a geographical setting and the type of project being executed. The developed RPIs attract a developer's attention to the potential risks that have the highest level of impacts on project objectives and to consider appropriate risk management procedures.

6.3. Summary

This section of the study proposes the use of ANP methodology to prioritize risks in transportation megaprojects under construction. Risk sources were identified in literature, from experts' opinions, source documents of past and existing megaprojects under construction and accordingly were categorised into clusters. A model for calculating Risk Priority Indexes (RPIs) was designed and its components were explained and discussed in detailed throughout this section. The developed models were applied to five risk areas (social, technical, economic, environmental and political) to evaluate their level of impact on project cost, time and quality.

Prioritization results revealed that technical risks have the highest average effect score (0.30) in the hierarchy risks areas considered in this research. The results further show that economic risks have the second highest effects score (0.25) followed by political risks (0.17), environmental risks (0.16) and social risks (0.13).

Based on the ANP RPIs, the results suggest that a developer that pursues transportation megaprojects needs to consider seriously technical risks in the construction phase of the project life cycle. Additionally, the interactions of all risks in the emerging economic, political and social environments of a developed nation can be very critical to developers to deal with. Therefore, the developed model can be implemented to facilitate a company’s decision on risk management based on the level of STEEP risks impact on project performance.

The relevancies of this section are that:

i. It provides practitioners with a tool to evaluate and prioritize risk impact levels in a megaproject in the construction phase and
ii. It provides researchers with risk areas and sub areas, a model to evaluate and prioritize risks and a methodology to quantify the qualitative effects of risks factors.

These conclusions are limited to the data collected. However, if the data set is extended to cover more transportation megaprojects and risk areas, it might truly represent the level of STEEP risks impact in megaprojects and so general conclusions can be drawn.

CHAPTER SEVEN: SD MODEL

7.1: Introduction

Following the ANP model construction in chapter six, this chapter introduces the development of the initial System Dynamics (SD) models that underpins the research focus. The model structure and the initial model development are described to reflect the construction phase of a transportation megaproject's lifecycle. Based on case scenarios, risk interdependencies (cause-effect interrelationships) in transportation megaprojects are addressed by causal loop diagrams. The chapter concludes with the verification of the initial model development. The explanation for this distinction is provided in the course of the discussion.

7.2: The Model Structure

To start with, a high level causal diagram for the entire system at the construction phase is constructed for the case study project (ETNP) and given in Figure 7.1. Variables in the high level causal diagram are causally related in the form of loops and may either have no influence or have a positive or negative influence on another factor. By and large, everything is dependent on everything else, directly or indirectly.

As a result of many system variables (entities) and loops in Figure 7.1, transportation megaprojects can be said to belong to the class of complex dynamic systems that, according to Sterman (1992), exhibit the following characteristics:

- They are complex and consist of multiple components.
- They are highly dynamic.
- They involve multiple feedback processes.
- They involve non-linear relationships and
- They involve both "hard" and "soft" data.

In this model, hard data such as cost would be measurable while soft data such as social uncertainties would be intangible. For simplicity, Figure 7.1 is modelled into five sub systems: (a) social risks system (b) technical risks system, (c) economic risks system; (d) environmental risks system and (e) political risks system. Each of these risk sub systems is simulated to reveal their respective level of impacts on project cost, time and quality during construction over time. In the end, the sub models are combined to form a generic MegaDS risk stock model to assess the overall impact of all risks on ETNP as a transportation megaproject. This way, the model structure would be clear for ease of management, especially when observing the risk value changes within the system. Further details of what are in the risk sub systems are discussed in section 7.1.3.

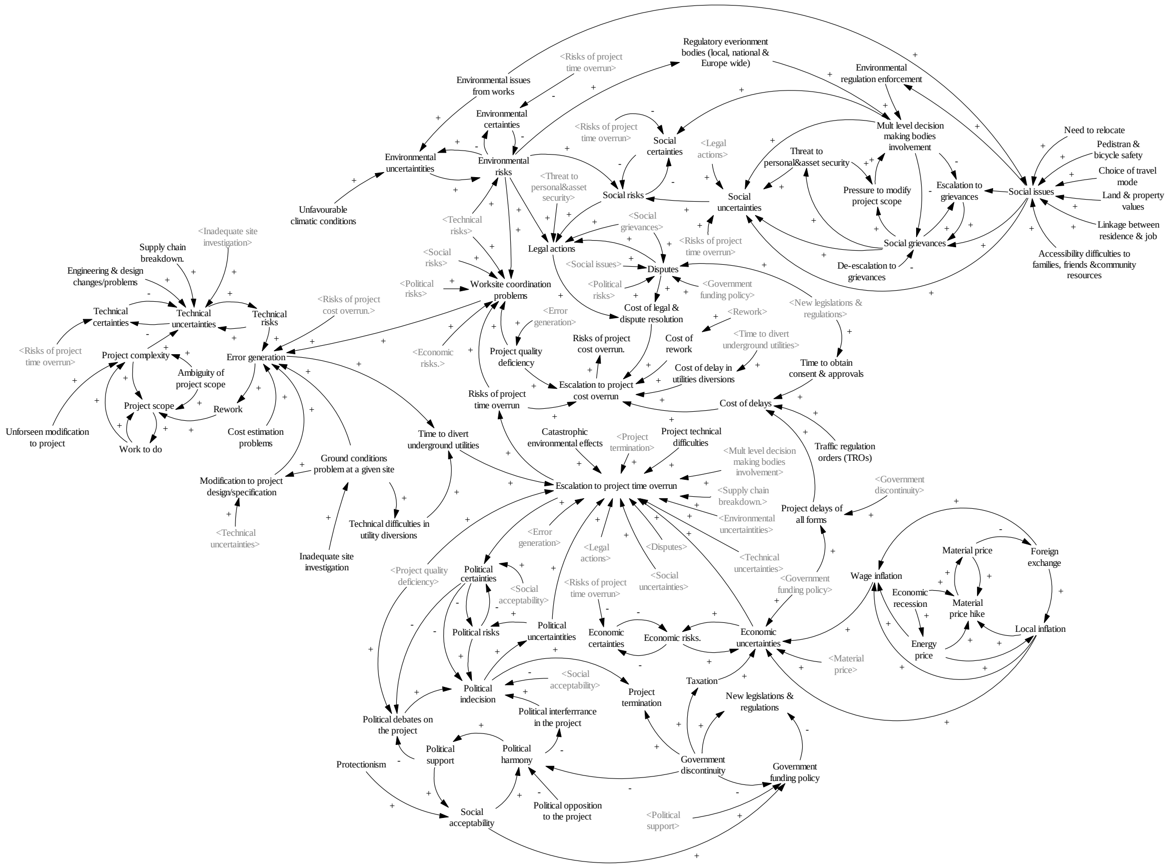


Figure 7.1: Causal Loop Diagram for STEEP Risks on ETNP

(See the attached sheet for clarity)

7.2.1. Model Causality

For each entity in the STEEP risks causal loop model, two different causality trees can be drawn. The first, called “causes tree” represents the entity in question as the end of the tree and includes all the variables (entities) that influence it. The second tree-like diagram, called “uses tree” has the entity in question at its head, and shows all other entities influenced by it. For example, Figure 7.2 shows the “causes” tree for ***technical uncertainties*** while Figure 7.3 shows respectively the “uses” tree for the same entity ***technical uncertainties.***

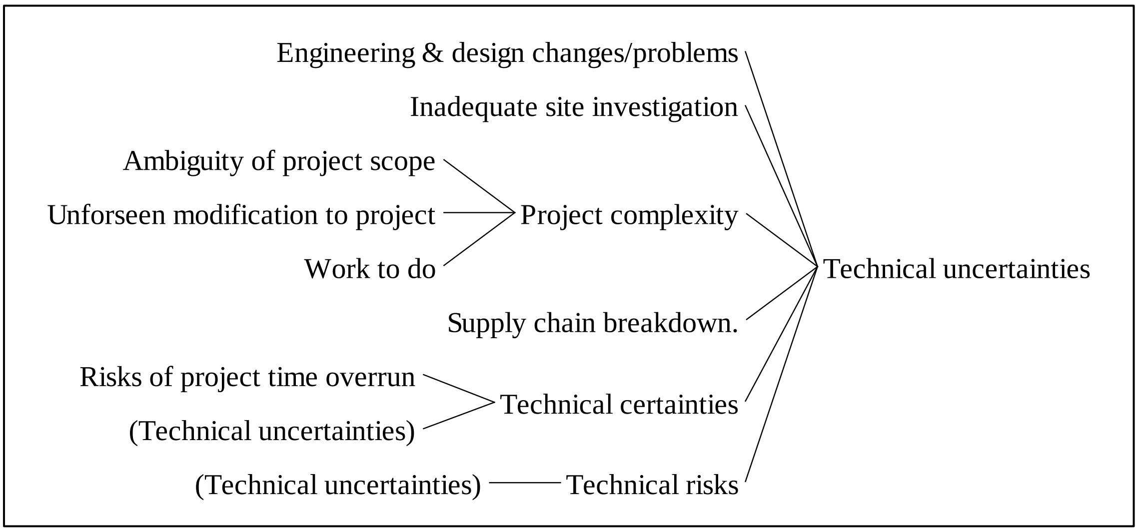


Figure 7.2: Causes Tree Diagram for Technical Uncertainties Entity

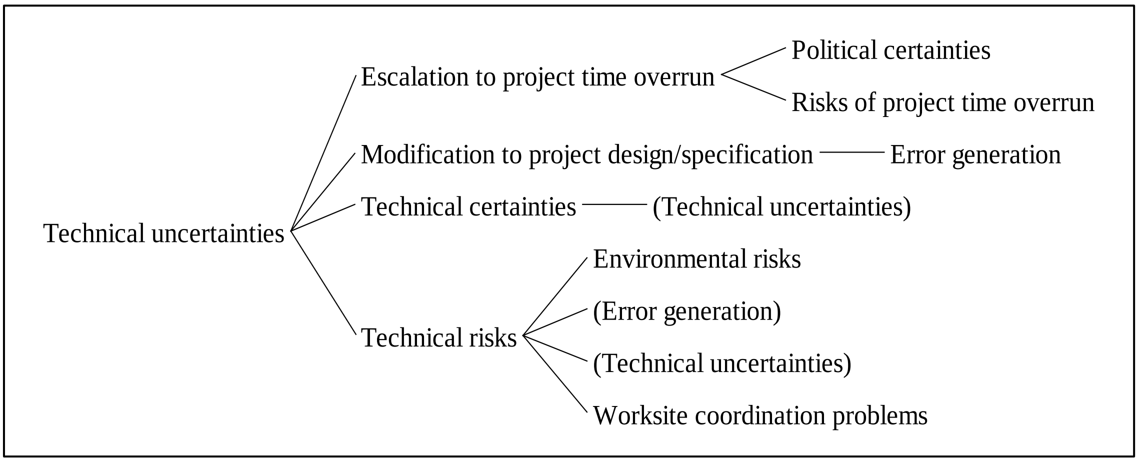


Figure 7.3: Uses Tree Diagram for Technical Uncertainties Entity

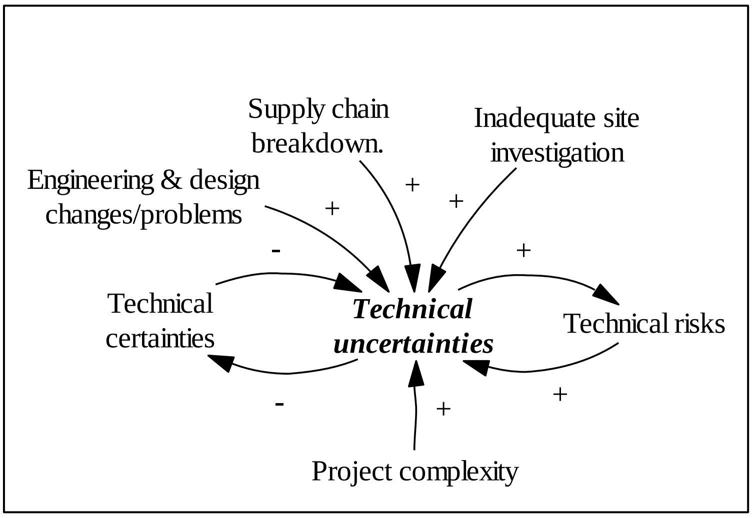


Figure 7.4: Causality of Technical Uncertainties

Considering the relation of ***technical uncertainties*** variable in Figure 7.1, by pure logic, project participants can associate and represent both the causes and uses tree diagrams in Figures 7.2 and 7.3 as shown in Figure 7.4 and Table 7.1 respectively.

Table 7.1: Technical Uncertainties Influence

Technical uncertainties			
Influence by		***Influence on***	
Positive	*Negative*	*Positive*	*Negative*
- Inadequate site investigation - Technical risks - Project complexity - Engineering & design problems - Supply chain breakdown	- Technical certainties	- Technical risks	- Technical certainties

In all causal tree diagrams entities in parenthesis, that is (Technical uncertainties) indicated in Figure 7.3, denote that this entity appears at least twice in the tree, and are therefore contained in a loop, as indeed can be seen in the causal loop model presented in Figure 7.1. In the same way, the high level causal diagrams for the entire system and sub systems were developed. It can also be observed that the high level causal diagram represented in Figure 7.1 contains several risk variables and loops which indicate cause-effect interrelationships for the entire STEEP risks.

7.3. Initial Model Development

The initial model defines the dynamic hypothesis of each STEEP risk systems considered in this research. The dynamic hypothesis is a statement that can be proved right or wrong after a thorough research based investigation. Ranganath and Rodrigues (2008) stated in system dynamics theory and case studies that a dynamic hypothesis can be proposed in the form of a statement, a causal loop diagram, or stock and flow diagram. According to Ranganath and Rodrigues, it basically expresses the model in a systematic term for conducting simulation by deciding on the factors of study. Refinement and revision can be made on this dynamic hypothesis, as and when required, because no model can be perfect in all respects.

As mention in chapter 3 (Section 3.4), details of the dynamic hypothesis are derived from the literature review, interviews conducted with academic staff, consultants, project managers, engineers and other top level management staff involved in megaproject development and through the modeller's interaction with industry practitioners in the United Kingdom. These hypotheses behave dynamically and are based on the interactions of risk variables within the overall model illustrated in Figure 7.1. This suggests that various variables which cause risks are interrelated within a chain of cause and effect loops. According to Yeganli *et al.*, (2011), each cause influences the latter one in a closed loop of cause and effects making a domino. Tables 7.2 to 7.6 in section 7.3.1 represent the system boundaries for each sub system within the MegaDS model while Sections 7.3.2 to 7.3.6 provide detail representations of the five dynamic hypotheses under each sub system.

7.3.1. System Boundaries

In order to show a complete picture of the level of STEEP risk variables impacting on project time, cost and quality in the construction phase, description of the system boundary is required. Tables 7.2 to 7.6 indicate consolidated risk variables obtained during literature search, case studies and interviews which are used to formulate the system boundaries for the MegaDS system models. The endogenous risk variables are those whose behaviours are generated within each STEEP model while the exogenous variables are considered as essentially parameters with values coming from the ANP Risk Priority Indexes (RPIs), and can usually be considered as constants. The boundaries of the MegaDS system models contain risk variables that are required to generate the problem behaviour on project performance (time, cost and quality) at the construction phase for transportation megaprojects only.

Table 7.2: System Boundary for Social Risks System

Risk Code	**Risk Type**
	Type I: Endogenous Variables
P_{R1}	Social risks
S_{V1}	Social grievances;
S_{V2}	Multi-level decision making bodies involvement
S_{V3}	Disputes
S_{V4}	Legal/Community actions
S_{V5}	Pressure to modify project scope
S_{V6}	Threats to personnel and asset security
S_{V8}	Cost of dispute resolution
S_{V9}	De-escalation to grievances
S_{V10}	Error generation
S_{V11}	Escalation to grievances
S_{V12}	Escalation to project cost overrun
S_{V13}	Escalation to project time overrun
S_{V14}	Project quality deficiency
S_{V15}	Risks of cost overrun.
S_{V16}	Risks of time overrun
S_{V17}	Social certainties
S_{V18}	Social uncertainties
S_{V19}	Worksite coordination problems
	Type II: Exogenous Variable
S_{V7}	Social Issues

Table 7.3: System Boundary for Technical Risks System

Risk Code	**Risk Type**
	Type I: Endogenous Variables
P_{R2}	Technical risks
T_{V2}:	Ground conditions problem at a given project site
T_{V3}:	Project complexity
T_{V6}:	Modification to project design & specification
T_{V7}:	Technical difficulties in utilities diversions
T_{V10}:	Risks of project time overrun
T_{V11}:	Risks of project cost overrun
T_{V13}:	Cost of delay in utility diversion
T_{V14}:	Cost of rework
T_{V15}:	Error generation
T_{V16}:	Project quality deficiency
T_{V17}:	Project scope.
T_{V18}:	Escalation to project cost overrun
T_{V19}:	Escalation to project time overrun
T_{V20}:	Rework
T_{V21}:	Technical certainties
T_{V22}:	Technical uncertainties
T_{V23}:	Time to divert underground utilities
T_{V24}:	Work to do
T_{V25}:	Worksite coordination problems
	Type II: Exogenous Variables
T_{V1}:	Ambiguity of project scope/ Scope change
T_{V4}:	Project modification
T_{V5}:	Project cost estimate problems
T_{V8}:	Engineering and design change
T_{V9}:	Supply chain breakdown
T_{V12}:	Inadequate site investigation
	Type III: Excluded Variables
xT_{V1}:	Buildability
xT_{V2}:	Constructability

Table 7.4: System Boundary for Economic Risks System

Risk Code	**Risk Type**
	Type I: Endogenous Variables
P_{R3}	Economic risks
E_{V1}:	Change in government funding policy
E_{V2}:	Taxation
E_{V4}:	Wage inflation;
E_{V5}:	Local inflation
E_{V6}:	Foreign exchange
E_{V7}:	Material price
E_{V9}:	Energy price
E_{V12}:	Project delays of all forms
E_{V13}:	Cost of delays
E_{V14}:	Cost of resolution
E_{V15}:	Disputes
E_{V16}:	Economic certainties
E_{V17}:	Economic uncertainties
E_{V18}:	Error generation
E_{V19}:	Escalation to project cost overrun
E_{V20}:	Escalation to project time overrun
E_{V21}:	Material price hike
E_{V22}:	Project quality deficiency
E_{V23}:	Risks of project cost overrun
E_{V24}:	Risks of project time overrun
E_{V25}:	Worksite coordination problems
	Type II: Exogenous Variables
E_{V3}:	Government discontinuity (change)
E_{V8}:	Economic recession
E_{V10}:	Catastrophic environmental effects;
E_{V11}:	Project technical difficulties

Table 7.5: System Boundary for Environmental Risks System

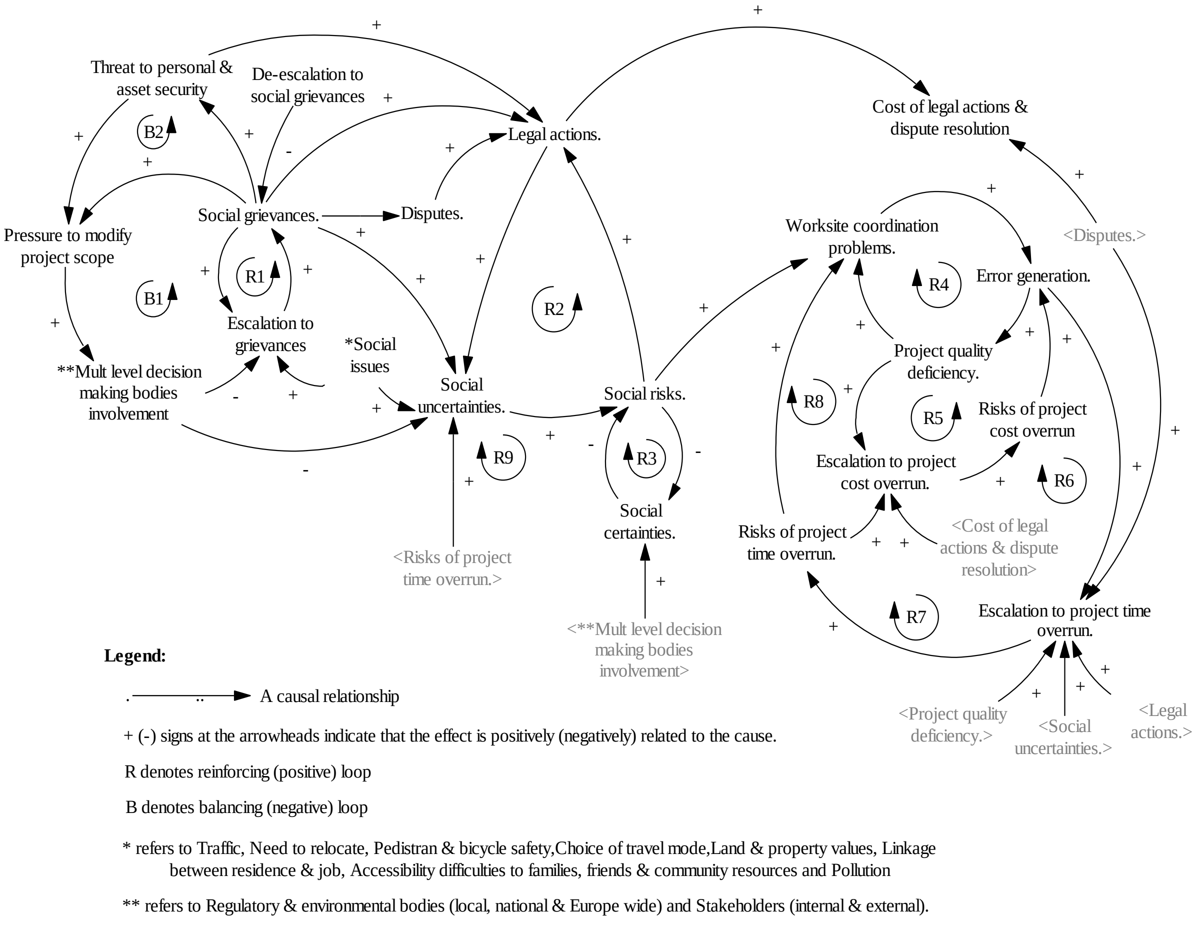
Risk Code	**Risk Type**
	Type I: Endogenous Risk Variables
P_{R4}:	Environmental risks
E_{NV3}:	Cost of legal action
E_{NV4}:	Disputes
E_{NV5}:	Environmental regulation enforcement
E_{NV6}:	Environmental certainties
E_{NV7}:	Environmental uncertainties
E_{NV8}:	Error generation
E_{NV9}:	Escalation to project cost overrun
E_{NV10}:	Escalation to project time overrun
E_{NV11}:	Legal action
E_{NV12}:	Multi decision making bodies involvement
E_{NV13}:	Project quality deficiency
E_{NV14}:	Risks of project cost overrun
E_{NV15}:	Risks of project time overrun
E_{NV16}:	Social issues
E_{NV17}:	Social grievances
E_{NV18}:	Worksite coordination problems
	Type II: Exogenous
E_{NV1}:	Environmental issues from works
E_{NV2}:	Unfavourable climate conditions

Table 7.6: System Boundary for Political Risks System

Risk Code	**Risk Type**
	Type I: Endogenous
P_{R5}	Political risks
P_{V1}:	Government funding policy
P_{V4}:	Political support
P_{V5}:	Political indecision (decision)
P_{V6}:	Project termination
P_{V7}:	Delay in obtaining consent/approval;
P_{V8}:	Legislative & regulatory changes
P_{V9}:	Cost of delays
P_{V10}:	Cost of legal & dispute resolution
P_{V11}:	Disputes
P_{V12}:	Error generation
P_{V13}:	Escalation to project cost overrun
P_{V14}:	Escalation to project time overrun.
P_{V15}:	Legal actions
P_{V16}:	Political certainties
P_{V17}:	Political debates on the project
P_{V18}:	Political harmony
P_{V19}:	Political interferences in the project
P_{V20}:	Political uncertainties
P_{V21}:	Project quality deficiency
P_{V22}:	Risks of project cost overrun.
P_{V23}:	Risks of project time overrun
P_{V24}:	Social acceptability.
P_{V25}:	Worksite coordination problems
	Type II: Exogenous
P_{V2}:	Political opposition
P_{V3}:	Government discontinuity
P_{V9}:	Protectionism
P_{V10}:	Delay in obtaining temporary Traffic Regulation Orders (TROs)

7.3.2: The Social Risks System

The social risks system is the first sub model within the Megaproject dynamics simulation (MegaDS) system models. The model is called Social Risks Model (S*o*RM) as it basically captures the dynamics of the social risks impacting on project performance at the construction phase. Its key parameters include variables such as those indicated in Table 7.2: System Boundary for Social Risks System. These parameters define the boundary of the social risks system and are grouped into endogenous and exogenous variables in order to understand how the system behaves and what their properties are.



Legend:

A causal relationship

+ (-) signs at the arrowheads indicate that the effect is positively (negatively) related to the cause.

R denotes reinforcing (positive) loop

B denotes balancing (negative) loop

* refers to Traffic, Need to relocate, Pedistran & bicycle safety,Choice of travel mode,Land & property values, Linkage between residence & job, Accessibility difficulties to families, friends & community resources and Pollution

** refers to Regulatory & environmental bodies (local, national & Europe wide) and Stakeholders (internal & external).

Figure 7.5: Causal Loop Diagram for Social Risks System
(See the attached sheet for clarity)

The dynamic hypothesis (cause-and-effect diagram) indicated in Figure 7.5 defines the interrelations between different causes which lead to occurrence of social risks in the system. This interconnecting chain of cause-and-effect loops makes risk variables a network of dynamic behaviours.

Developing such a model shed light into the systematic nature of risk behaviour which may possibly be neglected in the traditional ways of dealing with social risks during megaproject development. Since the dynamic behaviours of social risks are very difficult to understand and control in any business including megaproject development, the framework of the proposed social risks model illustrated in Figure 7.5 is limited only to the variables specified in the system boundary presented in Table 7.2. The S*o*RM contains two vicious cycles: the vicious cycle of reinforcing or positive loops (represented by R1 to R8) and the vicious cycle of balancing or negative loops (denoted by B1 and B2). Details of these vicious cycles are further explained in sections 7.3.2.1 and 7.3.2.2.

7.3.2.1: The Vicious Cycle of Social Risks Generation

The positive or reinforcing feedback loops R1 to R8 operate as vicious cycles that can drag transportation megaprojects under construction into time and cost overruns and quality deficiency. As indicated in the feedback loop R1, social issues cause an increase in escalation to grievances which in turn increase the level of social grievances in the system. Social grievances further reinforce escalation to grievances to form the loop R1.

In feedback loops R2, increases in social uncertainties increase the level of social risks impact in the system but decreases social certainties on the project. Increase in social risks increases legal actions which also increases social uncertainties to form a loop. The basis of the loop R2 is that the sources of social uncertainties such as social issues and grievances may cover a range of impacts a project may have in the social environment. The social environment encompasses local people with norms, beliefs and ways in which they live and interact with their environment and economy. All these may have been considered during planning and early consultation stages and still be affected directly or indirectly by project activities. Since communities in the project area may have characteristics, objectives and requirements that need to be considered, the dynamics of their behaviours toward the project, especially during execution stages may change with time. This may lead to unexpected legal actions as indicated in feedback loop R2 and cause further escalation to project time overrun and to reinforce risks of project time overrun to cause an increase in worksite coordination problems, error generation and back to escalate project time overrun as indicated by vicious cycles (feedback loops) R8, R7 and R6. Also, legal actions, disputes and error generation may cause delays in the system resulting in further escalation to project time overruns and then to risks of project time overrun. Likewise, risks of project time overrun, cost of legal actions and dispute resolution and quality deficiencies may escalate project cost to resort to risks of project cost overrun. Other feedback loops which reinforce risks within the system are loops R4 and R5. Both these feedback loops tend to increase the level of project quality deficiency in the project.

7.3.2.2: The Vicious Cycle of Grievance Prevention

It can be observed on Figure 7.5 that social issues and grievances covered a range of impacts a megaproject development may face in the social environment. In feedback loops B1 and B2, social complaint or issues raised by an individual or a group within communities affected by company operations can result from concerns such as traffic issues, need to relocate, pedestrian and bicycle safety, choice of travel modes, reduction in land and property values, linkage between residence and jobs, accessibility difficulties to families, friends and community resources and pollution (water, soil, air etc.). The difference between the amount of concern and or a complaint may be in a specific rate of time to resort to social grievance. The term “grievance” implies that there may be varying problems that communities and businesses along the routes of the project may want to bring to a company’s attention. Project developers should keep in mind that unanswered questions or ignored requests for information have the potential to increase threats to personnel and asset security and disputes, which will then lead to legal actions and social uncertainties if grievances are not addressed promptly and satisfactorily.

Based on the level of grievances, pressure will be mounted on both the developer and the project owner by the communities in the project area to modify the project scope, through the involvement of multi decision making bodies such as regulatory and environmental bodies (local, national and regional), and stakeholders (internal and external) to balance the inflow of social grievances into the system as indicated by the vicious cycles B1 and B2. Complexity will evolve and progress will be at stake when multi – decision making bodies exceed the expected level to convey what they think the main contractor must do to reduce the rate of inflow of grievances. It will be a good practice for developers at this stage to intensify responses to community feedback through the relevant pillars of community engagement, such as disclosure, consultation, and participation in project monitoring as construction proceeds.

7.3.2.3: Causalities for Social Risk Stock Variables

Causalities for the main risk factors within the S*o*RM namely social grievances; social risks; risks of project time overrun, risks of project cost overrun and quality deficiency are given in the causes tree diagrams in Figure 7.6.

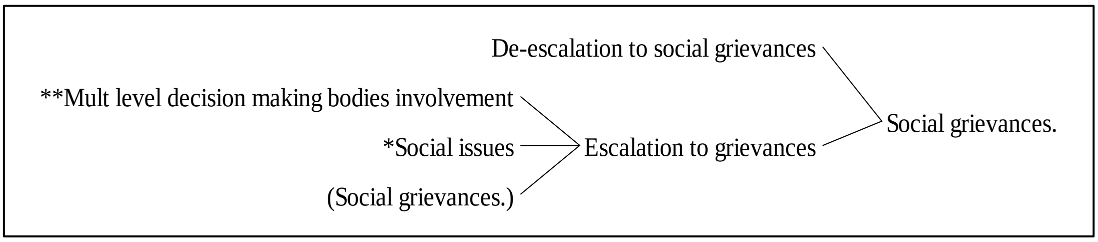


Figure 7.6a: Causes tree for social grievances

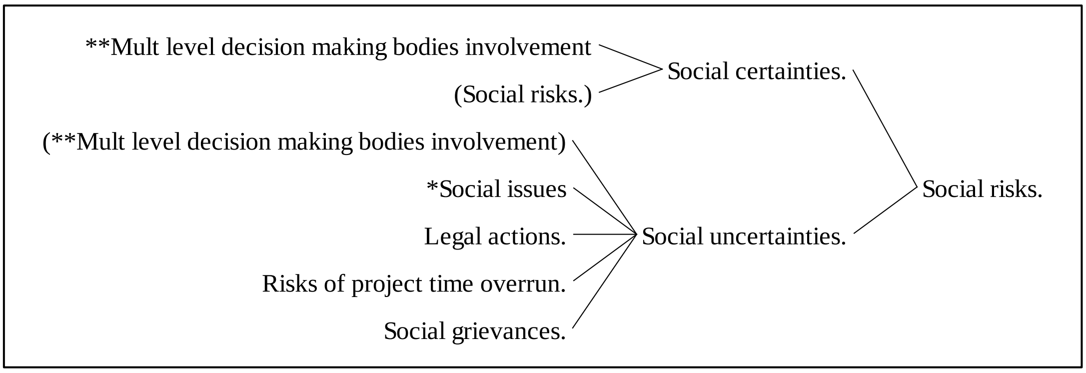


Figure 7.6b: Causes tree for social risks

Figure 7.6: Causes Tree Diagrams for Social Risks Model

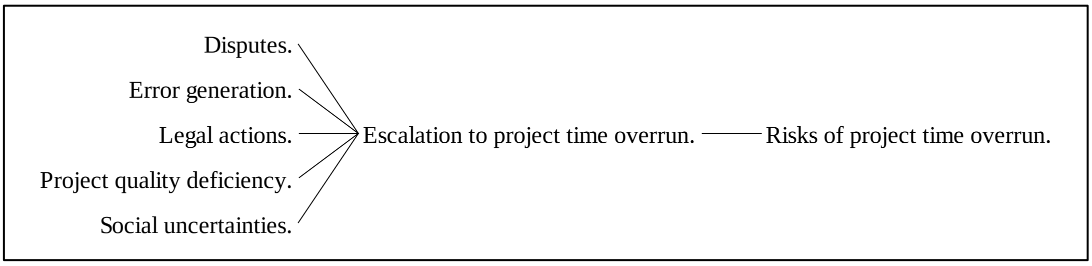


Figure 7.6c: Causes tree for risks of project time overrun

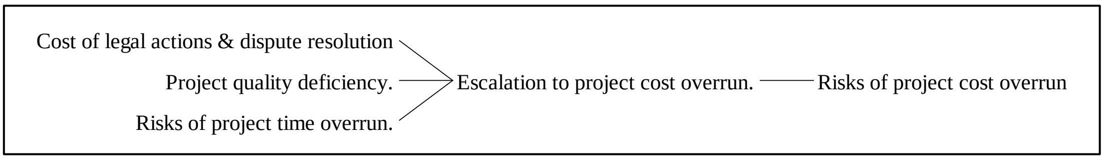


Figure 7.6d: Causes tree for risks of project cost overrun

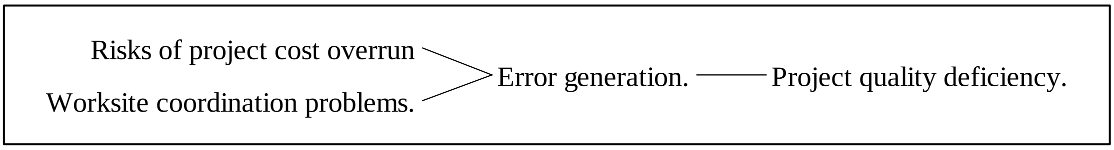


Figure 7.6e: Causes tree for project quality deficiency

Figure 7.6: Causes Tree Diagrams for Social Risks Model (Continued)

The causes’ tree diagrams 7.6a to 7.6e depict the causal relation between system variables. It can be observed that social grievances are influenced mainly by two system variables, namely escalation and de-escalation to social grievances. Similarly, social risks are influenced by two system variables viz., social uncertainties and social certainties. Additionally, risks of project time overrun and risks of project cost overrun are influenced by escalation to project time overrun and escalation to project cost overrun respectively. The last stock or level is the project quality deficiency. This is also influenced mainly by just one system variable (error generation).

On the other hand, the uses trees indicated in Figure 7.7 have the system variables in question at the head, and show all other risk variables influenced by it for the social grievances, social risks, risks of project time overrun, risks of project cost overrun and project quality deficiency entities.

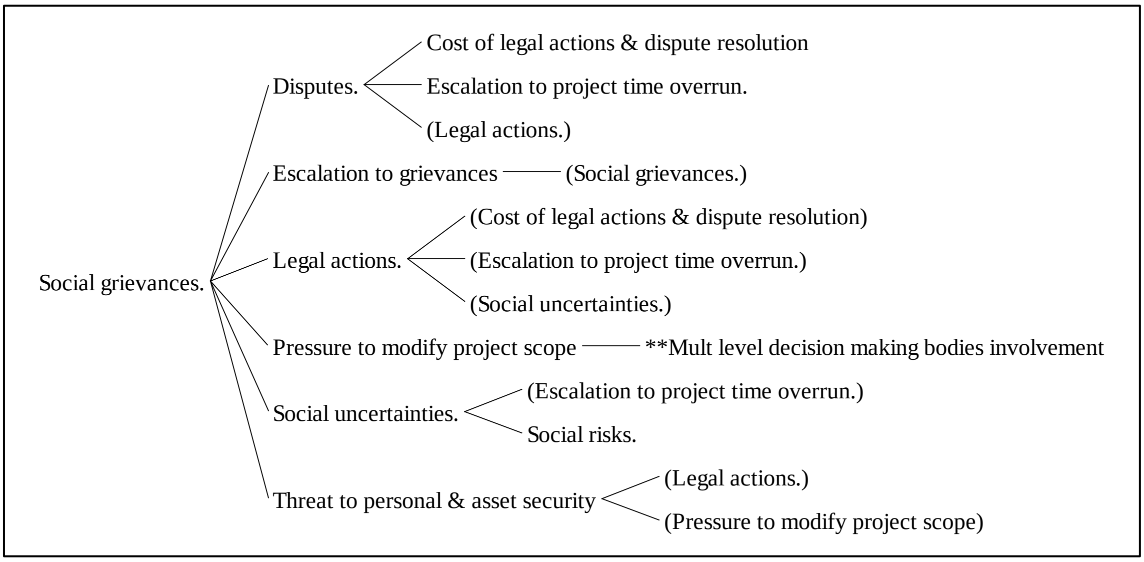


Figure 7.7a: Uses Tree Diagram for the Social Grievances Entity

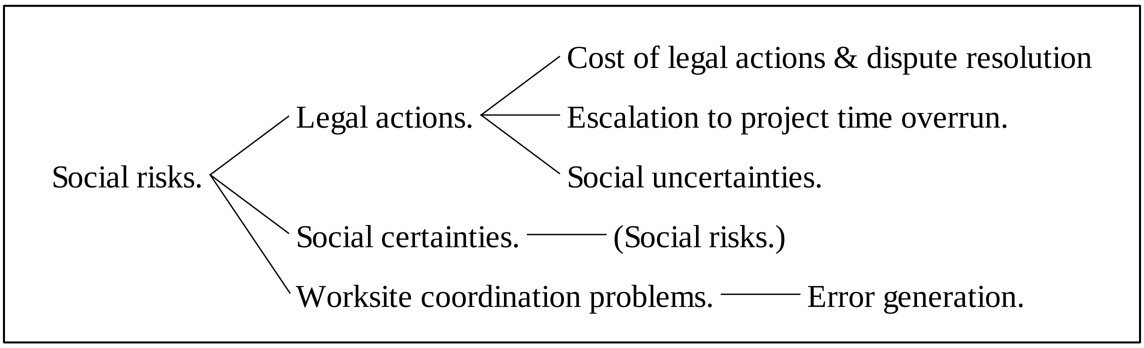


Figure 7.7b: Uses Tree Diagram for the Social Risks Entity

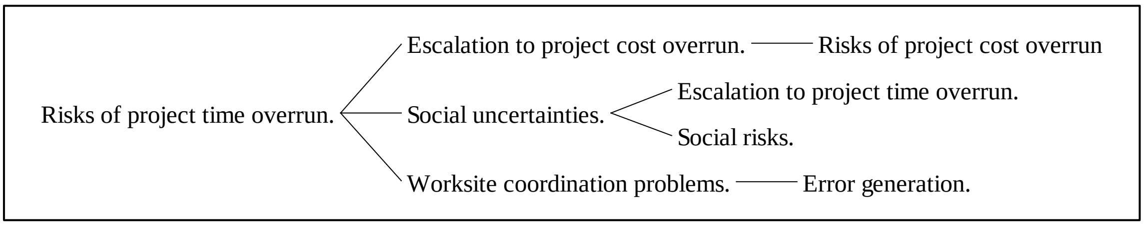


Figure 7.7c: Uses Tree Diagram for the Risks of Project Time Overrun Entity

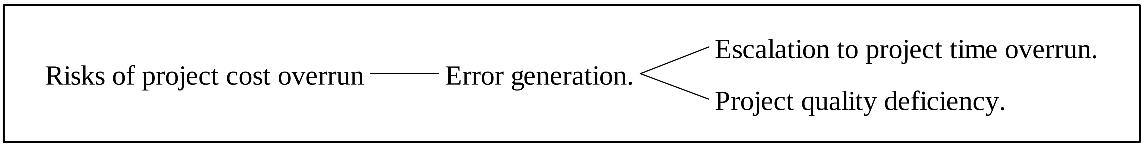


Figure 7.7d: Uses Tree Diagram for the Risks of Project Cost Overrun Entity

Figure 7.7: Uses Tree Diagrams for the Social Risks Model

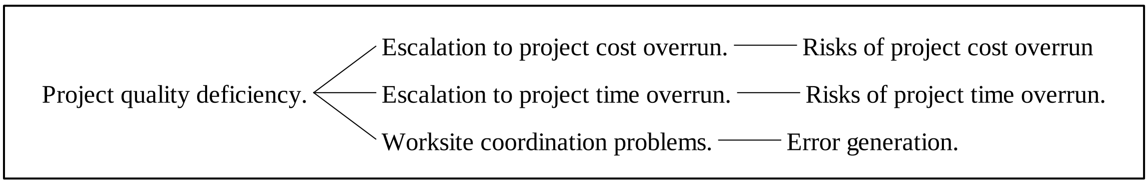


Figure 7.7e: Uses Tree Diagram for the Project Quality Deficiency Entity

Figure 7.7: Uses Tree Diagrams for the Social Risks Model (Continued)

There may be other influencing system variables which are beyond the scope of this research and further work is needed to identify some more variables to modify the social risks model developed in this research. Also, it must be noted that the level of impacts of social risks described in this model applies to the construction phase of the life cycle of transportation megaproject development and may vary depending on geographical location of the project components and the type of social environment setting in which the project is executed.

7.3.3: The Technical Risks System

The technical risks model (T*e*RM) is the second model under the MegaDS system models. The elements of T*e*RM are not easily characterized. They are often problematic in megaproject development in that they are dependent on people and environment, as well as the laws of science. Some of these are known, and some are unknown at any point in time. Because of the dependability involved, actions to comprehend and mitigate the nature of such risks are interrelated through the laws of science, patterns of rational processes, and the personalities of people involved. That is to say, technical risks are very complex and dynamic in nature during megaproject development.

One way to deal with this type of risk is to perform a purely subjective analysis by modelling their causes and effects as indicated in Figure 7.8. In this approach, the key elements, factors or variables of the entire sub system, are related through a network map, which becomes a model system in which connections between the system variables represent physical flows or knowledge flows. Typically, managing work to be done in vicious cycle (R4) must involve a project group such as consultants, contractors, specialists, the staff of the project owner and the project control team itself. A typical situation is where a unit or person in a particular division will tend to show allegiance to two higher authorities, the project manager and his “home” department or firm. This dual reporting relationship is often a problem with a “matrix” project organisation structure and accounts for most of the project scope increases and further complexity problems that project managers face during megaproject development. This implies that the higher the complexity of a project, the higher its technical uncertainties will be. Apparently, the inherent complexity uncertainty and technical risk of the project may increase if the size of the total project and cost estimate relative to the average cost of the organization’s projects is large.

On the other hand, unforeseen modifications to the project in the construction phase such as engineering design and specification changes can trigger an increase in the project uncertainties. For instance, changes in a civil engineering design specification of a highway project and a tunnel design that includes many geotechnical, structural, environmental, and safety elements (Ruuska et al., 2009) as the construction proceeds can pose additional technical challenges in the system. Also, inadequate site investigations and supply chain breakdown can further be added factors to project complexity. All of these will increase the rate at which technical risks will impact on the project and verse versa. Technically, the higher the level of risks impact in the system, the more errors will be generated to create reworks. This implies that the process of correcting errors can further increase the volume of work that needs to be done in order to fix the original problem, or can increase the work volume required because fixing the errors can take more effort than doing the original work. These phenomena will however create a reinforcing feedback loop to increase the level of technical risks in the vicious cycle (feedback loop) R3.

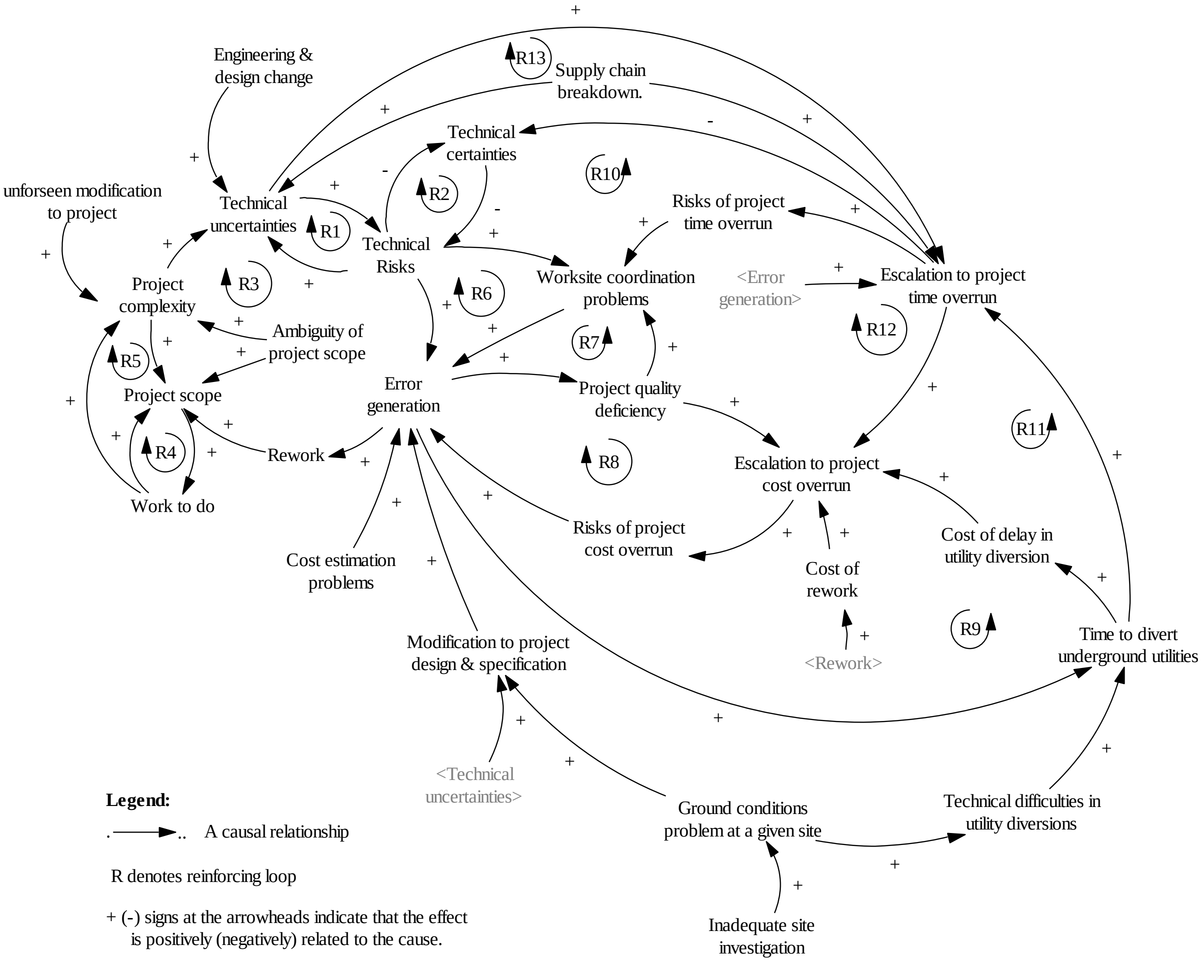


Figure 7.8: Causal Loop Diagram for Technical Risks System

7.3.3.1: Causalities for Technical Risk Stock Variables

Causalities for the main risk factors within the T*e*RM namely work to do; technical risks; risks of project time overrun, risks of project cost overrun and quality deficiency are given in causes tree diagrams in Figures 7.9.

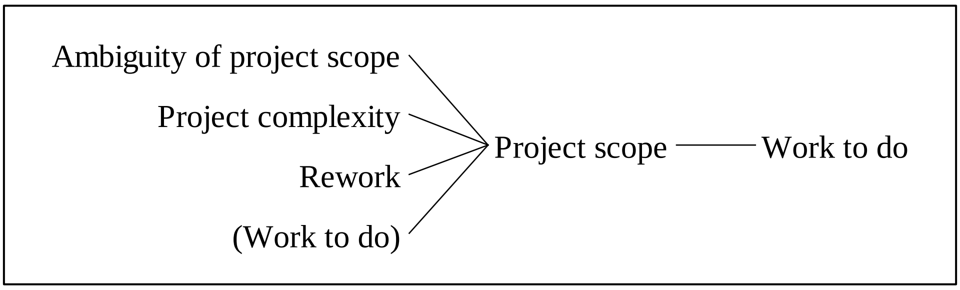


Figure 7.9a: Causes Tree for Work to do Entity

Figure 7.9: Causes Tree Diagrams for Technical Risks Model

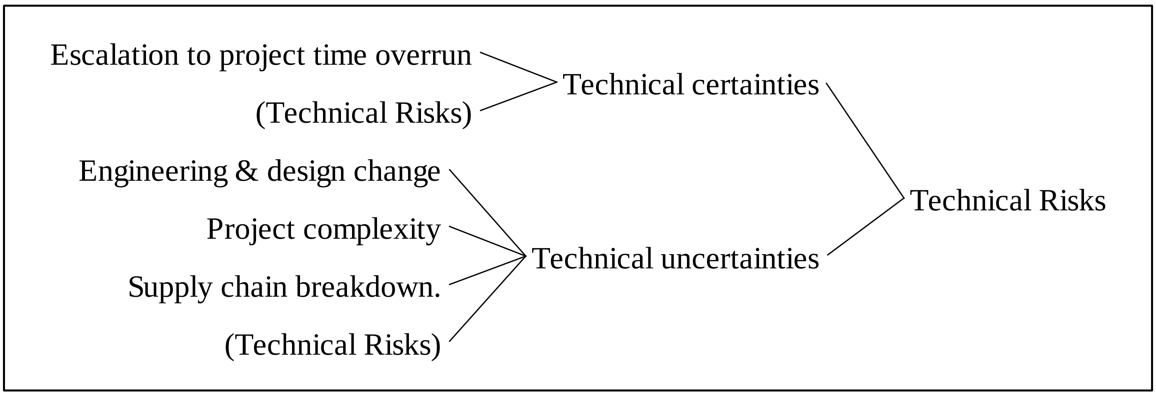


Figure 7.9b: Causes Tree for Technical Risks Entity

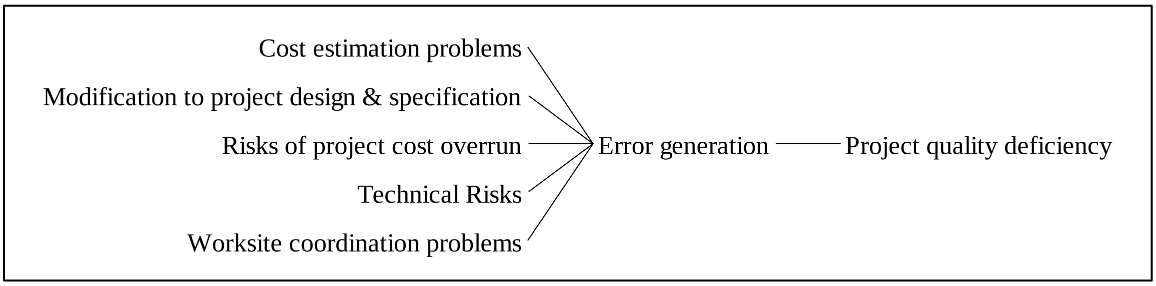


Figure 7.9c: Causes Tree for Risks of Project Quality Deficiency Entity

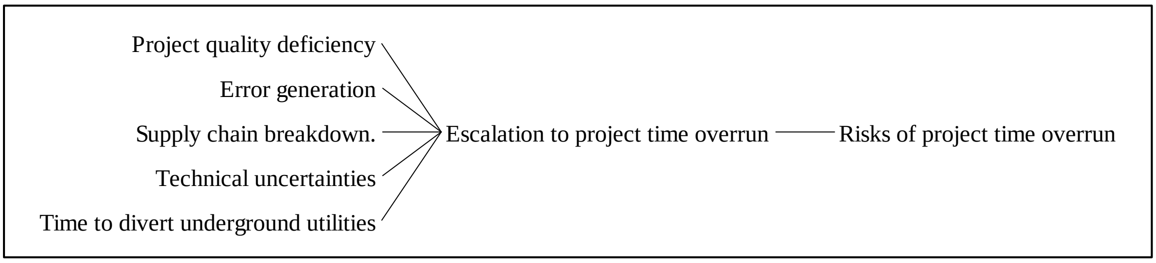


Figure 7.9d: Causes Tree for Risks of Project Time Overrun Entity

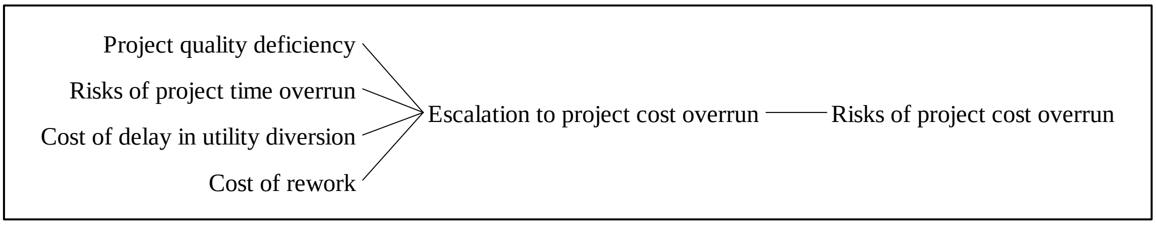


Figure 7.9e: Causes Tree for Risks of Project Cost Overrun Entity

Figure 7.9: Causes Tree Diagrams for Technical Risks Model (Continued).

It can be observed that work to be done and risks of project cost overrun are each influenced mainly by project scope and inflow of project cost overrun in the causes trees indicated in Figure 7.9a and Figure 7.9e respectively. Additionally, technical risks and project quality deficiency are each being influenced by two risk factors viz., technical certainties and technical uncertainties, and risk of project cost overrun and error generation respectively.

Similarly, the uses trees indicated in Figure 7.10 have the system variable in question at the head, and show all other risk variables influenced by it for the same variables considered for the causes trees diagrams in Figures 7.9.

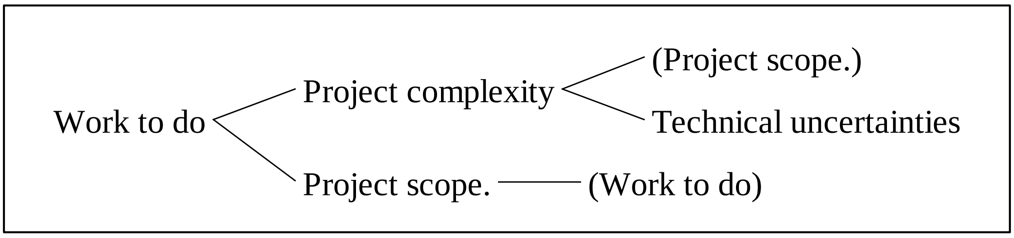


Figure 7.10a: Uses Tree Diagram for Work to do Entity

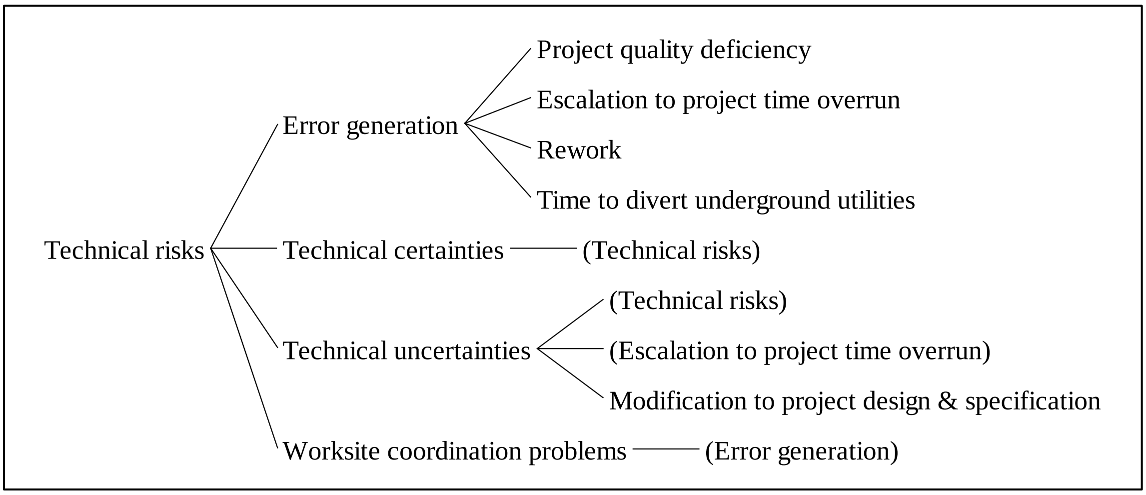


Figure 7.10b: Uses Tree Diagram for Technical Risks Entity

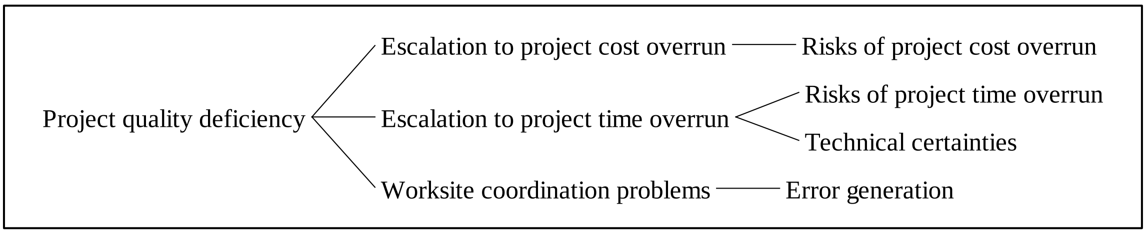


Figure 7.10c: Uses Tree Diagram for Project Quality Deficiency Entity

Figure 7.10: Uses Tree Diagrams for Technical Risks Model

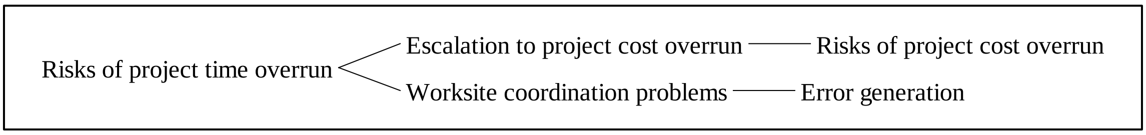


Figure 7.10d: Uses Tree Diagram for Risks of Project Time Overrun Entity

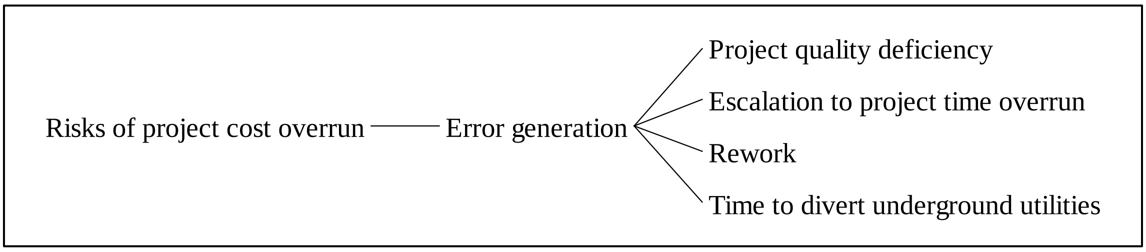


Figure 7.10e: Uses Tree Diagram for Risk of Project Cost Overrun Entity

Figure 7.10: Uses Tree Diagrams for Technical Risks Model (Continued).

It must be noted that, the level of impacts of technical risks on the system described in this model is in the construction phase of the life cycle of the case study megaproject (ETNP) during development. Risk variables used for developing this model may vary depending on the geographical location of the project components and the type of technical environment in which the project is executed.

7.3.4: The Economic Risks System

In this section of the report, the economic risks model (E*c*RM) sets out to describe the interactions of system variables within the economic risk model to generate risks of project time and cost overruns and project quality deficiency at the construction phase of transportation megaproject development. The key issue considered within the E*c*RM is what is the magnitude of the economic risks impacts on transportation megaproject construction activity during construction?

Often times, transportation megaproject construction activities can act as a reliable bellwether for economic performance yet they are complex developments that can be affected by a number of different economic factors. Unexpected changes in interest rates, exchange rates, material prices, energy prices and changes in inflation and recession may have considerable impacts on the budget costs of such megaprojects during construction. For example, rising interest rates can affect the debt service cost component of a megaproject development. Also, shortages of materials, fuel (energy) and skilled labour which often characterize periods of rapid economic growth are likely to have consequential economic impacts on project time, cost and quality.

Although process and project contingencies may have been included in estimates to account for unknown costs that are omitted or unforeseen due to a lack of complete project definition and engineering, contingencies are added because experience has shown that such costs are likely, and expected, to be incurred even though they cannot be explicitly determined at the time the estimate is prepared. However, in many instances capital cost contingencies do not cover the uncertainties or risks associated with scope changes, changes in labour availability or productivity, delays in equipment deliveries, changes in regulatory requirements, unexpected cost escalation and plant performance (e.g availability, efficiency) after start up. Beyond the economic factors, there are events that are impossible to predict but can also have a major bearing on both the level of construction activity and the cost entailed in delivering schemes.

Additionally, the deregulation of financial institutions and risks linked with the economic indicators of a country will further generate unanticipated problems related to the financing of megaprojects under construction. For instance, rising fuel (energy) costs will basically affect the price of almost everything from lunches to construction materials. Thus, increased energy prices induce wage inflation and building material prices increase to give high impact on the construction industry (See Figure 7.11), which is one of the country’s engines of growth, and consequently, it may experience slowdown for the rest of the year. For example, a hike in energy prices will affect all levels of the value chain from building materials such as steel bars, sand, cement, concrete and roofing materials to logistics. Prices of many construction related materials, machinery and transportation costs will also be increased substantially. Thus, price increases of fuel needed to operate trucks and heavy machinery which rely on large amounts of diesel required to transport steel bars, cement, sand and stones from ports/plants to construction sites reinforce the economic uncertainty to the megaproject development and affect construction time and cost.

House prices, food and transport may also increase and affect employees’ wages and hinder sections of work packages under the developer’s plan reaching specific targets. Some of the highly skilled employees such as engineers, schedulers, assistant project managers and even subcontractors and suppliers will tend to reject certain offers for their respective jobs because of lack of profit to be made due to local inflation, high cost of living and high prices of building materials. This will cause further delay in the megaproject developer’s programs and even the country’s other infrastructure projects. Whereby, the construction of affordable housing, including low and medium cost units, may no longer be feasible.

Furthermore, increases in the prices of building materials severely impact both developers and contractors. Contractors would definitely want to re-negotiate contract prices. They are likely to ask for variation orders (VOs) to cover the rise in raw material prices. If contractors are unable to obtain VOs, especially those sub-contractors with low financial strength to absorb higher raw material prices, the possibility of projects being abandoned will be high. Even large contractors would be making losses from projects. Contractors cannot proceed with such projects and would have to return their tenders.

Although there is no certainty regarding what might happen in the months ahead, the difficulties that a transportation megaproject developer or contractor faces from economic risks will inevitably impact the construction phase of projects. However, the continuous increase in energy and construction material prices, taxation and government funding policy change and wage inflation is proving to be an ordeal and it is hoped that the construction industry will be able to overcome these challenges. The key to success lies in having a positive and dynamic system mind-set to enhance both efficiency and productivity in the whole construction value chain.

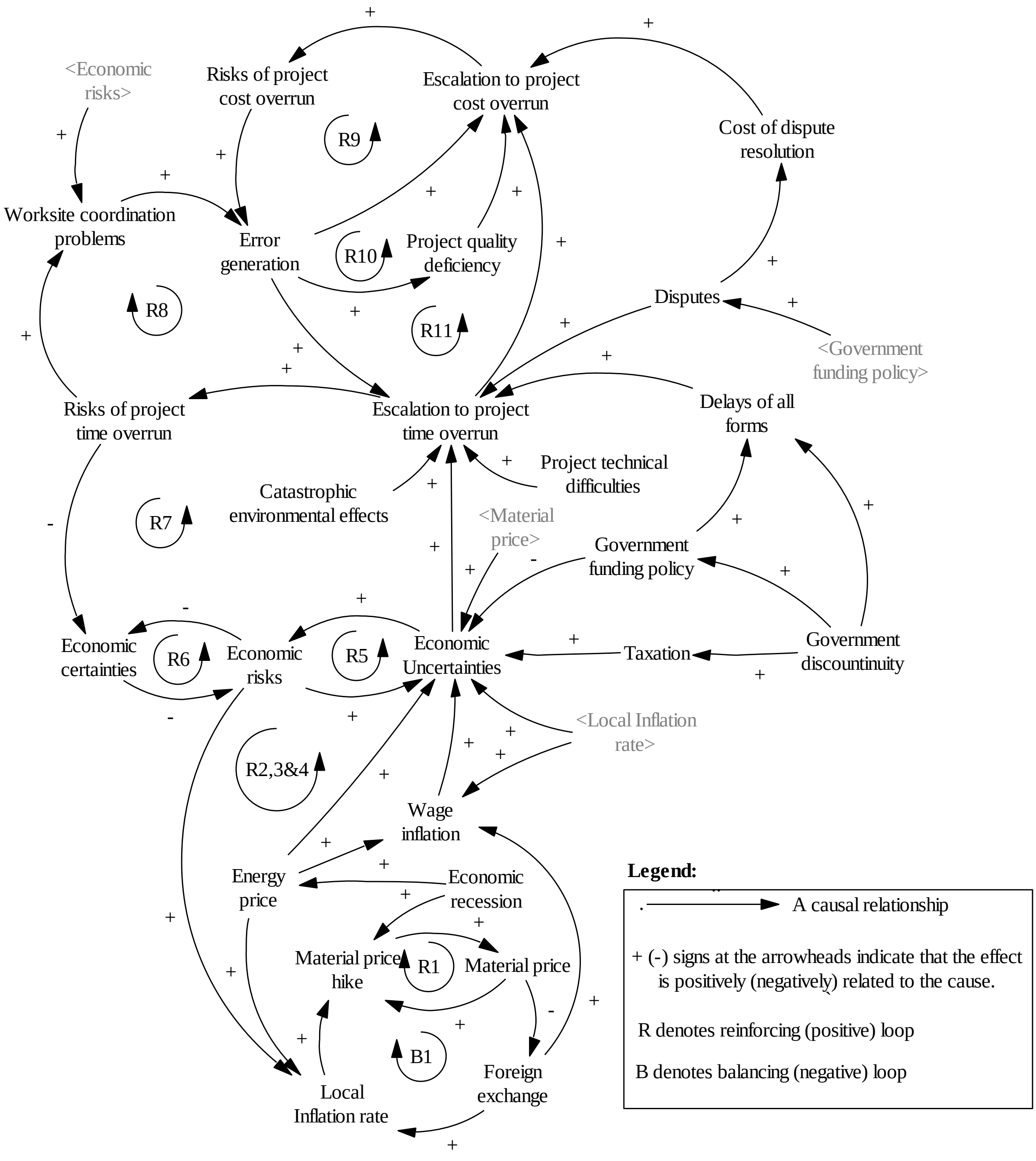


Figure 7.11: Causal Loop Diagram for Economic Risks System

7.3.4.1: Causalities for the Economic Risks Stock Variables

Causalities for system variables within the economic sub model follow the same principle as those described for social and technical sub model. Therefore, the causes and uses trees for the economic risks model indicated in Figure 7.12 and 7.13 have the risk variables in question at the head, and show all other risk variables influenced by it for the same risk variables considered for the causes and uses tree diagrams in Figures 7.9 and 7.10.

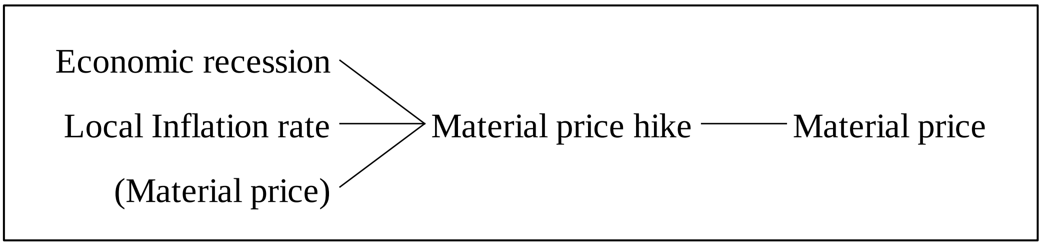


Figure 7.12a: Causes Tree Diagram for Material Price Entity

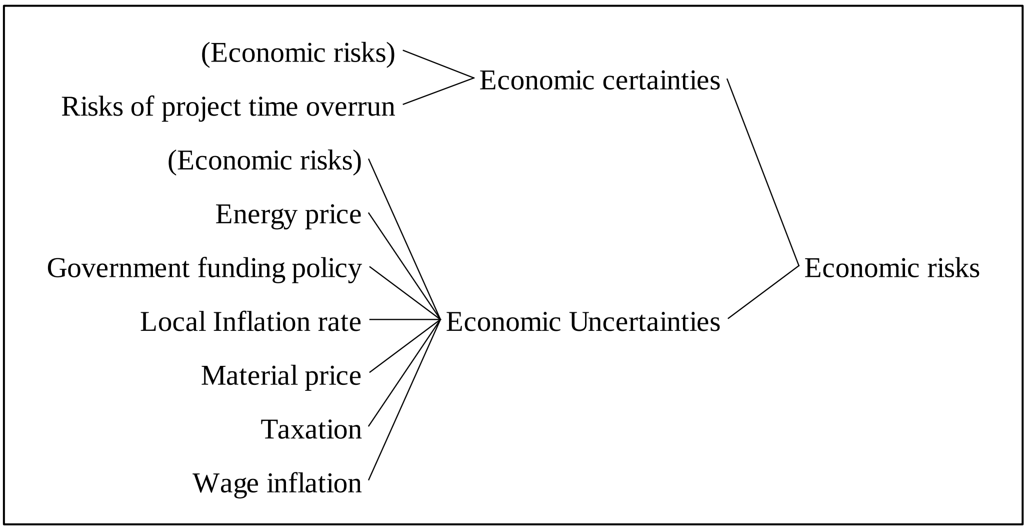


Figure 7.12b: Causes Tree Diagram for Economic Risks Entity

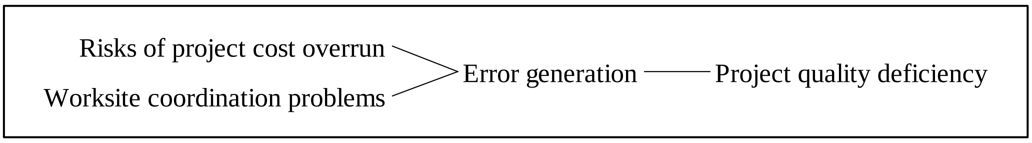


Figure 7.12c: Causes Tree Diagram for Project Quality Deficiency Entity

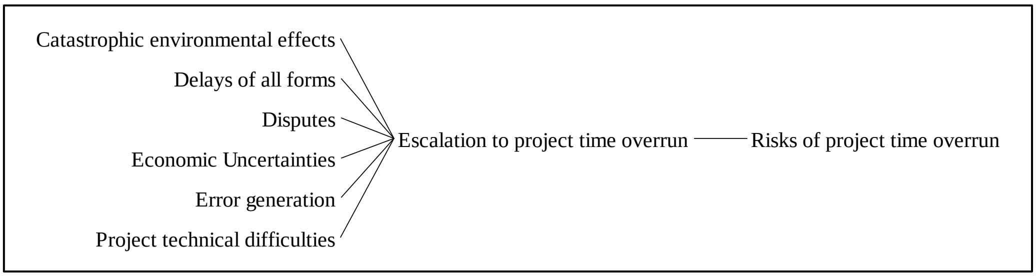


Figure 7.12d: Causes Tree Diagram for Risks of Project Time Overrun Entity

Figure 7.12: Causes Tree Diagrams for Economic Risks Model

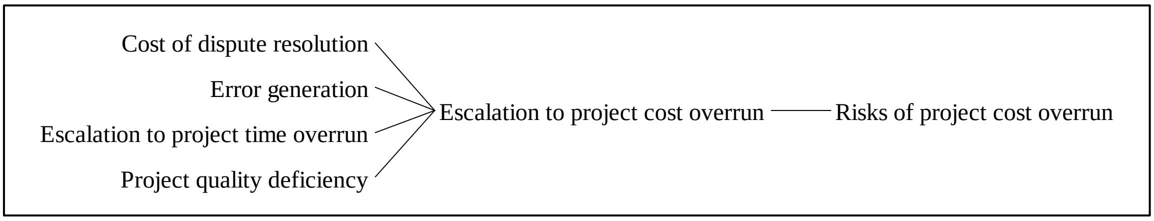


Figure 7.12e: Causes Tree Diagram for Risks of Project Cost Overrun Entity

Figure 7.12: Causes Tree Diagrams for Economic Risks Model (Continued)

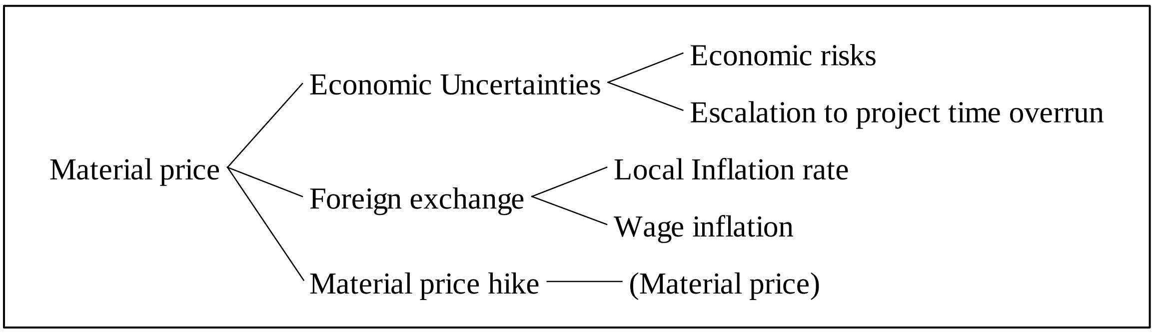


Figure 7.13a: Uses Tree Diagram for Material Price Entity

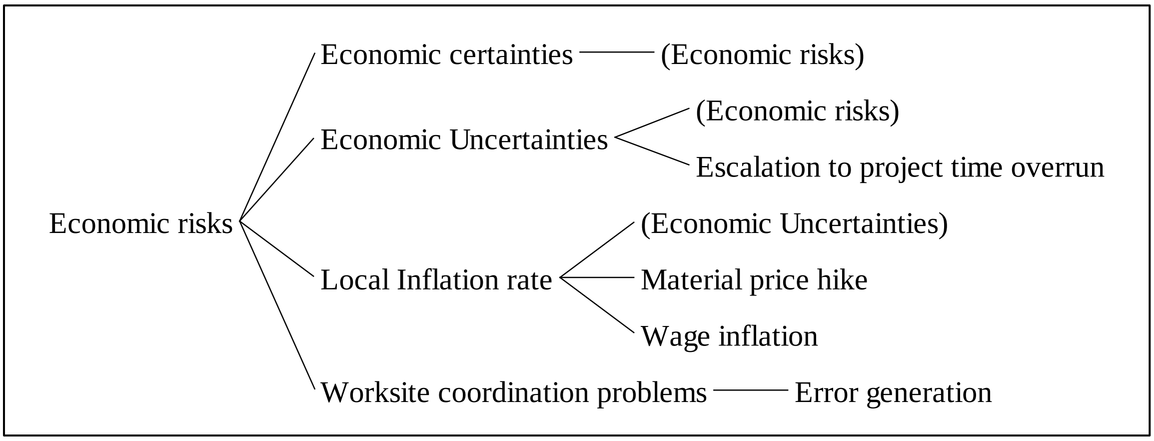


Figure 7.13b: Uses Tree Diagram for Economic Risks Entity

Figure 7.13c: Uses Tree Diagram for Project Quality Deficiency Entity

Figure 7.13: Uses Tree Diagrams for Economic Risks Model

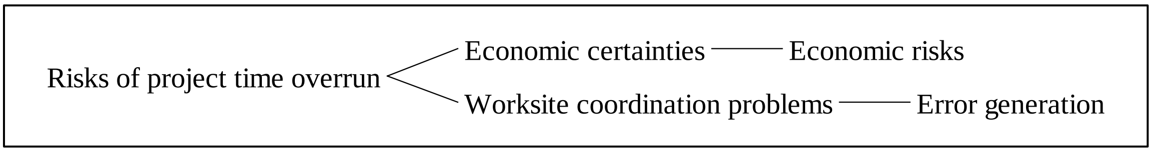


Figure 7.13d: Uses Tree Diagram for Risks of Project Time Overrun Entity

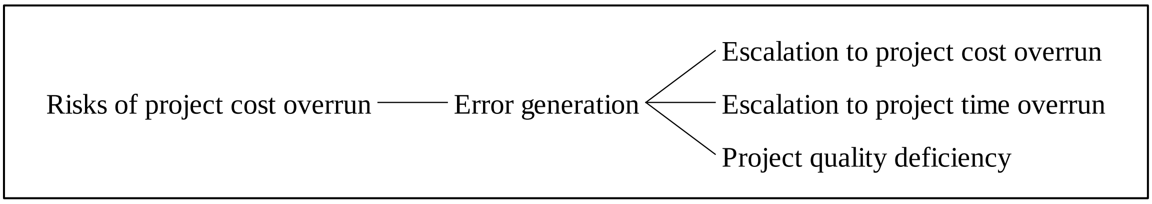


Figure 7.13e: Uses Tree Diagram for Risks of Project Cost Overrun Entity

Figure 7.13: Uses Tree Diagrams for Economic Risks Model (Continued)

Again, it must be noted that, the impact of the economic risks described in this model is in the construction phase of the life cycle of ETNP during development. System variables used for developing this model may vary depending on geographical location of the project components and the type of economic environment in which the project is executed.

7.3.5: The Environmental Risks System

The fourth system within the Megaproject dynamics simulation (MegaDS) model systems is the environmental risks model (E*n*RM). It specifically defines the interrelations between different environmental variables which lead to project quality deficiency, time and cost overruns in the system. The boundary within which the model is constructed together with the dynamic hypothesis for this sub system is indicated in Table 7.5 and Figure 7.14 respectively. A description of the system vicious cycles (feedback loops) is required to show a complete picture of interactions of risk variables affecting project performances in this sub model.

As represented in Figure 7.14, the vicious cycles suggest that the level of impact of environmental issues from work (pollution of soil, water, air, noise and traffic from construction activities) and unfavourable climatic conditions will negatively influence the financial performance of businesses, residents along the project development routes and the contractors involved in the project. As the vicious cycle (feedback loop) R1 indicates, the causal relations between the environmental issues and the environmental uncertainties will generate environmental risks and various public concerns or issues that could sometimes result to social grievances, disputes and legal actions or even work stoppages and could successively cause time and cost overruns and quality deficiencies in the system.

Conversely, companies perceived to have low impacts of environmental risks from works may be assumed to have a lower probability of being fined, sued, or publicly criticized. In contrast, if the public perceives that a firm is overly exposed to such risks, the firm may face greater scrutiny from regulatory agencies and be a more attractive target for lawsuits and take-over. Additionally, unfavourable climatic conditions (heavy rain, cold, snow etc.) can severely impact construction activities leading to significant deviations from project time schedule. Although project planners may estimate the potential impacts of such conditions, the severities of such conditions beyond estimated values will consequently result to late delivery of the project. In this regard, the combined effects of both phenomena (environmental issues from works and the unfavourable climatic conditions) will cause worksite coordination problems which will then cause non-achievement of project quality as results of overdue time on project delivery and error generations in the system leading to risks of project time and cost overruns.

Since time and cost are typically used as key criteria for examining project performance in the construction industry (e.g., Love et al., 2002; Nguyen and Ogunlana 2005; Ng et al., 2001), any problem relating to them will reflect poor performance, which is quite relevant to the political, legal, technical, and managerial reasons that commonly arise from failed megaprojects (Seung et al., 2009).

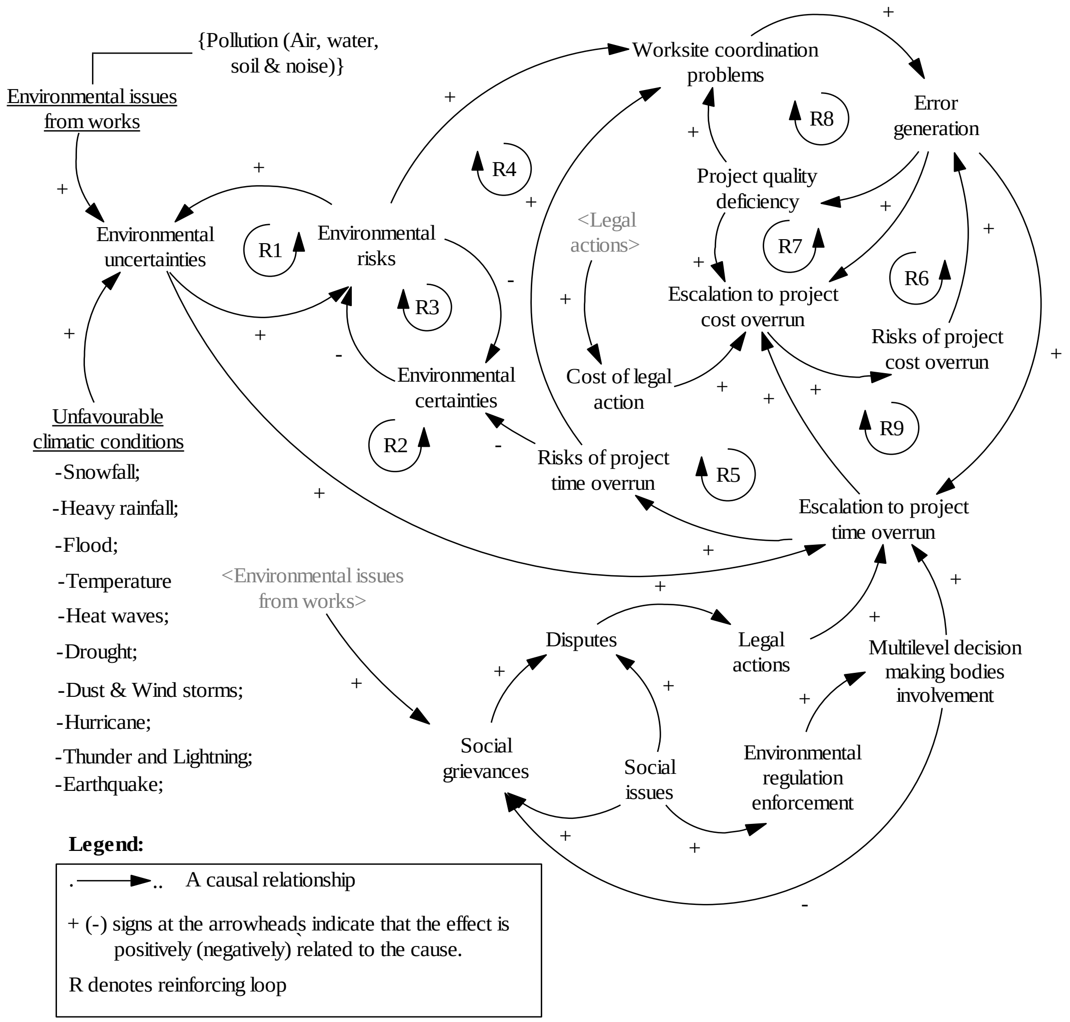


Figure 7.14: Causal Loop Diagram for Environmental Risks System

Example of transportation megaprojects that encountered similar environmental related time and cost overruns are the InterCity Express (ICE) in Germany, the French Train a Grande Vitesse' (TGV) in France, and Edinburgh Tram Network project (ETNP) in the United Kingdom. These projects were delayed in the construction phase and were involved in many significant controversies throughout their development. For example, the original plan of the German InterCity Express (ICE) project designed to pass through a bird protection area was forced by the German government to be redirected to minimize the impacts from environmental disturbances. This was as a result of vigorous public resistance to both new and old lines upgrades which resulted in much delays and overruns (Sands, 1992). Inevitably, increasing needs for environmental protection compelled the owner to revise the initial design to install a six metre high and six kilometres long protection wall along the railway route. Consequently, the project duration was extended by a year mainly due to this change.

In the case of the TGV project in France, monuments and archaeological sites on the proposed high speed line and serious environmental protests against it caused delays in its planning phases. Apparently, the French Minister of Transport was compelled to delay the final announcement of the final routes for almost a year in the 1990s (New Scientist Newspaper article, 1990) to decide the location of the main line through more than 2000 meetings. Although the plan of the TGV was successfully adjusted, actual construction started in September 1995, three years after the public announcement of the plan was made in October 1992.

In the case of ETNP, working in a World Heritage Site was always a challenge. The complexities of dealing with issues such as severe weather conditions and the rerouting of underground pipes caused major time and physical cost overruns to the project. A visit to ETNP sites during the early 2011 and mid-2013, revealed tracks repair works on Princes Street and Haymarket respectively. The repairs were believed to have been probably caused by the weight of traffic and possibly, the extreme weather conditions suffered in 2009 and 2010. This emphasised the fact that significant risks of project time and cost overruns and quality deficiency in transportation projects in Europe cases are largely related to environmental problems.

7.3.5.1: Causalities for Environmental Risks Stock Variables

Causalities for environmental risks stock variables also follow the same principle as those described for the previous three sub-models. The causes and uses trees for this sub-model are indicated in Figure 7.15 and 7.16 and have the stock variable in question at the head to show how all other system variables within the model are influenced by it.

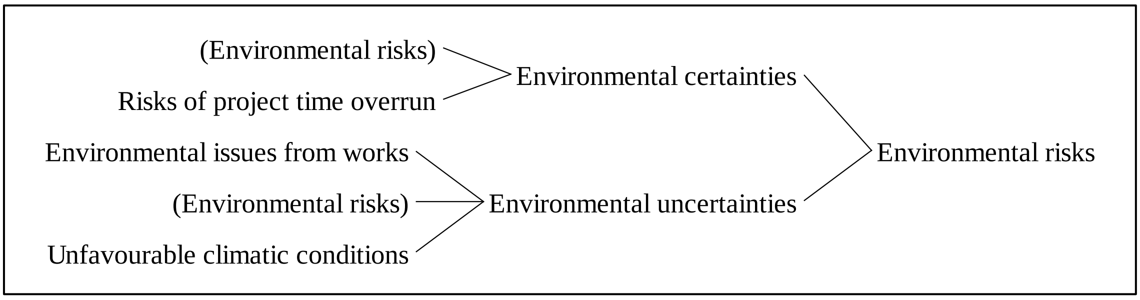


Figure 7.15a: Causes Tree Diagram for Environmental Risks Entity

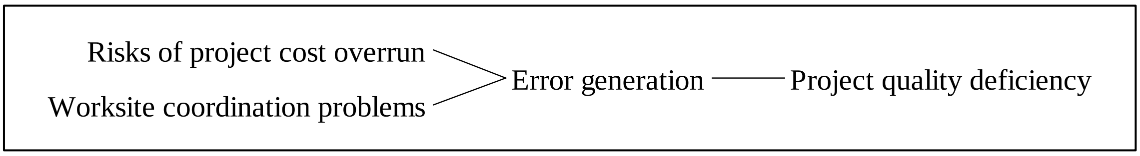


Figure 7.15b: Causes Tree Diagram for Project Quality Entity

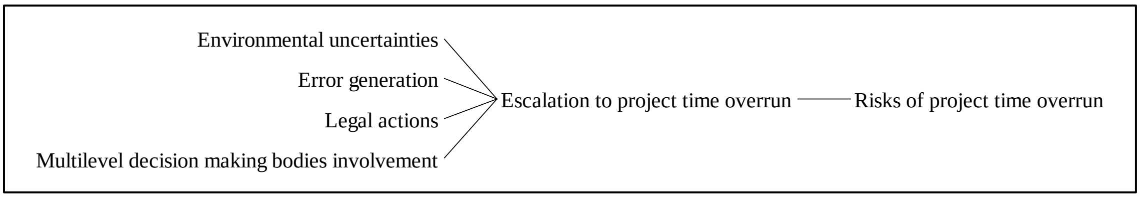


Figure 7.15c: Causes Tree Diagram for Risks of Project Time Overrun Entity

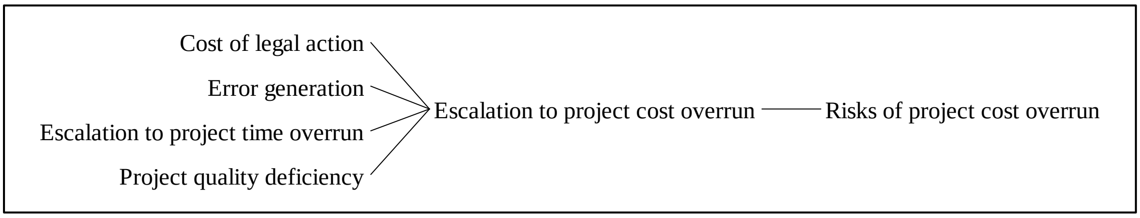


Figure 7.15d: Causes Tree Diagram for Risks of Project Cost Overrun Entity

Figure 7.15: Causes Tree Diagrams for Environmental Risks Model

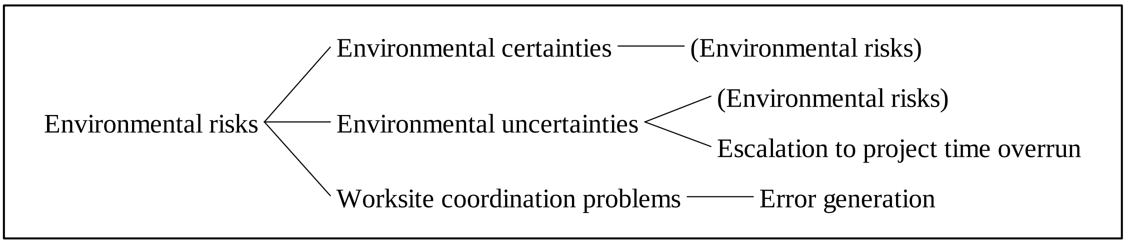


Figure 7.16a: Uses Tree Diagram for Environmental Risks Entity

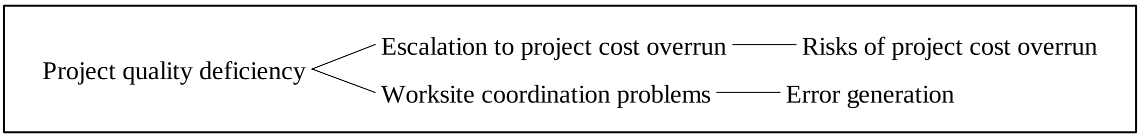


Figure 7.16b: Uses Tree Diagram for Project Quality Deficiency Entity

Figure 7.16: Uses Tree Diagrams for Environmental Risks Model

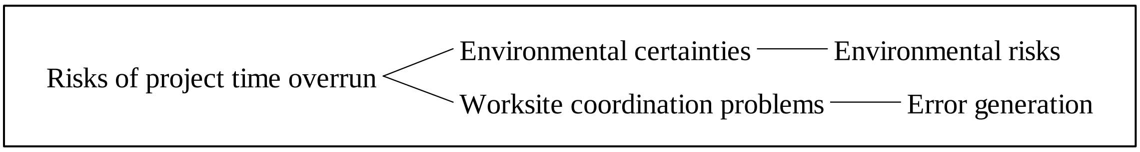


Figure 7.16c: Uses Tree Diagram for Risks of Project Time Overrun Entity

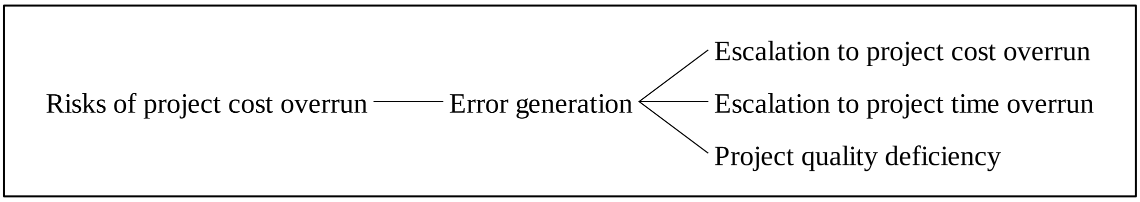


Figure 7.16d: Uses Tree Diagram for Risks of Project Cost Overrun Entity

Figure 7.16: Uses Tree Diagrams for Environmental Risks Model (Continued)

Again, it must be noted that the level of impacts of environmental risks described in this model is in the construction phase of the life cycle of ETNP during development. System variables used for developing this model may vary depending on geographical location of the project components and the type of natural and ecological environments in which the project is executed.

7.3.6: The Political Risks System

The political risks model (P*o*RM) is the last model within the MegaDS systems. It can be defined as a potential harm to a business operation arising from political behaviour (McKellar, 2010 pp. 3). It involves the possibility that political authorities in the host political jurisdiction might interfere with the timely development of a project or business (Finnerty, 2007 pp.82). The relevance of the political risks model in this research is to understand the interactions of its variables within an environment which serve as a common language for businesses and political actors to impact project performances negatively.

According to McKellar (2010), managers and investors across all business sectors share a very specific language and mind-set oriented around market share, growth, margin, and return on investment objectives, while political actors are concerned with the social organisation and its underlying ideals. The common language of political actors consists of authority, ideology, political culture and identity, the social goods and the levers of power to influence these. This distinction alone makes political risk a unique challenge to megaprojects developers who need to understand the basics of a very different language and mind-set in order to address it.

In addition, businesses occur in a framework set by political authority and social consensus and, as a result, there is nowhere in the political realm that businesses are unaffected by the laws of a state. Generally, there is consensus across the global political spectrum that infrastructure is critical to economic development, job creation, national security and competitiveness, but a lack of harmony in the political process and between contractors may limit the ability of project owners (nations) to accomplish their infrastructure dreams in time. This implies that each source of political risk in a system can exacerbate the others and they work together to generate a range of political risks which cannot necessarily be attributed to a single source. For example, in feedback loops R1 and R2 of Figure 7.17, political support for the project reinforces when political harmony and social acceptability intensify which reinforces the need to increase government funding policy for the project.

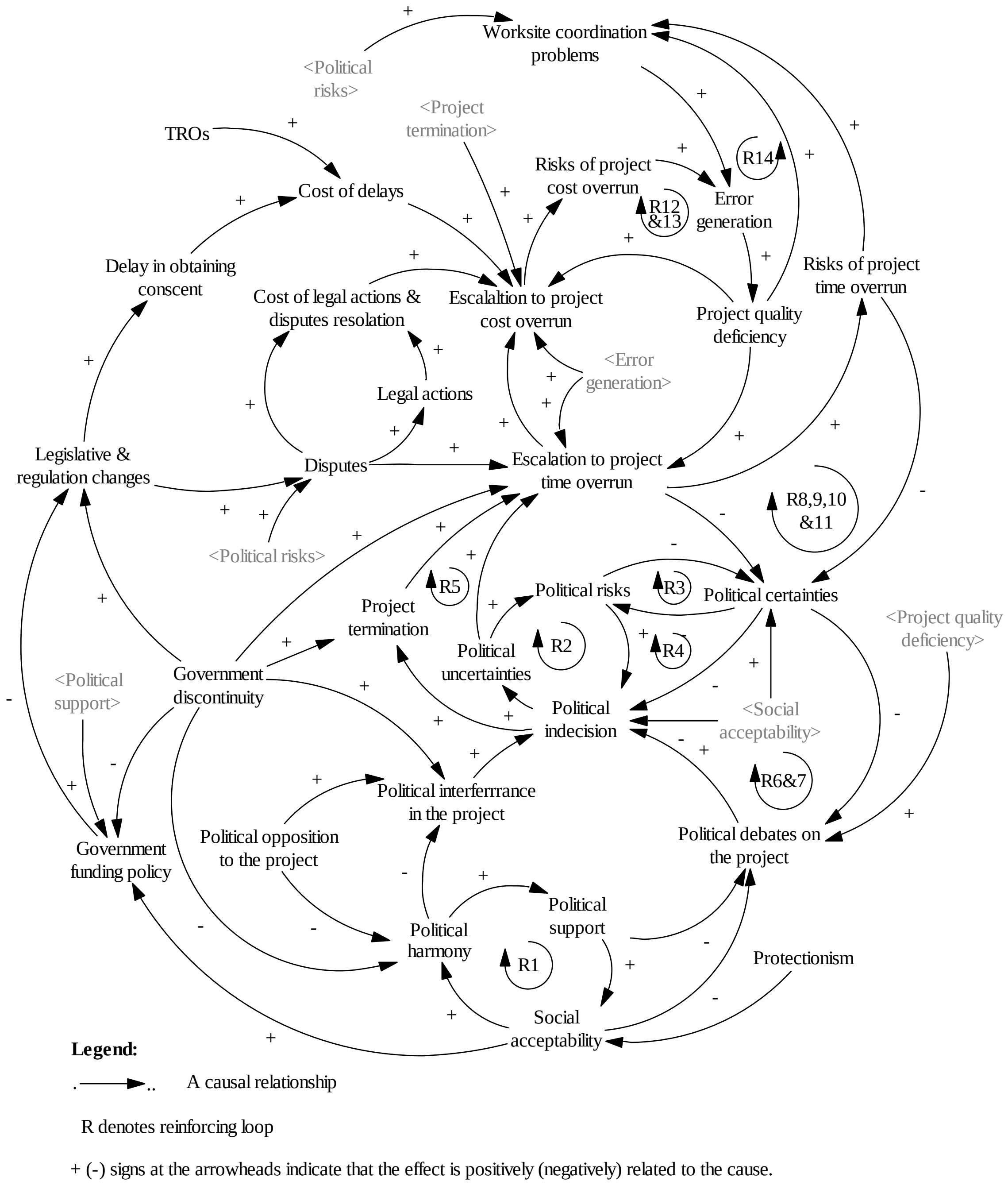
By contrast, political opposition to the project and government discontinuity impede political harmony. Government discontinuity is a critical political risk which often impacts significantly on megaproject schedules. Political appointees overseeing state funded projects tend to have shorter time horizons than the estimated project completion time and as such, are usually replaced when the initiating government is changed through national elections. Such a change may tighten legislation; contribute to project time overruns, cost overruns, and project quality deficiency as indicated in feedback loops R8 to R13. Such change will further bring about project termination or reduction in government funding the project even if the project is regarded as desirable or necessary to the new regime.

The project's social acceptability depends mainly on the development of a sound agreement with actors (landlords and businesses owners) within the project area. Most of the residents in the communities where the transportation megaproject is to pass may have known the practical implications of the construction activities on them and their businesses in the early planning and consultation stages and the important benefits the project may bring to them. However, others will still be concerned with the impact that such large projects may cause on their environment and the economy of the area. Therefore, different positions may be formed in the public opinion in the areas when actual construction is about to start with a number of people supporting, others encouraging in a conditional way, and still others opposing implementation of the project in their territory.

In each area, the different positions may be dependent on several local factors, including socio-economic conditions, cultural background, and individual or group interests. Most frequently, individual and collective attitudes towards project development usually change with time as the project reaches the construction stage, when heavy equipment and plant are involved. Indeed, undesirable effects may result from these activities on: i) ecosystem (air, land, flora, fauna, and superficial and underground water); ii) human health (from water pollution, noise, and gas emission); and iii) economy (detrimental impact on some business activities and tourism, and damage to crops and private properties). Moreover, iv) reaction often grows against landscape modifications and alteration of natural features of cultural or religious interest, caused by civil and industrial works, and by changes in the use of public areas resulting from project activities.

Depending on the nature of the effects from the project activities and on the type of measures adopted by the main contracting firm to prevent their occurrence, such effects may either increase or reduce political risks on the project. In general, political harmony, support and social acceptability for the project will be high when the adverse effects are minimal. As such, opposition by residents and political opponents in the project area, political interferences and debates on the project will often be reduced as construction proceeds.

Conversely, no transportation megaproject development initiative exists without a slight possibility of impact on the natural environment (ecosystem) and people of the area concerned even when initiatives of wide interest are involved. In a modern society, political interferences and indecision evolve when a debate begins among politicians, public administrators, economic lobbies, "green" groups, and indigenous communities, on whether or not, and in the affirmative on how, such a project should be carried out. That is to say, realization of any transportation megaproject depends, in many instances, on its socio-political acceptance in the project area.



Legend:

.——►.. A causal relationship

R denotes reinforcing loop

+ (-) signs at the arrowheads indicate that the effect is positively (negatively) related to the cause.

Figure 7.17: Causal Loop Diagram for Political Risks System

Therefore, political support and social acceptability are important requisites for the smooth execution of megaprojects, especially those for transportation megaprojects. As earlier mentioned, the three main conditions to reduce political risks and win project acceptance by politicians and communities residing in the project area are minimization of environmental impact; avoidance of adverse effects on people's health; and the creation of direct benefits for local populations. To meet these conditions, the project developer must be prepared to bear specific burdens in the form of external costs, whose amounts will be dependent on the site, type, and size of the project activity. This will in turn allow for the project to proceed in the fastest way possible, reduce disputes, legal actions, quality deficiency, risks of time and cost overruns and result eventually in considerable external benefits for the megaproject developer, consisting mainly of saving of labour, reduction of passive interests on bank loans, and shortening of pay-back time.

7.3.6.1: Causalities for Political Risks Stock Variables

Causalities for the main risk variables within the PoRM namely political support; political risks; risks of project time overrun, risks of project cost overrun and quality deficiency are given in the causes and uses tree diagrams in Figure 7.18 and 7.19.

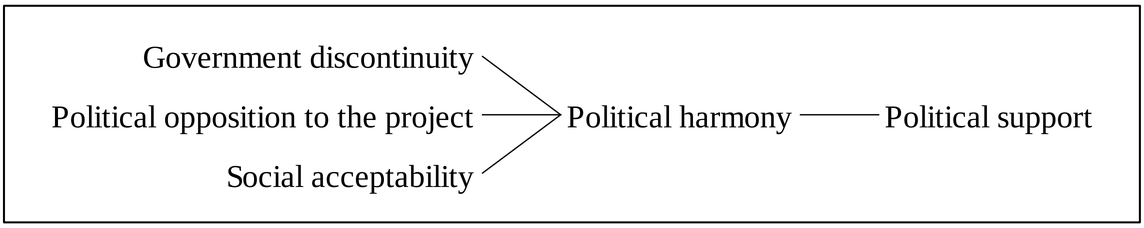


Figure 7.18a: Causes Tree Diagram for Political Support Entity

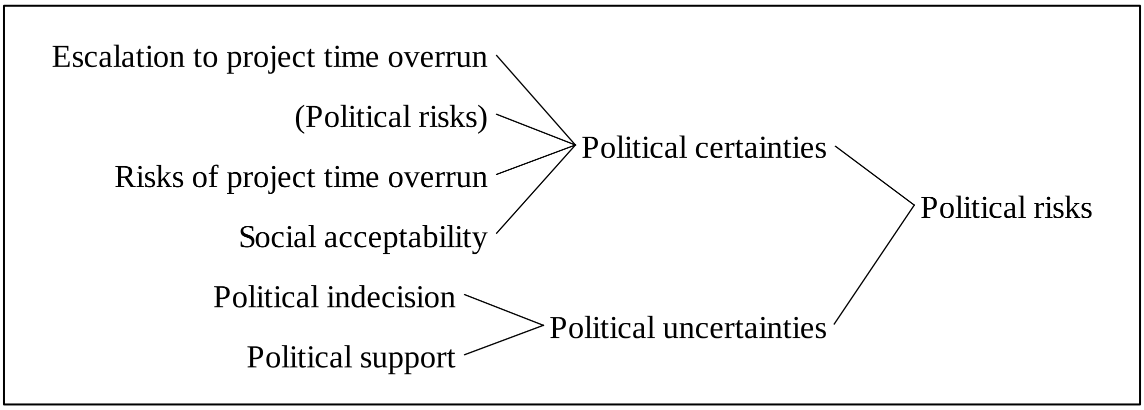


Figure 7.18b: Causes Tree Diagrams for Political Risks Entity

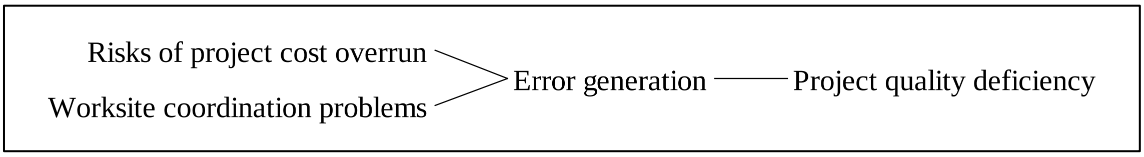


Figure 7.18c: Causes Tree Diagrams for Project Quality Deficiency Entity

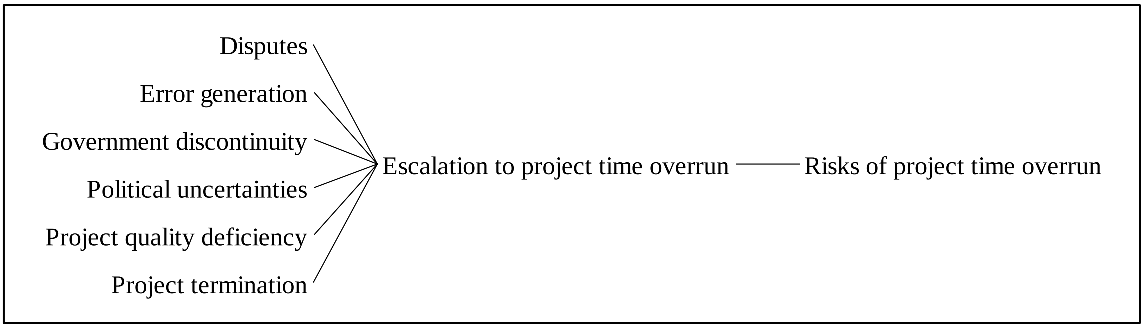


Figure 7.18d: Causes Tree Diagrams for Risks of Project Time Overrun Entity

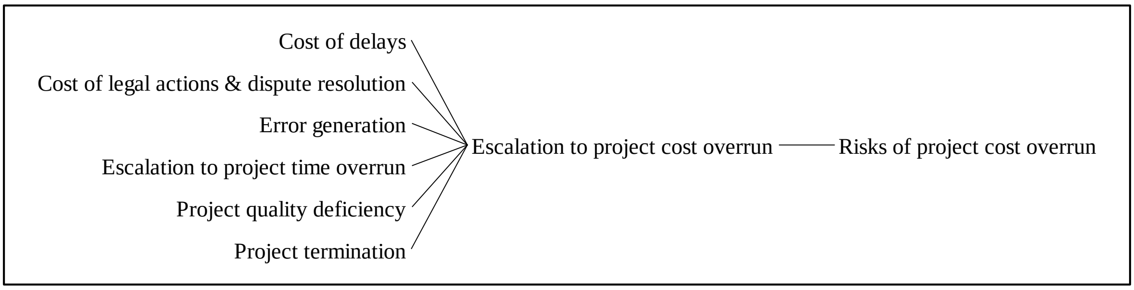


Figure 7.18e: Causes Tree Diagrams for Risks of Project Cost Overrun Entity

Figure 7.18: Causes Tree Diagrams for Political Risks Model

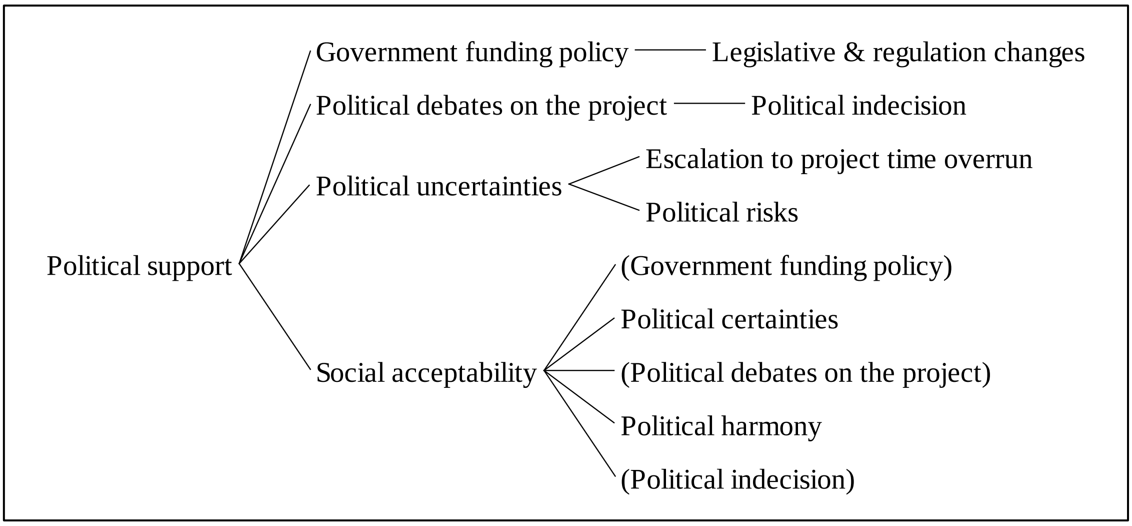


Figure 7.19a: Uses Tree Diagrams for Political Support Entity

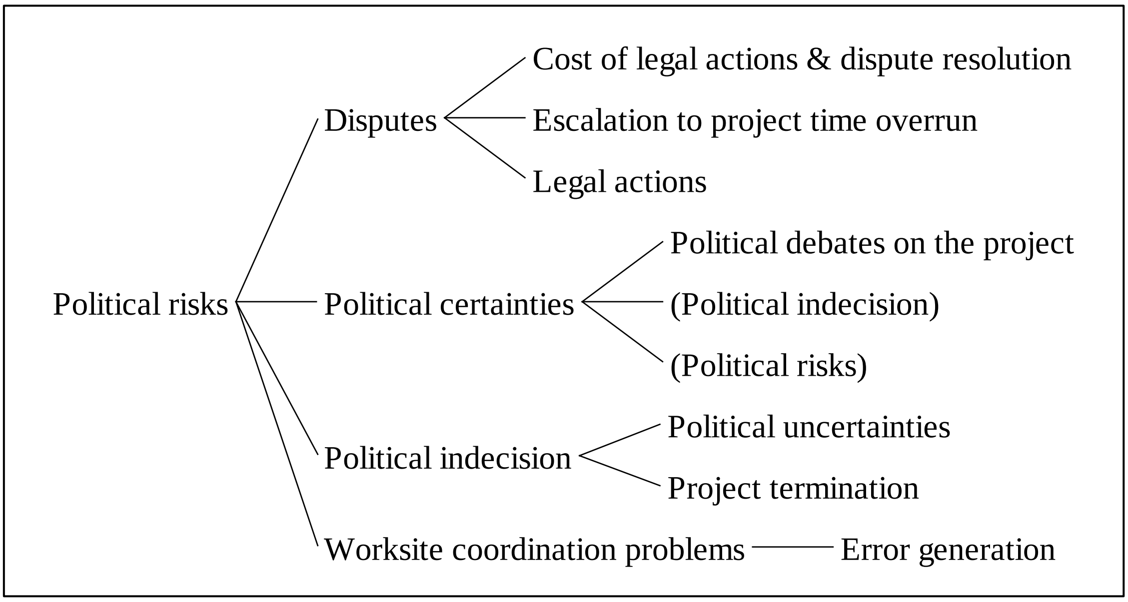


Figure 7.19b: Uses Tree Diagrams for Political Risks Entity

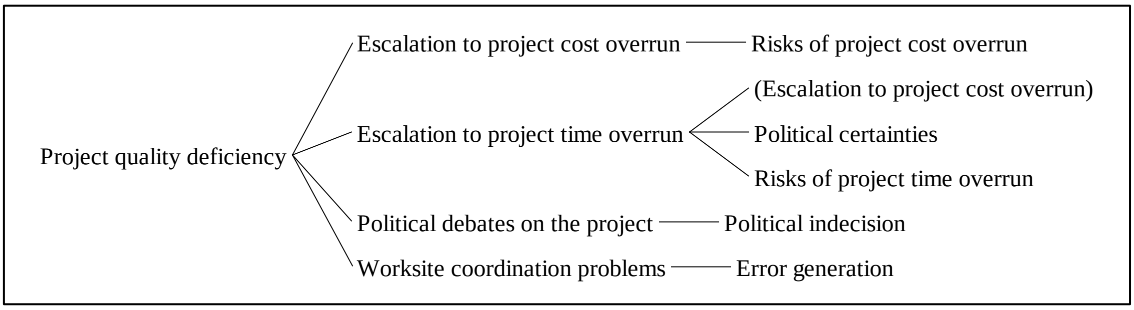


Figure 7.19c: Uses Tree Diagrams for Project Quality Deficiency Entity

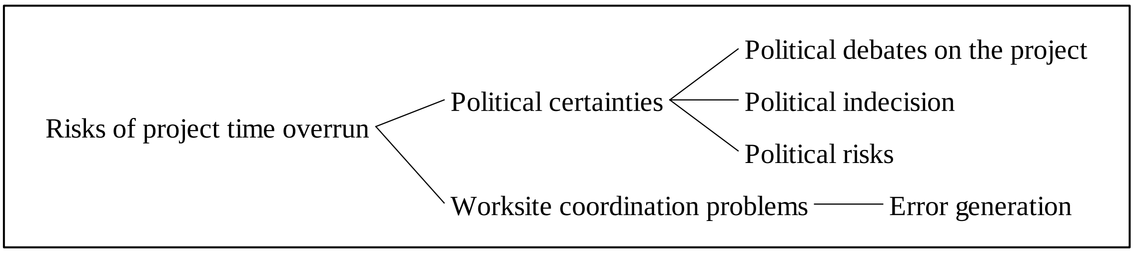


Figure 7.19d: Uses Tree Diagrams for Risks of Project Time Overrun Entity

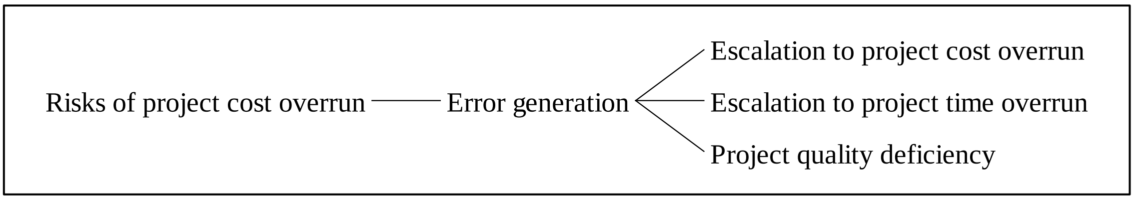


Figure 7.19e: Uses Tree Diagrams for Risks of Project Cost Overrun Entity

Figure 7.19: Uses Tree Diagrams for Political Risks Model

7.4. Model Verification

In Chapter 2, the researcher discussed the fact that megaprojects are usually unique and have unprecedented historical data on cost and time overruns, especially for transportation megaprojects. However, it is necessary to elicit further information from project experts who have knowledge and expertise in risks assessment in transportation megaprojects during construction. Some researchers argue that experts' judgment tends to have cognitive limitations as a result of the potential biases associated with the individual subjective views (Akintoye *et al*., 2003, Ayyub, 2001 and Cooke, 1991). It is still necessary to incorporate the views of experts into this research to aid the application of the system dynamics and statistical techniques for assessing subjective data in a systematic way, thus reducing subjective bias.

For consistent decision, the initial models were sent to seven participants (a group of risk experts and consultants) to criticise. The principal role of the verification in the first (qualitative) stage of modelling is to identify risks of inconsistency within the causal loop diagrams (CLDs) and to obtain sufficient information for the final model construction and for model simulation. Participants in the verification process include a project manager, a project engineer, a departmental stakeholder, a technical consultant and an operational manager involved in the ETNP. Others include an insurer, and a financial and legal adviser who are experienced in many facets of large-scale transportation infrastructure projects.

The breadth of the model verification was to build confidence in the models. Although there is no single verification method in literature, verification by the experts mentioned in this report improved confidence gradually as the models were constructively criticised by these experts as new points of correspondence between the models and the identified empirical reality. From the stand point of verification, a number of errors were identified in the initial model development. Application of verification ideas were then used to refine the initial models. It suffices to say that the process helped to establish confidence in the soundness and usefulness of the final models with respect to their purposes.

7.5. Summary

This chapter has presented the initial system dynamics modelling. Causal loop diagrams were developed using the Vensim software and were explained in detail throughout the chapter. The developed models were applied to five risk areas (social, technical, economic, environmental and political) to establish their cause and effects relationship based on risk information obtained through questionnaire surveys and interviews conducted on ETNP. The chapter concluded with the model verification process. In the next chapter, the development of the final model development for STEEP risks will be described.

CHAPTER EIGHT: THE SDANP MODEL

8.1: Introduction

Following the initial model (causal loop diagram) presented in chapter seven, this chapter describes the final model development of the substantive SDANP models for the STEEP risks considered in this research to reflect the construction phase of transportation megaproject.

Drawing from the causal loop diagrams (CLDs), qualitative risks causal loop diagrams are converted into quantitative MegaDS system models to evaluate the physical interactions of risk variables in the entire system. Thereafter, the risk priority indexes (RPIs) derived from the ANP are incorporated into the stock and flow diagrams to simulate the dynamics of risk effects and impacts on project cost, time and quality during construction overtime using Vensim DSS software. The explanation for this distinction is provided in the course of the discussion.

8.2: Final Model Development

Based on the verified causal loop diagrams in chapter seven, a high level stock and flow diagram was developed for the construction phase of the case study transportation megaproject (ETNP). The entire graph also known as the MegaDS stock and flow diagram was finalised in October 2013, after a last meeting between experts (Kitzen, Cole, Bailey and Claire, 21-22 October 2013). The MegaDS diagram is illustrated in Figure 8.1 with several parameters removed for clarity.

It must be noted that modelling the dynamics of each of the STEEP risks system in disaggregation will not neglect emergent properties between systems. The researcher implicitly assumed that all risk impacts on megaproject performance and as such a project manager may want to selectively identify risk of different classes and their level of impacts in order to maximize mitigation strategies. This may help the project manager to capitalize on differentials in the risk impact levels that are higher or lower. A model of the different risk systems such as STEEP cohorts in megaproject construction would require that risk analysts disaggregate the stocks and flows of the entire MegaDS system into different risk system classes and introduce risk specific modelling and simulation to extract impact levels on project performance. This idea of disaggregating stocks into sub groups or systems of individuals STEEP risks are used to model the dynamics of risk impacts on megaproject performance in this chapter. Each of the five STEEP risk systems makes up part of the entire "MegaDS stock and flow model" illustrated in Figure 8.1.

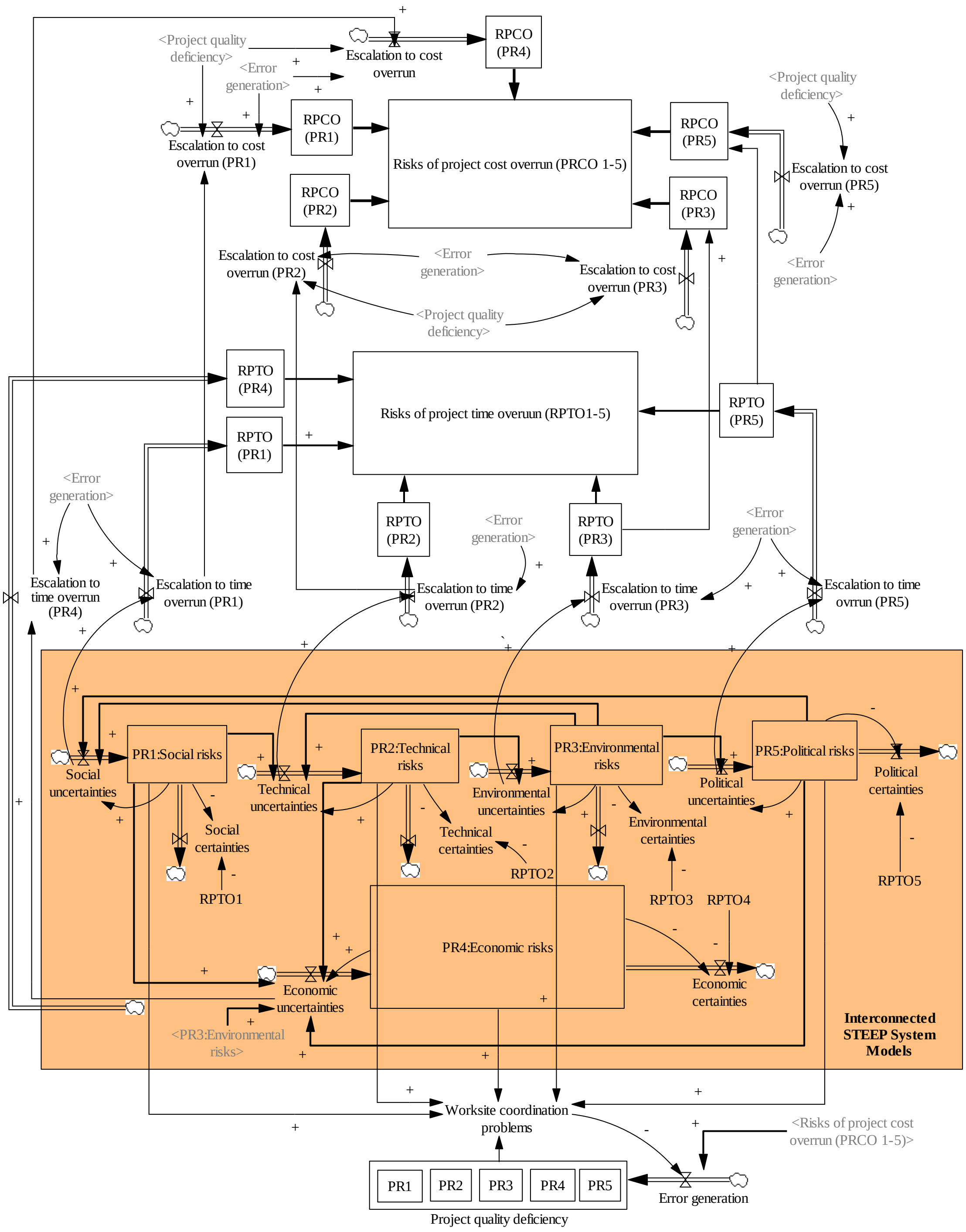


Figure 8.1: Stock and Flow Diagram for the MegaDS Model

As indicated in Figure 8.1, the final MegaDS stock and flow diagram consists of five interconnected STEEP risk models. The model (P_{R1}) represents the "social risks" system; (P_{R2}) represents the "Technical risks" system; (P_{R3}) represents the "Environmental risks" system; (P_{R4}), the "Economic risks" system and (P_{R5}), the "Political risks" system. All of these models feed into project quality deficiency via worksite coordination problems and error generation, risks of project time overruns via the escalation to project time overruns entity and risks of project cost overruns via the escalation to project cost overruns entity.

In total, the MegaDS system models contained over 5000 feedback loops, 112 variables, and hence, 112 model equations. Among the 112 model variables, 24 were of the type 'Stock or Level' (See Table 8.1 for the list of the stock or level variables). As a result of the large number of the model components and parameters, it is impossible to present the MegaDS models as a single graph with larger fonts in this thesis. As such, in the subsequent sections, each STEEP system is modelled separately and illustrated in detail to ensure that all legends are legible.

Table 8.1: Stock Variables for the MegaDS Model

System Model	Code	Variable Type	Status
S*o*RM	P_{R1}	Social risks	Level
	S_{V1}	Social grievances	Level
T*e*RM	P_{R2}	Technical risks	Level
	T_{V24}	Work to do	Level
E*c*RM	P_{R3}	Economic risks	Level
	E_{V7}	Material price	Level
E*n*RM	P_{R4}	Environmental risks	Level
P*o*RM	P_{R5}	Political risks	Level
	P_{V4}	Political support	Level
	S_{V13}, T_{V16}, E_{V22}, E_{NV13}, P_{R21}	Project quality deficiency	Level
All models	S_{V14}, T_{V18}, E_{V23}, E_{NV14}, P_{R22}	Risks of project cost overrun	Level
	S_{V15}, T_{V19}, E_{V24}, E_{NV15}, P_{R23}	Risks of project time overrun	Level

8.3: Integrated SDANP Model

The casual loop diagrams for social, technical, economic, environmental and political risks systems illustrated in Figures 7.5, 7.8, 7.11, 7.14, and 7.17 provide the foundation to develop the integrated stock and flow diagrams. The stocks as well as the flows (inflows and outflows) for these systems are illustrated in Figure 8.1.

8.3.1: Model Equation Formulation, Testing and Simulation

To have the model equations formulated in system dynamics, full structural stock and flow diagrams for individual integrated stock and flow system models are assessed structurally. Thereafter, formulation of equations for risk variables (endogenous variables) for each risk system model is performed. This sets a good foundation to enable consistency checks to be performed on all the system variables that must appear in the equations and to provide a good starting point to conduct simulation. Various tests performed for the integrated system models are further explained in detail in chapter nine of this thesis. In order to capture the meaning of the relationships depicted in the models properly, equations used and their respective units in left hand side (LHS) must balance with the right hand side (RHS).

With regard to model simulation, its primary objective is to study the critical variables which have influence on project time, cost and quality within each risk system model. Simulation is the only practical way to test the MegaDS system models. Typical conceptual models such as the type shown in Figure 7.1, page 173 and those for the individual system models are too large and complex to simulate mentally. As a result, simulation becomes the only reliable way to test hypotheses and evaluate the likely effects of policies to mitigate risk impacts on project time, cost and quality. Sections 8.3.2 to 8.3.6 provide detail commentary on the respective stock diagrams, equations and simulation results to the integrated MegaDS system models in this report.

8.3.2: Integrated Stock and Flow Model for the Social Risks System

This model is mainly controlled by social issues, i.e. concerns from environmental issues from works (pollution, traffic, noise, need to relocate, pedestrian and bicycle safety, choice of travel mode, reduction in land and property values along the project routes, linkage between residence and job difficulties and accessibility difficulties to families, friends and community resources) and sometimes political ideology which are transferred through transfer parameters from the environmental and political sub-models.

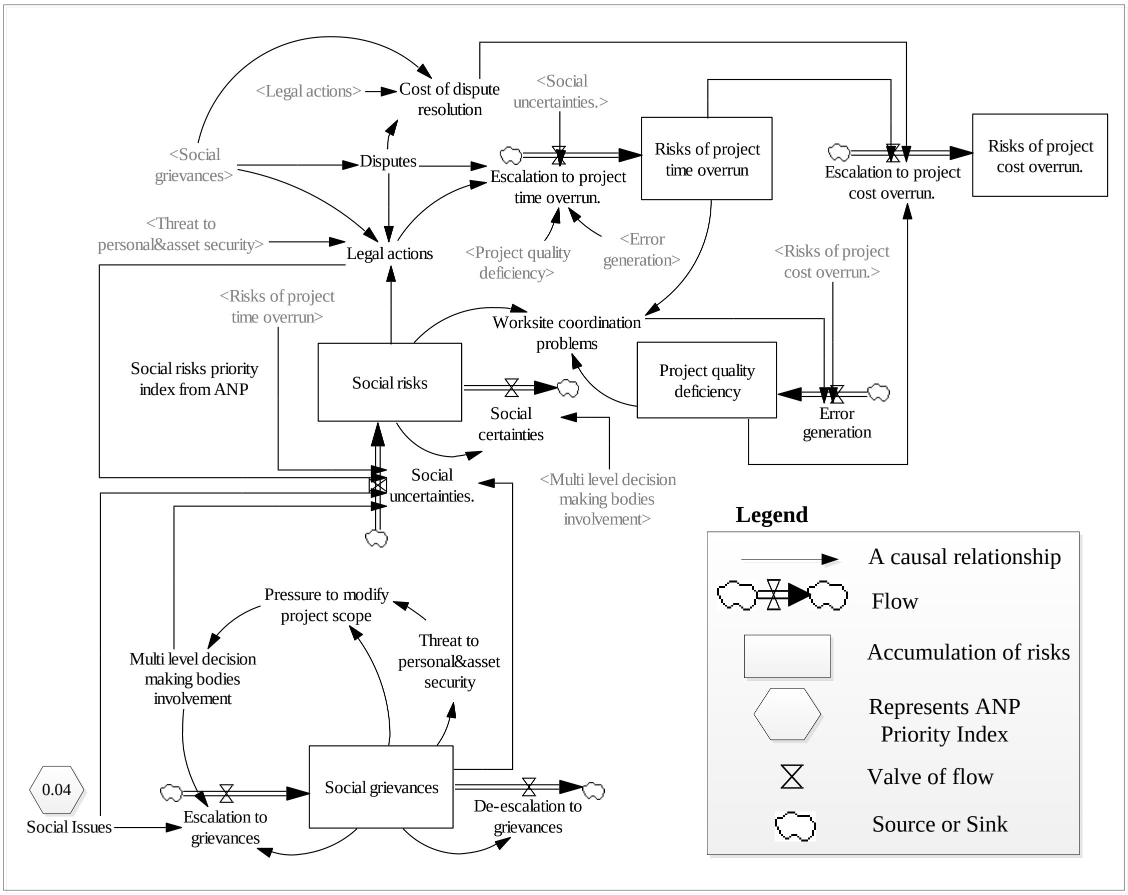


Figure 8.2: Integrated Stock and Flow Diagram for Social Risks System Model

It is important to note that quantifying risks in this model on an absolute scale is a difficult proposition compared to measurement of vectors as force in newtons. However, in system dynamics it is always the trend and the pattern of variation that is of significance and not the accuracy of the numbers and absolute units. It can be observed from Figure 8.2 that the rate variables viz., escalation to grievances and de-escalation to grievances, social uncertainties and social certainties, escalation to project time overrun, escalation to project cost overrun and error generation are influenced by parameters as related in the causal loop diagram illustrated in Figure 7.5 (See Chapter 7).

8.3.2.1: Model Equation Formulation for the Social Risks System Model

After the integrated stock and flow diagram for the social risks sub-model is constructed and structurally assessed, mathematical models (equations) for the individual system variables (endogenous variables) for the model are formulated as indicated in Table 8.1.

Table 8.2: Mathematical Model for the Integrated Social Risks System Model

Code	*System Variables*	*Equations*	*Measurement*
P_{R1}	*Social risks*	*INTEG ((Social uncertainties-Social certainties), Social risks priority index from ANP)*	*Dimensionless*
S_{V1}	*Social grievances;*	*INTEG (Escalation to grievances-De-escalation to grievances, ANP's RPI for* S_{V1}*)*	*Dimensionless*
S_{V2}	*Multi-level decision making bodies involvement*	*Pressure to modify project scope*	*Dimensionless*
S_{V3}	*Disputes*	*Social grievances*	*Dimensionless*
S_{V4}	*Legal/Community actions*	*(Social risks*"Threat to personal & asset security" + Disputes*Social grievances)*	*Dimensionless*
S_{V5}	*Pressure to modify project scope*	*"Threat to personal & asset security" * Social grievances*	*Dimensionless*
S_{V6}	*Threats to person and asset security*	*Social grievances*	*Dimensionless*
S_{V7}	*Social issues*	*Constant (ANP's RPI for* S_{V7}*)*	*Dimensionless*
S_{V8}	*Cost of dispute resolution*	*Disputes*Social grievances*Legal actions*	*Dimensionless*
S_{V9}	*De-escalation to grievances*	*Social grievances per Unit time*	*Dimensionless /Year*
S_{V10}	*Error generation*	*(Worksite coordination problems * "Risks of project cost overrun") per Unit time*	*Dimensionless /Year*
S_{V11}	*Escalation to grievances*	*((Social grievances*Social Issues)/Multi level decision making bodies involvement) per Unit time*	*Dimensionless /Year*
S_{V12}	*Escalation to project cost overrun*	*(Risks of project time overrun + Project quality deficiency*Cost of dispute resolution) per Unit time*	*Dimensionless /Year*
S_{V13}	*Escalation to project time overrun*	*(Legal actions*Disputes/Unit time) + "Social uncertainties" + Error generation * Project quality deficiency*	*Dimensionless /Year*
S_{V14}	*Project quality deficiency*	*INTEG (Error generation, 0)*	*Dimensionless*
S_{V15}	*Risks of cost overrun.*	*INTEG (Escalation to project cost overrun, 0)*	*Dimensionless /Year*
S_{V16}	*Risks of time overrun*	*INTEG (Escalation to project time overrun, 0)*	*Dimensionless*

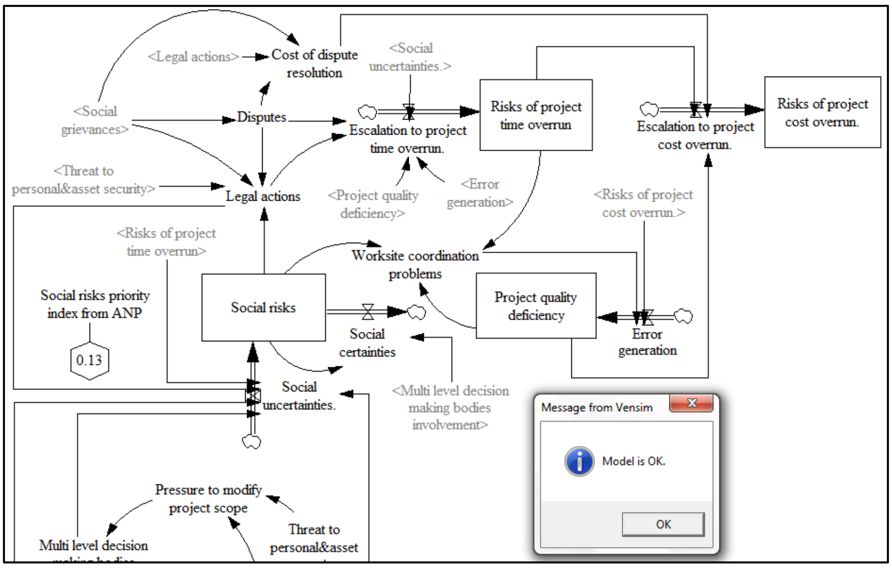
Table 8.2: Mathematical Model for the Integrated Social Risks System Model

(Continued)

Code	System Variables	Equations	Measurement
S_{V17}	*Social certainties*	*(Multi-level decision making bodies involvement/Social risks) per Unit time*	*Dimensionless/Year*
S_{V18}	*Social uncertainties*	*((Social grievances*Social Issues*Legal actions +Risks of project time overrun)*Multi level decision making bodies involvement) per Unit time*	*Dimensionless/year*
S_{V19}	*Worksite coordination problems*	*(Social risks*Project quality deficiency + Risks of project time overrun)*	*Dimensionless*

8.3.2.2: Model Tests for the Social Risks System Model

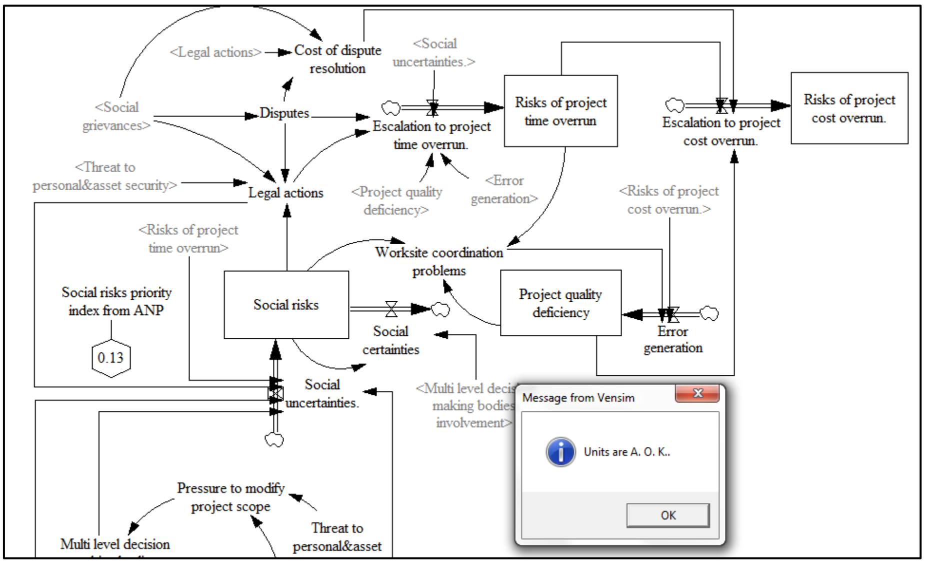
Evaluation of the model is done in the following way. A dimensional consistency test is conducted by the Vensim's built-in function. As indicated in Figure 8.3, the message from Vensim shows that the level (stocks), auxiliaries, constants, units and their speed are dimensionally consistent.



Message from Vensim

Model is OK.

Figure 8.3a: Structural Assessment Test for Social Risks Stock and Flow Model



Units are A. O. K..

Figure 8.3b: Dimensional consistency checks for the social risks stock and flow model

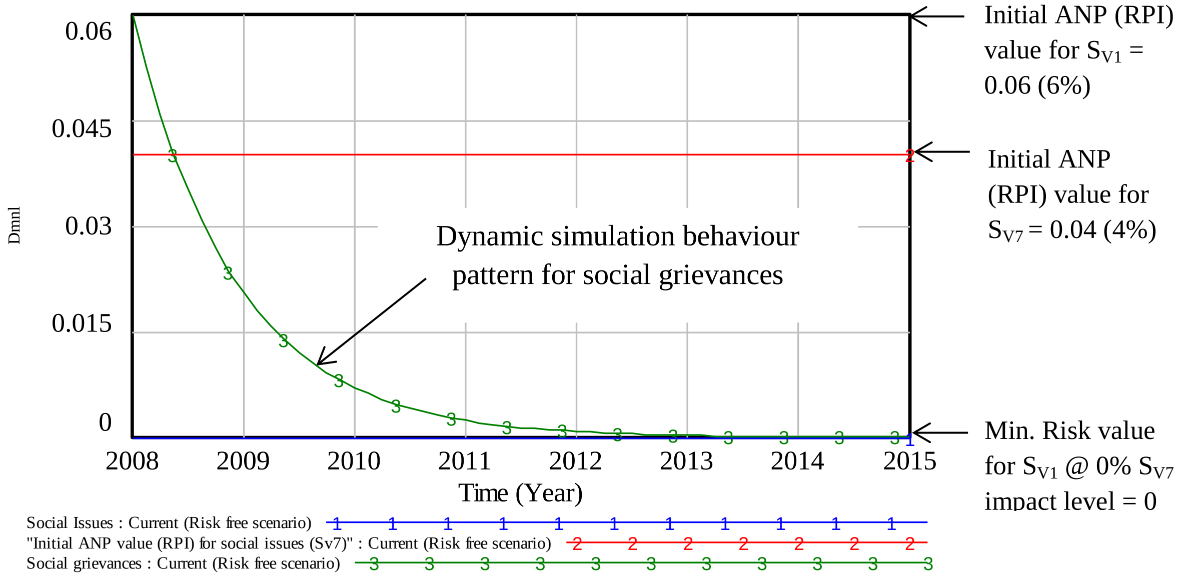
Figure 8.3: Evaluation Tests for the Social Risks Model

8.3.2.3: Dynamic Simulation Results for Social Risks System Model

The interaction of risks in the social risks sub system is analysed quantitatively by a dynamic simulation model. The most outstanding feature of the dynamic simulation model is its effectiveness in simulating scenarios where several social risk system variables interact. The feedback nature of the simulation model ensures that the cross impacts of different risks on project cost, time and quality are captured and the direct and indirect impacts of risks quantified by switching on/ off procedures in two ways.

First, the critical risk entity which is the ‘social issues’ is switched off to zero value by simulating a risk free scenario and the resulting behaviour patterns for social grievances, social risks, risks of project time and cost overruns and quality deficiency are used as base runs. Figure 8.4 illustrates graphs of the simulated risk free patterns for the social risks sub model.

a. Social issues at 0% vs Social grievances



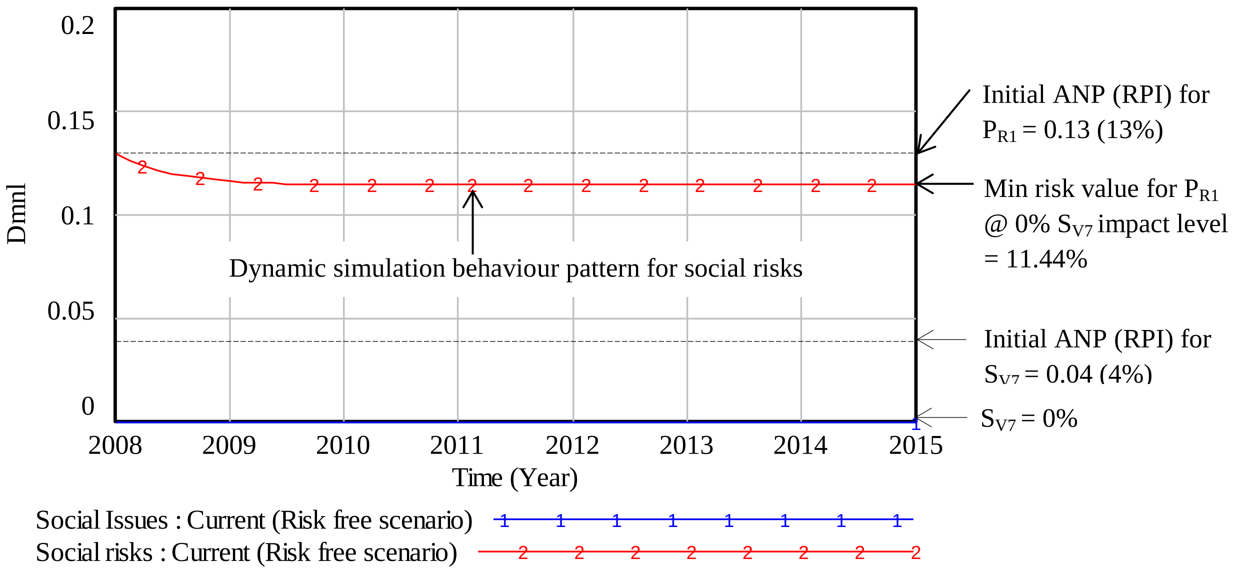
Initial ANP (RPI) value for S_{V1} = 0.06 (6%)

Initial ANP (RPI) value for S_{V7} = 0.04 (4%)

Dynamic simulation behaviour pattern for social grievances

Min. Risk value for S_{V1} @ 0% S_{V7} impact level = 0

b: Social issues vs Social risks



Initial ANP (RPI) for P_{R1} = 0.13 (13%)

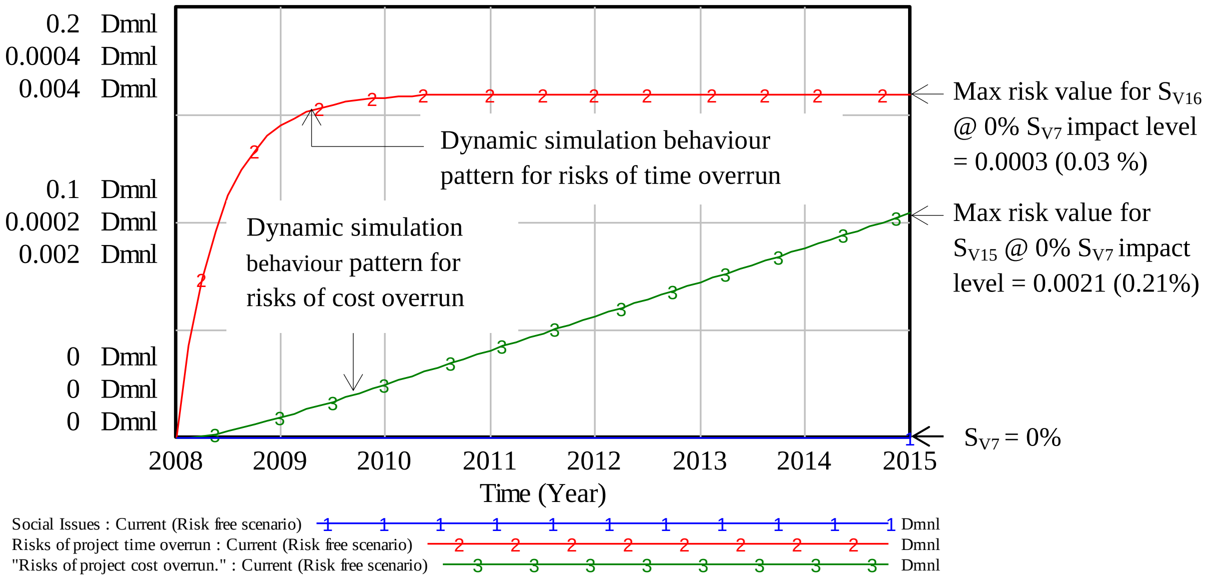
Min risk value for P_{R1} @ 0% S_{V7} impact level = 11.44%

Dynamic simulation behaviour pattern for social risks

Initial ANP (RPI) for S_{V7} = 0.04 (4%)

S_{V7} = 0%

Figure 8.4: Dynamic Risk-Free Simulation Patterns for Social Risks System Model


c:Social issues vs risks of project time & cost overruns

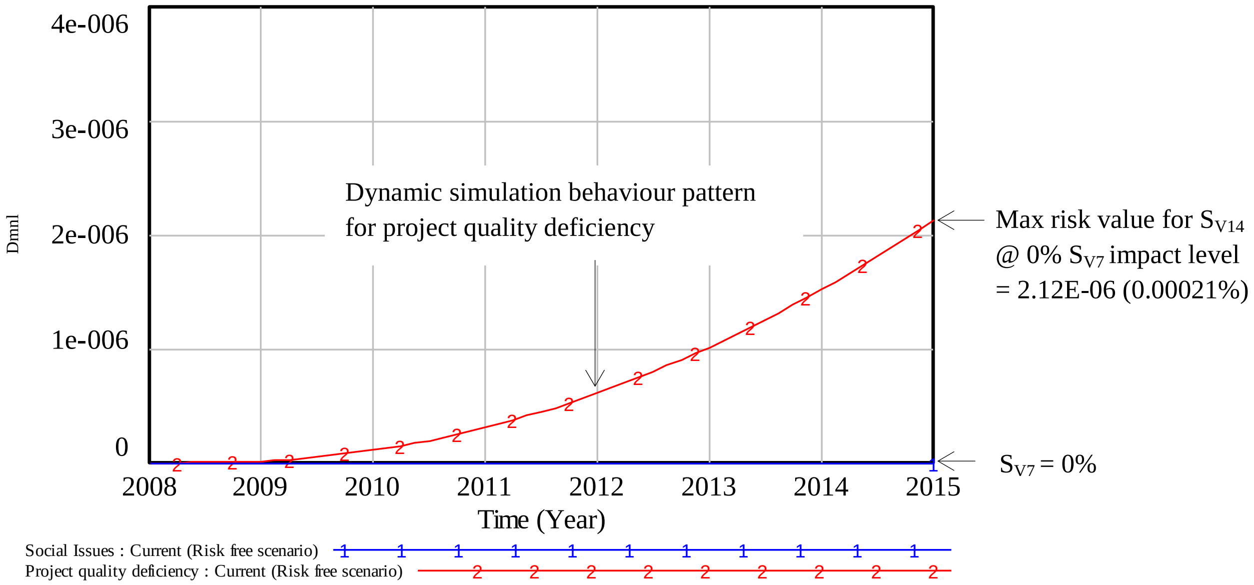
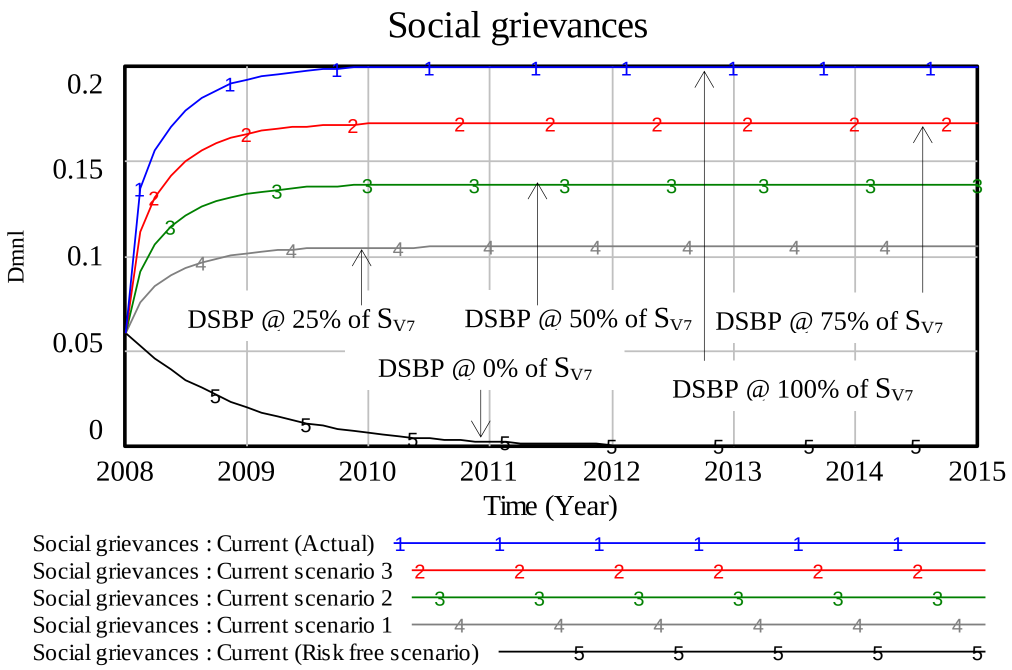

d: Social issues vs project quality deficiency

Figure 8.4: Dynamic Risk-Free Simulation Patterns for Social Risks System Model (Continued)

From the analysis results in Figure 8.4, it can be observed that, when social issues are at 0% influence level, the simulated pattern of social grievances declined steadily from the original risk priority value of 0.06 (6%) at year 2008 when physical construction works of ETNP commenced to 0% in the second quarter of year 2013 when major construction works were completed (See Figure 8.4a). It can further be observed on Figures 8.4c and 8.4d that, at 0% of social issues, simulated patterns for risks of project time and cost overruns and project quality deficiency also fell below 0% level of influence on the

ETNP at the construction stage. However, in Figure 8.4b, the behaviour pattern of social risks declined steadily to 0% within the last quarter of 2010 and continued to decline in values until the first quarter of 2013. Between the first and second quarters of 2013, the simulated pattern rose sharply to more than 0% before declining to values below zero for the rest of the simulated periods.

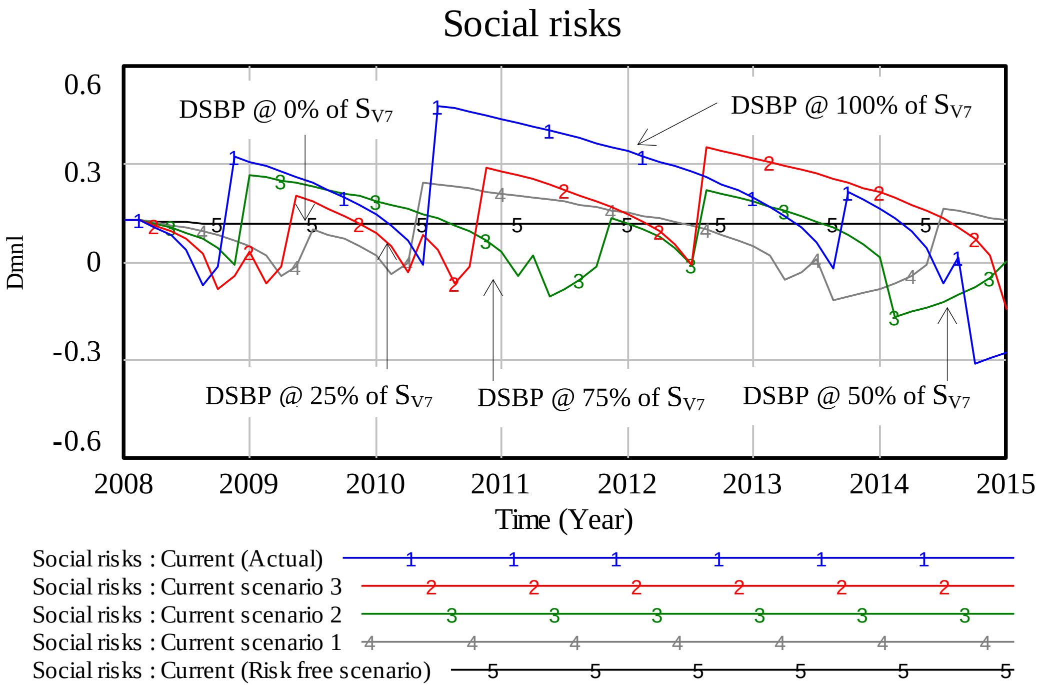
Second, the ‘social issues’ entity is switched on and its value (RPI) input into the system. Simulations are performed at 0.01, 0.02, 0.03 and 0.04 (at 25% intervals of the ANP value (RPI) for the social issues entity) to represent scenarios 1 to 4 of risk impact levels on project performance to enable the resulting behaviour patterns obtained to be evaluated and compared with the simulated base run patterns. The objective of this process is to study the influence of the social issues on project time, cost and quality. It is also to reveal the level of impacts of risk variables which generate social risks in the system in physical values so that measures can be proposed to mitigate such issues.



DSBP = Dynamic simulation behaviour pattern

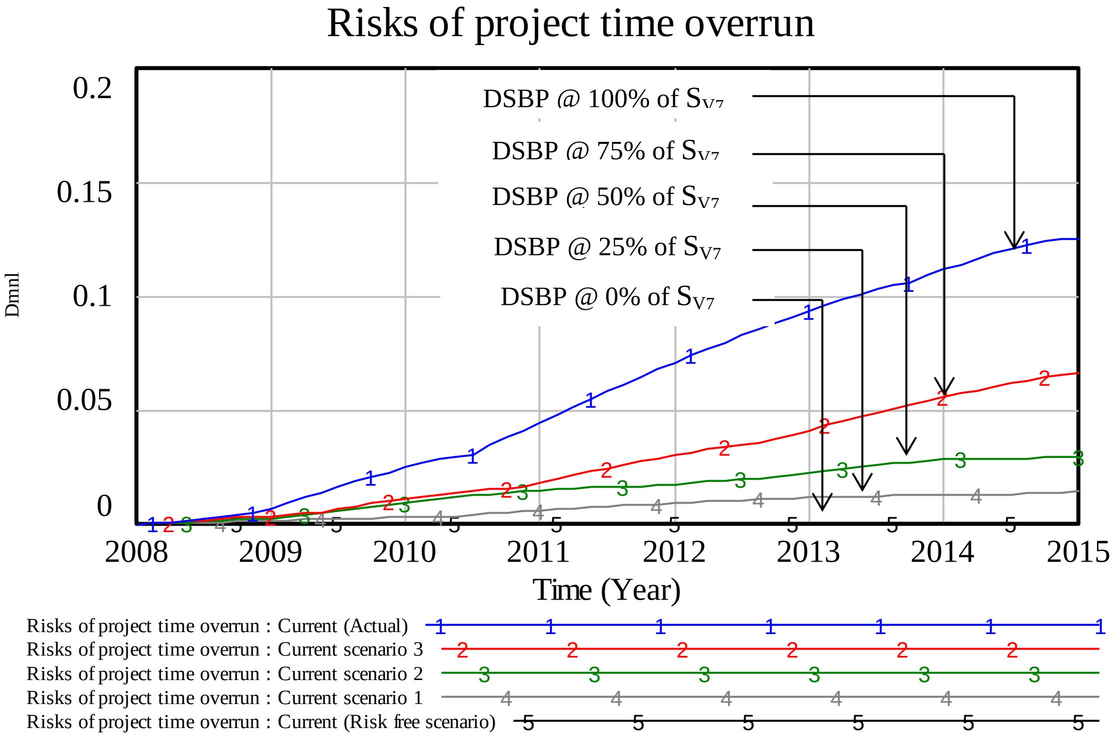
a: Dynamic simulation scenario graphs for social grievances

Figure 8.5: Dynamic Scenario Graphs for the Social Risks System Model



DSBP = Dynamic simulation behaviour pattern

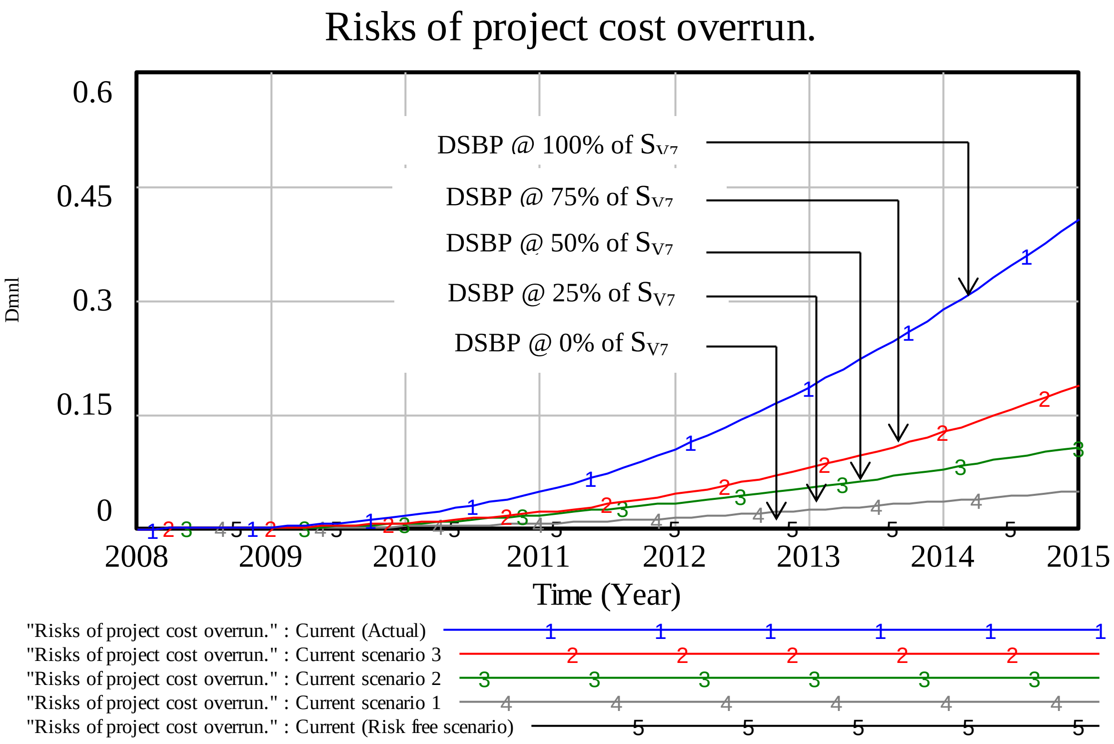
b: Dynamic simulation scenario graphs for social risks



DSBP = Dynamic simulation behaviour pattern

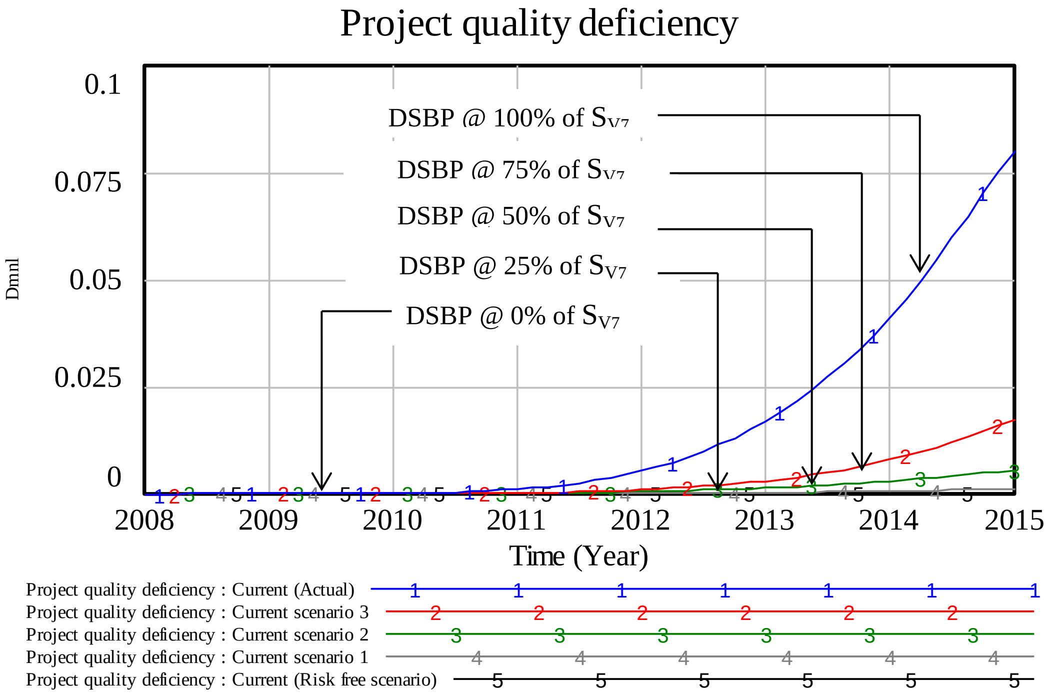
c: Dynamic simulation scenario graphs for risks of project time overrun

Figure 8.5: Dynamic Scenario Graphs for the Social Risks System Model (Continued)



DSBP = Dynamic simulation behaviour pattern

d: Dynamic simulation scenario graphs for risks of project cost overrun



DSBP = Dynamic simulation behaviour pattern

e: Dynamic simulation scenario graphs for project quality deficiency

Figure 8.5: Dynamic Scenario Graphs for the Social Risks System Model (Continued)

To reveal the dynamics of the level of impact of social risks in the system over time, simulations are performed on the entire social risks system model to study the influence of the social risk system variables on project time, cost and quality. Simulated behaviour patterns of scenarios 1, 2, 3 and 4 were generated and compared to the base run patterns. As indicated in Figure 8.5, the simulated graphs for the four scenarios reveal the patterns of time and cost overruns and quality deficiency over 6 years simulation time.

Also, detailed results of all variables within the social risks sub model are generated by the system and tabulated in Table 8.3. The advantages of such dynamic results in aiding risks assessment are that all risk variables within the social risks model are quantified and represented in physical values that can be compared with real values. That is to say, statistical values generated helped to understand the effects of social risk factors on project performance at different stages within the construction phase. Secondly, scenarios just as those indicated in Figure 8.5 and sensitivity analysis can easily be performed by adjusting various parameters during policy making through various design mechanisms to realize preferred risks levels affecting the project outcome, where the designed measures in the form of model parameters can be recommended to management.

Table 8.3: Dynamic Simulation Results for Social Risks System

Time (Year)	**ANP Inputs*(%)**			**SD Simulation Outputs (%)**																	
	S_{V7}	P_{R1}	S_{V1}	S_{V2}	S_{V3}	S_{V4}	S_{V5}	S_{V6}	S_{V8}	S_{V9}	S_{V10}	S_{V11}	S_{V12}	S_{V13}	S_{V14}	S_{V15}	S_{V16}	S_{V17}	S_{V18}	S_{V19}
2008.000	04	13	06	00	06	01	00	06	00	06	00	67	00	00	00	00	00	03	00	00
2008.125		13	14	02	14	04	02	14	00	14	00	29	00	00	00	00	00	15	00	00
2008.250		11	16	02	16	04	02	16	00	16	00	26	00	01	00	00	00	22	00	00
2008.375		08	17	03	17	04	03	17	00	17	00	24	00	01	00	00	00	35	00	00
2008.500		04	18	03	18	04	03	18	00	18	00	23	00	01	00	00	00	86	00	00
2008.625		-07	18	03	18	02	03	18	00	18	00	22	00	01	00	00	00	-47	00	00
2008.750		-01	19	04	19	03	04	19	00	19	00	21	00	01	00	00	00	-2.68	00	00
2008.875		32	19	04	19	10	04	19	00	19	00	21	00	02	00	00	00	11	00	00
2009.000		31	19	04	19	10	04	19	00	19	00	21	01	02	00	00	01	12	00	01
2009.125		29	19	04	19	10	04	19	00	19	00	21	01	02	00	00	01	13	00	01
2009.250		28	20	04	20	09	04	20	00	20	00	02	01	02	00	00	01	14	00	01
2009.375		26	20	04	20	09	04	20	00	20	00	02	01	02	00	01	01	15	00	01
2009.500		24	20	04	20	09	04	20	00	20	00	02	02	02	00	01	02	16	00	02
2009.625		22	20	04	20	08	04	20	00	20	00	02	02	02	00	01	02	18	00	02
2009.750		20	20	04	20	08	04	20	00	20	00	02	02	02	00	01	02	02	00	02
2009.875		17	20	04	20	07	04	20	00	20	00	02	02	02	00	01	02	23	00	02
2010.000		14	20	04	20	07	04	20	00	20	00	02	02	01	00	02	02	27	00	02

** Refer to Table 6.11: Summary of final ANP decision making priority results for all risks on page 169.*

Table 8.3: Dynamic Simulation Results for Social Risks System (Continued)

Time (Year)	**SD Simulation Outputs (%)**																			
	S_{V7}	P_{R1}	S_{V1}	S_{V2}	S_{V3}	S_{V4}	S_{V5}	S_{V6}	S_{V8}	S_{V9}	S_{V10}	S_{V11}	S_{V12}	S_{V13}	S_{V14}	S_{V15}	S_{V16}	S_{V17}	S_{V18}	S_{V19}
2010.125		11	20	04	20	06	04	20	00	20	00	20	03	01	00	20	03	36	00	03
2010.250		07	20	04	20	05	04	20	00	20	00	20	03	01	00	20	03	61	00	03
2010.375		-01	20	04	20	04	04	20	00	20	00	20	03	01	00	03	03	-3.91	00	03
2010.500		48	20	04	20	14	04	20	01	20	00	20	03	03	00	03	03	08	00	03
2010.625		47	20	04	20	13	04	20	01	20	00	20	03	03	00	03	03	09	00	03
2010.750		46	20	04	20	13	04	20	01	20	00	20	04	03	00	04	04	09	00	04
2010.875		45	20	04	20	13	04	20	01	20	00	20	04	03	00	04	04	09	00	04
2011.000		44	20	04	20	13	04	20	01	20	00	20	04	03	00	05	04	09	00	05
2011.125		43	20	04	20	13	04	20	01	20	00	20	05	03	00	05	05	09	00	05
2011.250		41	20	04	20	12	04	20	00	20	00	20	05	03	00	06	05	10	00	05
2011.375		40	20	04	20	12	04	20	00	20	00	20	05	03	00	07	05	10	00	06
2011.500		39	20	04	20	12	04	20	00	20	00	20	06	03	00	07	06	10	00	06
2011.625		38	20	04	20	12	04	20	00	20	01	20	06	03	00	08	06	11	00	06
2011.750		36	20	04	20	11	04	20	00	20	01	20	06	03	00	09	06	11	00	07
2011.875		35	20	04	20	11	04	20	00	20	01	20	07	02	00	10	07	11	00	07
2012.000		34	20	04	20	11	04	20	00	20	01	20	07	02	01	10	07	12	00	07
2012.125		32	20	04	20	10	04	20	00	20	01	20	07	02	01	11	07	12	00	08
2012.250		31	20	04	20	10	04	20	00	20	01	20	08	02	01	12	08	13	00	08
2012.375		29	20	04	20	10	04	20	00	20	01	20	08	02	01	13	08	14	00	08
2012.500		28	20	04	20	10	04	20	00	20	01	20	08	02	01	14	08	15	00	09
2012.625		26	20	04	20	09	04	20	00	20	01	20	09	02	01	15	09	16	00	09
2012.750		24	20	04	20	09	04	20	00	20	01	20	09	02	01	16	09	17	00	09
2012.875		22	20	04	20	08	04	20	00	20	02	20	09	02	01	17	09	18	00	09
2013.000		20	20	04	20	08	04	20	00	20	02	20	09	02	02	19	09	20	00	10

Table 8.3: Dynamic Simulation Results for Social Risks System (Continued)

Time (Year)	**SD Simulation Outputs (%)**																			
	S_{V7}	P_{R1}	S_{V1}	S_{V2}	S_{V3}	S_{V4}	S_{V5}	S_{V6}	S_{V8}	S_{V9}	S_{V10}	S_{V11}	S_{V12}	S_{V13}	S_{V14}	S_{V15}	S_{V16}	S_{V17}	S_{V18}	S_{V19}
2013.125		17	20	04	20	07	04	20	00	20	02	20	10	02	02	20	10	23	00	10
2013.250		14	20	04	20	07	04	20	00	20	02	20	10	02	02	21	10	28	00	10
2013.375		11	20	04	20	06	04	20	00	20	02	20	10	02	02	22	10	37	00	10
2013.500		06	20	04	20	05	04	20	00	20	02	20	10	02	03	23	10	66	00	10
2013.625		-02	20	04	20	04	04	20	00	20	03	20	10	01	03	25	10	-1.87	00	10
2013.750		21	20	04	20	08	04	20	00	20	03	20	11	02	03	26	11	19	00	11
2013.875		19	20	04	20	08	04	20	00	20	03	20	11	02	04	27	11	21	00	12
2014.000		16	20	04	20	07	04	20	00	20	03	20	11	02	04	29	11	24	00	12
2014.125		13	20	04	20	07	04	20	00	20	04	20	11	02	05	30	11	30	00	12
2014.250		10	20	04	20	06	04	20	00	20	04	20	12	02	.05	32	12	41	00	12
2014.375		05	20	04	20	05	04	20	00	20	04	20	12	02	05	33	12	88	00	12
2014.500		-06	20	04	20	03	04	20	00	20	04	20	12	01	06	34	12	-63	00	12
2014.625		02	20	04	20	04	04	20	00	20	04	20	12	02	06	36	12	2.62	00	12
2014.750		-31	20	04	20	-02	04	20	00	20	04	20	12	00	07	38	12	-13	00	10
2014.875		-29	20	04	20	-02	04	20	00	20	04	20	12	00	08	39	12	-14	00	10
2015.000		-28	20	04	20	-02	04	20	00	20	04	20	13	01	08	41	13	-14	01	10

Table 8.4: Summary of the Simulation Results for the Social Risks System Model

Code	**System Variables**	**ANP/SD Simulation Results (%)**					
		ANP Inputs*					
S_{V1}	Social grievances	06					
S_{V7}	Social Issues	04					
P_{R1}	Social risks	13					
		SD Simulation Outputs					
		Min	Max	Mean	Median	StDev	(Norm)
P_{R1}	Social risks	-31	48	19	20	18	96
S_{V1}	Social grievances	06	20	19	20	02	11
S_{V2}	MLDMB	00	04	04	04	01	16
S_{V3}	Disputes	06	20	19	20	02	11
S_{V4}	Legal/Community actions	-02	14	08	08	04	51
S_{V5}	Pressure to modify project scope	00	04	04	04	01	16
S_{V6}	TPAS	06	20	19	20	02	11
S_{V8}	Cost of dispute resolution	00	01	00	00	00	54
S_{V9}	De-escalation to grievances	06	20	19	20	02	11
S_{V10}	Error generation	00	04	01	00	01	1.21
S_{V11}	Escalation to grievances	20	67	21	20	06	29
S_{V12}	Escalation to project cost overrun	00	13	06	06	04	71
S_{V13}	Escalation to project time overrun	00	03	02	02	01	42
S_{V14}	Project quality deficiency	00	08	01	00	02	1.48
S_{V15}	Risks of cost overrun.	00	41	12	07	12	1.03
S_{V16}	Risks of time overrun	00	13	06	06	04	71
S_{V17}	Social certainties	-3.91	2.62	06	14	81	14.23
S_{V18}	Social uncertainties	00	01	00	00	00	71
S_{V19}	Worksite coordination problems	00	12	06	06	04	70

*Base runs Time (Year) for social risks system variables = 2008 to 2015, * Refer to Table 6.11: Summary of final ANP decision making priority results for all risks on page 169, MDMBI - Multi-level decision making bodies involvement, PMPS - Pressure to modify project scope, TPAS - Threats to person & asset security*

- ***Analysis of the Simulation Results for the Level of Risk Impact on Project Objectives***

The findings of the dynamic simulation results for social risks are explored in relation to the level of impact of such risks on the objectives of transportation megaprojects identified as being mainly risks of project time and cost overruns and project quality deficiency. Table 8.5 presents a one-way analysis of variance (ANOVA) of the social risks impact on project time, cost and quality. The aim of the one-way analysis of variance (ANOVA) is to explore whether one particular project objective experiences more of the social risks impact than those of other project objectives when using an alpha of .001. If so, what will be the nature of these distinctions and if not, what will be the form of the similarities.

Table 8.5: One-Way Analysis of Variance: The Level and Extent to which Social Risks affect the Objectives of Transportation Megaproject during construction

Project objectives	**Level of Social Risks Impacts on Project Objectives (%)**				
	Mean		Std. deviation		
Time	06		04		
Cost	12		12		
Quality	01		02		
Variance	**The Extent to which Social Risks Have Impacts on Project Performance (Time, Cost and Quality)**				
	Sum of squares	Degrees of freedom (df).	Mean square	F	P
Between project objectives	3712.642	2	1856.321	30.890	.000
Within project objectives	10095.936	168	60.095		
Total	13808.578	170			

Source: Field Survey 2013

As indicated on Table 8.5, the one-way analysis of variance reveals that project time, cost and quality of the case study transportation megaproject are all impacted by social risks. The mean scores indicate that project cost (12%) is affected most, followed by the project time (6%) and then the project quality (1%). Subjecting the results to one-way analysis of variance (ANOVA), the F (obtained) is 30.890 which far exceeds the F-critical value of 7.41 for this test when using an alpha of .001. Correspondingly, the observed p-value of .000 is well below the chosen alpha of .001. By either standard, it implies that the difference between the levels of social risks impact on the objectives of the cases study project is statistically non-significant.

8.3.3: Integrated Stock and Flow Model for the Technical Risks System

Figure 8.6 illustrates the integrated technical risks stock and flow diagram. It is developed based on the validated causal loop diagram illustrated in Figure 7.8. As indicated in Table 8.6, mathematical equations are formulated for each of the endogenous system variables within the model. Following the mathematical models (equation formulation), model structural assessment and the dimensional test are performed using the Vensim's built-in function. Figure 8.7 illustrates messages from the Vensim's built-in function indicating that the structural assessment and dimensional test are consistent.

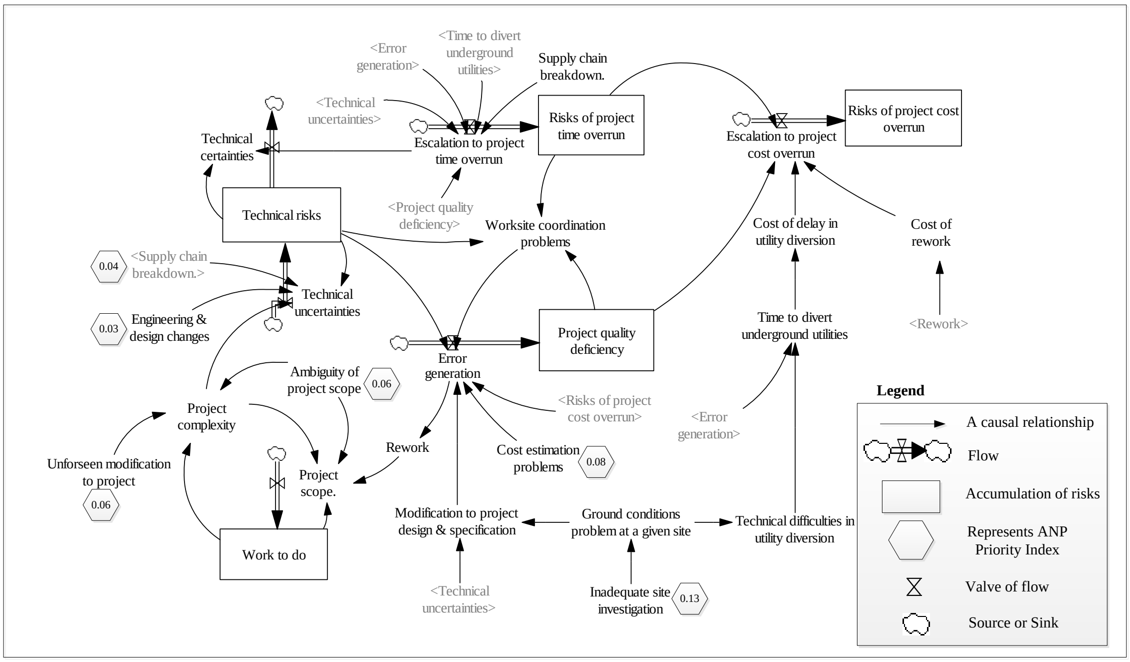


Figure 8.6: Integrated Stock and Flow Diagram for Technical Risks System Model

Finally, simulations (current runs) are performed on the entire technical risks system model to reveal the patterns of risk influences on project time, cost and quality under the following time steps:

i. *The initial time for the simulation = 2008, Units: Year*
ii. *The final time for the simulation= 2015, Units: Year and*
iii. *The time step for the simulation = 0.125, Units: Year*

Table 8.6: Mathematical Model for the Integrated Technical Risks System Model

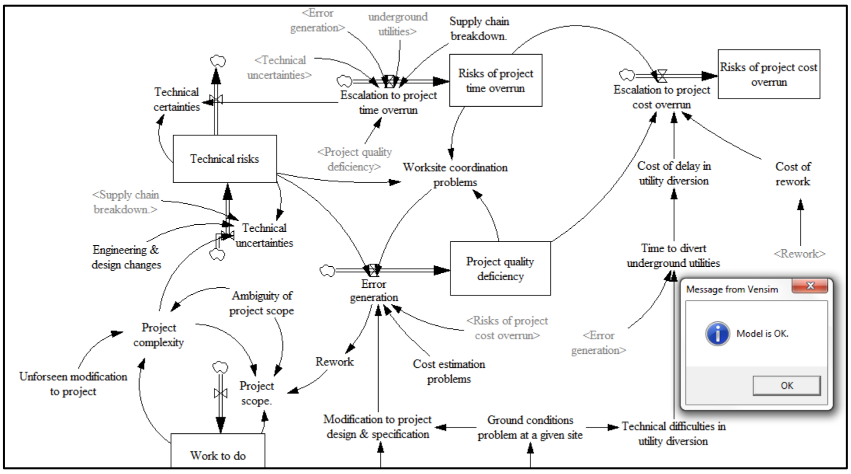
Code	System Variables	Equations	Measurement
P_{R2}	Technical risks	INTEG (Technical uncertainties-Technical certainties, 0.3)	Dimensionless
T_{V1}:	Ambiguity of project scope	Constant (ANP value (RPI) for T_{V1})	Dimensionless
T_{V2}:	Ground conditions problems	Inadequate site investigation	Dimensionless
T_{V3}:	Project complexity	Work to do+(Ambiguity of project scope*Unforeseen modification to project)	Dimensionless
T_{V4}:	Project modification	Constant (ANP value (RPI) for T_{V4})	Dimensionless
T_{V5}:	Project cost estimate problems	Constant (ANP value (RPI) for T_{V5})	Dimensionless

Source: Field Survey 2013

Table 8.6: Mathematical Model for the Integrated Technical Risks System Model (Continued)

Code	System Variables	Equations	Measurement
T_{V6}:	Modification to project design & specification	(Ground conditions problem at a given site*Technical uncertainties)*Unit Time	Dimensionless
T_{V7}:	Technical difficulties in utilities diversions	Ground conditions problem at a given site	Dimensionless
T_{V8}:	Engineering and design change	Constant (ANP value (RPI) for T_{V8})	Dimensionless
T_{V9}:	Supply chain breakdown	Constant (ANP value (RPI) for T_{V9})	Dimensionless
T_{V10}:	Risks of project time overrun	INTEG (Escalation to project time overrun, 0)	Dimensionless
T_{V11}:	Risks of project cost overrun	INTEG (Escalation to project cost overrun, 0)	Dimensionless
T_{V12}:	Inadequate site investigation	Constant (ANP value (RPI) for T_{V12})	Dimensionless
T_{V13}:	Cost of delay in utility diversion	Time to divert underground utilities	Dimensionless
T_{V14}:	Cost of rework	Rework	Dimensionless
T_{V15}:	Error generation	(Technical risks*Worksite coordination problems+ (Cost estimation problems + Modification to project design & specification)*Risks of project cost overrun) per Unit Time	Dimensionless/ Year
T_{V16}:	Project quality deficiency	INTEG (Error generation, 0)	Dimensionless
T_{V17}:	Project scope.	((Work to do + Rework) * (Project complexity*Ambiguity of project scope)) per Unit Time	Dimensionless/ Year
T_{V18}:	Escalation to project cost overrun	((Risks of project time overrun +Project quality deficiency)+(Cost of delay in utility diversion +Cost of rework)) per Unit Time	Dimensionless/ Year
T_{V19}:	Escalation to project time overrun	((Error generation*Time to divert underground utilities + Project quality deficiency/Unit Time + Technical uncertainties)*"Supply chain breakdown)	Dimensionless/ Year
T_{V20}:	Rework	Error generation*Unit Time	Dimensionless
T_{V21}:	Technical certainties	Technical risks*Escalation to project time overrun	Dimensionless/ Year
T_{V22}:	Technical uncertainties	Technical risks *Project complexity * (Supply chain breakdown + Engineering & design changes) per Unit Time	Dimensionless /Year
T_{V23}:	Time to divert underground utilities	(Error generation*Technical difficulties in utility diversion)*Unit Time	Dimensionless
T_{V24}:	Work to do	INTEG ("Project scope" ,0)	Dimensionless
T_{V25}:	Worksite coordination problems	Project quality deficiency*Technical risks * Risks of project time overrun	Dimensionless

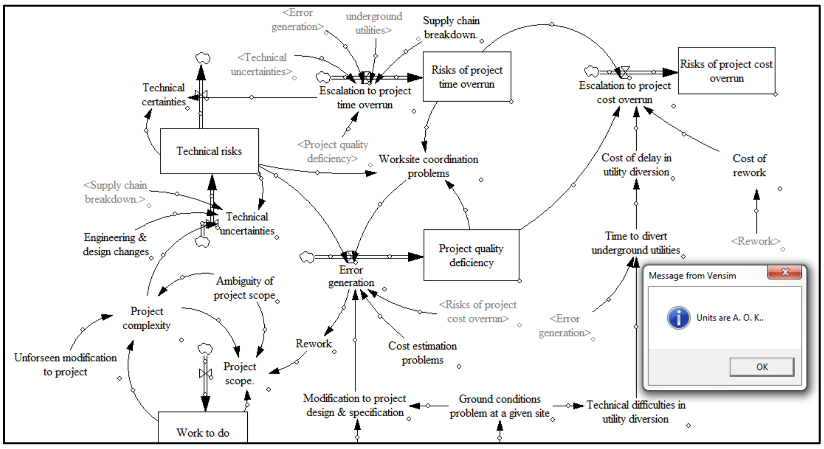
Source: Field Survey 2013



Message from Vensim

Model is OK.

Figure 8.7a: Structural Assessment Test for Technical Risks Stock and Flow Model



Message from Vensim

Units are A. O. K..

Figure 8.7b: Dimensional Consistency Check for Technical Risks Stock and Flow Model

Figure 8.7: Evaluation Tests for the Technical Risks Model

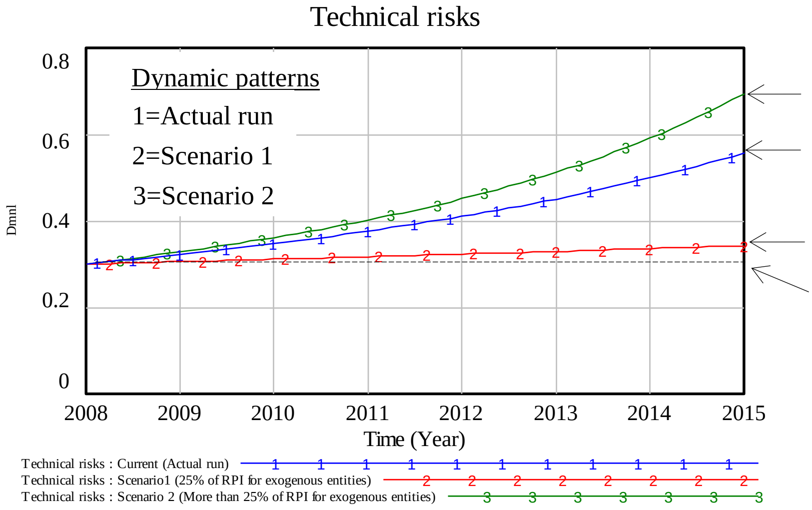
8.3.3.1: Dynamic Simulation Results for Technical Risks System System

The simulated dynamic trajectories of technical risks system variables on megaproject performance in the construction phase constitute predictions on the basis of risk interrelation and connectivity. Their interrelation and connectivity, as formalized by the technical risks model, will need empirical validation once the appropriate data on perceptions of risk are available. Empirical validation (or calibration) normally requires the gathering of data on the dynamic processes that the simulation model aims to represent: does the simulation match relevant real-world data?

In general, the level of anticipated correspondence between model outputs and empirical data depends to a great extent on the purpose of the model and hence on the model specification and structure as dictated by the dynamic hypothesis (causal loop diagram for technical risks sub model) employed in its construction. In modelling complex technical processes, such as the formation of risk perceptions on project time, cost and quality, the richness of the theoretical approaches required to adequately formalize dynamic processes makes a simple approach to empirical validation extremely difficult. However, it is of paramount importance in this research to establish the internal validity of the model (its logic and consistency). Before calibrating the technical risks model, its inner validity was first checked and verified to ensure that the model produces outputs which behave as postulated by the reality of technical risks impacts on ETNP.

As Figure 8.8 illustrates, three simulation scenarios were performed for this model, the current (Actual), base run scenario 1 and base run scenario 2. Risk Priority Indexes (RPIs) for technical risks system variables derived from the ANP methodology were employed as data inputs for the simulations runs. It must be noted that simulations were performed basically to study the influence of change of the level of impact the exogenous risk variables have on the system, and hence their risk priority indexes (RPIs) used for the current (Actual) run were reduced to 25% for base run scenario 1.

Similarly, the RPIs for exogenous system variables were increased by 25% making 125% of the actual value to perform the simulation base run scenario 2. Results of the three simulation scenarios (Current, scenarios 1 and 2) allow the modeller to explore the dynamics of the level of technical risks influences on ETNP in the construction phase based upon the integrated stock and flow diagram deduced from the hypothesized causal loop diagram. The simulations have been run for a period of approximately seven years (2008-2015). The dynamic simulation patterns for the main levels (stocks) within the model namely work to do, technical risks, risks of project time and cost overruns and project quality deficiency are represented in Figure 7.27.



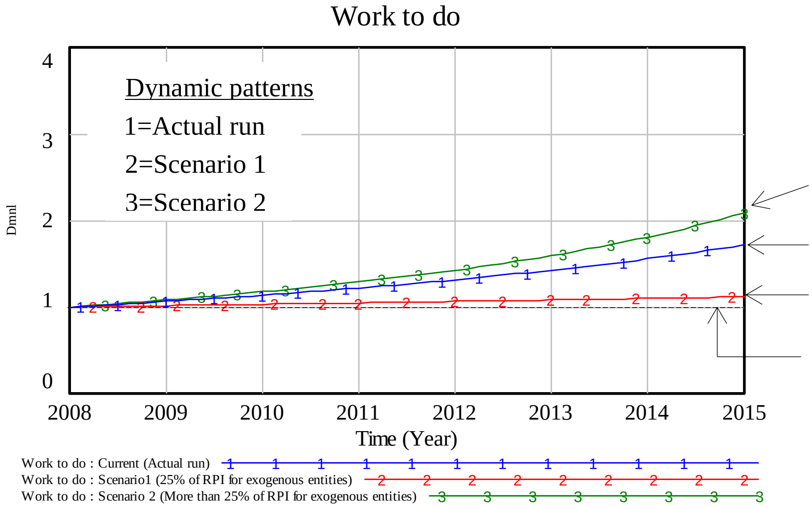
Max value for run 2= 69.50%

Max value (Actual run) = 55.69%

Max value for run 1= 34.25%

Initial RPI for P_{R2} =0.30
(30%) impact level.

a. Dynamic simulation graph for technical risks



Max value for run 2= 108.8%

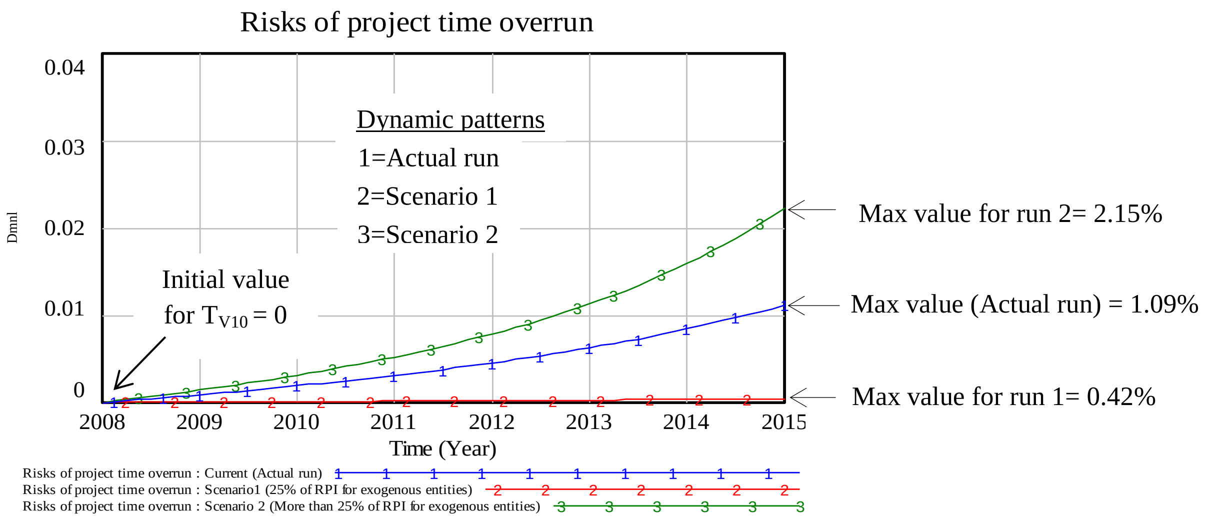
Max value (Actual run) = 71.7%

Max value for run 1= 11.7%

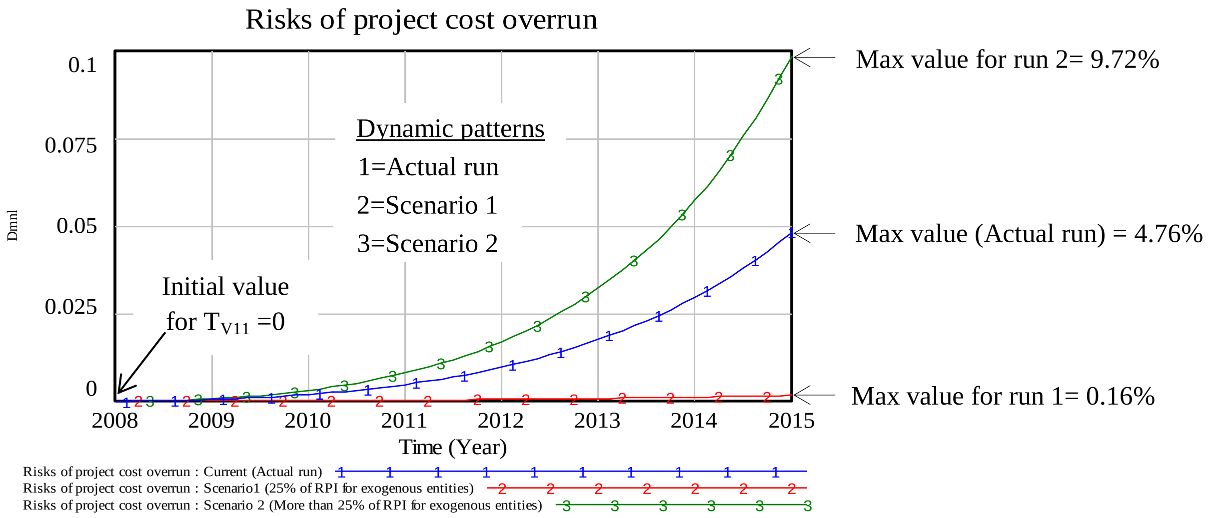
Initial RPI for $\boldsymbol{T_{V24}}$ = 1 (100%)

b. Dynamic simulation graph for work-to-do

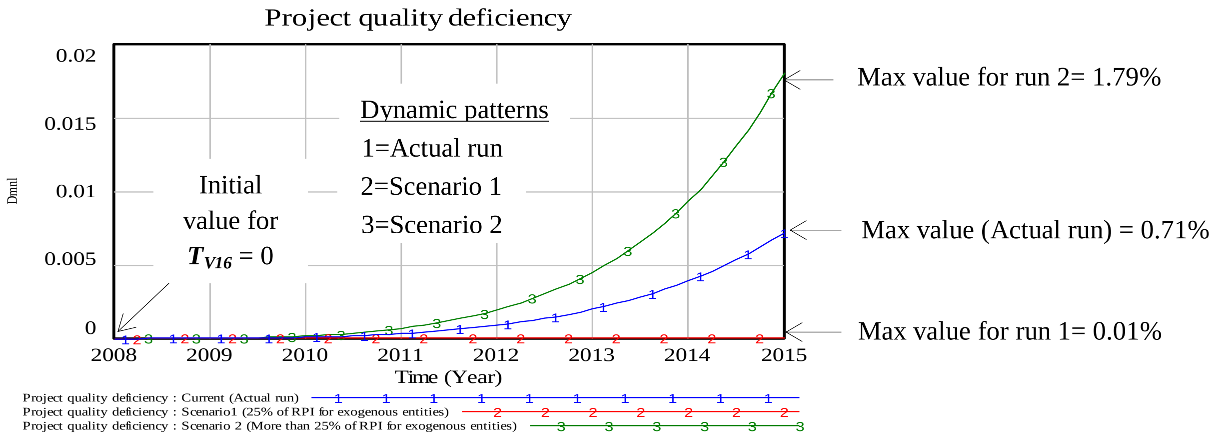
Figure 8.8: Dynamic Simulation Behaviour Patterns for Stocks in the Technical Risk System Model



c. Dynamic simulation graph for risks of project time overrun



d. Dynamic simulation graph for risks of project cost overrun



e. Dynamic simulation graph for project quality deficiency.

Figure 8.8: Dynamic Simulation Behaviour Patterns for Stocks in the Technical Risk System Model (Continued)

As indicated in Figure 8.8a, the actual behaviour pattern of technical risks reveals that the influences of risk variables within the system led to gradual exponential growth of 0.3 (30%) from 2008 to 0.5569 (55.69%) by 2015. This implies that, more rework will be carried out and hence increase in work to do as depicted by the dynamic pattern in Figure 8.8b. As illustrated in Figures 8.8c and d, growths observed in the technical risks and work to do cause dramatic impacts on project time, cost and quality and as such contributed amplified effects to the level of risks of project time and cost overruns and quality deficiency.

Table 8.7 provides detailed dynamic results of all risk variables within the technical risks system model generated by Vensim's built-in function. The results have added advantages for the project manager during risk assessment in transportation megaprojects in the construction phase such that they can be compared with real values generated during the course of construction. Where risk levels try to exceed expected levels, proactive mitigation can be implemented to reduce such risks. This implies that statistical values generated by the SDANP approach can help to understand the effects of technical risk factors on project performance at different stages within the construction phase over time before construction begins. Summaries of the dynamic risk results on the performance of ETNP are indicated in Table 8.7 and Table 8.8 respectively.

Table 8.7: Dynamic Simulation Results for Technical Risks System

Time (Year)	**ANP Inputs*(%)**														**T_{V1}**	**T_{V4}**	**T_{V5}**	**T_{V8}**	**T_{V9}**	**T_{V12}**
															06	06	08	03	04	13
	SD Simulation Outputs (%)																			
	P_{R2}	T_{V2}	T_{V3}	T_{V6}	T_{V7}	T_{V10}	T_{V11}	T_{V13}	T_{V14}	T_{V15}	T_{V16}	T_{V17}	T_{V18}	T_{V19}	T_{20}	T_{V21}	T_{V22}	T_{V23}	T_{V24}	T_{V25}
2008.000	30*	13	100	0.27	13	0.00	0.00	0.00	0.00	0.00	0.00	6.02	0.00	0.08	0.00	0.03	2.11	0.00	100.00	0.00
2008.125	30	13	101	0.28	13	0.01	0.00	0.00	0.00	0.00	0.00	6.11	0.01	0.09	0.00	0.03	2.14	0.00	100.75	0.00
2008.250	31	13	102	0.28	13	0.02	0.00	0.00	0.00	0.00	0.00	6.21	0.02	0.09	0.00	0.03	2.18	0.00	101.52	0.00
2008.375	31	13	103	0.29	13	0.03	0.00	0.00	0.00	0.00	0.00	6.30	0.03	0.09	0.00	0.03	2.21	0.00	102.29	0.00
2008.500	31	13	103	0.29	13	0.04	0.01	0.00	0.00	0.00	0.00	6.40	0.04	0.09	0.00	0.03	2.25	0.00	103.08	0.00
2008.625	31	13	104	0.30	13	0.05	0.01	0.00	0.00	0.00	0.00	6.50	0.06	0.09	0.00	0.03	2.29	0.00	103.88	0.00
2008.750	32	13	105	0.30	13	0.07	0.02	0.00	0.00	0.00	0.00	6.60	0.07	0.09	0.00	0.03	2.33	0.00	104.69	0.00
2008.875	32	13	106	0.31	13	0.08	0.03	0.00	0.00	0.00	0.00	6.70	0.08	0.09	0.00	0.03	2.37	0.00	105.52	0.00
2009.000	32	13	107	0.31	13	0.09	0.04	0.00	0.00	0.00	0.00	6.81	0.09	0.10	0.00	0.03	2.41	0.00	106.35	0.00
2009.125	33	13	108	0.32	13	0.10	0.05	0.00	0.00	0.00	0.00	6.92	0.11	0.10	0.00	0.03	2.45	0.00	107.21	0.00
2009.250	33	13	108	0.32	13	0.11	0.06	0.00	0.01	0.01	0.00	7.03	0.12	0.10	0.01	0.03	2.49	0.00	108.07	0.00
2009.375	33	13	109	0.33	13	0.13	0.08	0.00	0.01	0.01	0.00	7.15	0.14	0.10	0.01	0.03	2.53	0.00	108.95	0.00
2009.500	33	13	110	0.34	13	0.14	0.10	0.00	0.01	0.01	0.00	7.26	0.15	0.10	0.01	0.03	2.58	0.00	109.84	0.00
2009.625	34	13	111	0.34	13	0.15	0.12	0.00	0.01	0.01	0.00	7.38	0.17	0.11	0.01	0.04	2.62	0.00	110.75	0.00
2009.750	34	13	112	0.35	13	0.17	0.14	0.00	0.01	0.01	0.01	7.51	0.18	0.11	0.01	0.04	2.67	0.00	111.67	0.00
2009.875	34	13	113	0.35	13	0.18	0.16	0.00	0.01	0.01	0.01	7.63	0.20	0.11	0.01	0.04	2.72	0.00	112.61	0.00
2010.000	35	13	114	0.36	13	0.19	0.18	0.00	0.02	0.02	0.01	7.76	0.22	0.11	0.02	0.04	2.77	0.00	113.57	0.00

** Refer to Table 6.11: Summary of final ANP decision making priority results for all risks on page 169*

Table 8.7: Dynamic Simulation Results for Technical Risks System (continued)

Time (Year)	**ANP Inputs*(%)**														**T_{V1}**	**T_{V4}**	**T_{V5}**	**T_{V8}**	**T_{V9}**	**T_{V12}**
															06	06	08	03	04	13
	SD Simulation Outputs (%)																			
	P_{R2}	T_{V2}	T_{V3}	T_{V6}	T_{V7}	T_{V10}	T_{V11}	T_{V13}	T_{V14}	T_{V15}	T_{V16}	T_{V17}	T_{V18}	T_{V19}	T_{20}	T_{V21}	T_{V22}	T_{V23}	T_{V24}	T_{V25}
2010.125	35	13	115	0.37	13	0.21	0.21	0.00	0.02	0.02	0.01	7.90	0.24	0.11	0.02	0.04	2.82	0.00	114.54	0.00
2010.250	35	13	116	0.37	13	0.22	0.24	0.00	0.02	0.02	0.01	8.03	0.26	0.12	0.02	0.04	2.87	0.00	115.52	0.00
2010.375	36	13	117	0.38	13	0.23	0.27	0.00	0.02	0.02	0.02	8.17	0.28	0.12	0.02	0.04	2.93	0.00	116.53	0.00
2010.500	36	13	118	0.39	13	0.25	0.31	0.00	0.03	0.03	0.02	8.32	0.30	0.12	0.03	0.04	2.98	0.00	117.55	0.00
2010.625	37	13	119	0.40	13	0.26	0.35	0.00	0.03	0.03	0.02	8.47	0.32	0.12	0.03	0.04	3.04	0.00	118.59	0.00
2010.750	37	13	120	0.40	13	0.28	0.38	0.00	0.03	0.03	0.02	8.62	0.34	0.12	0.03	0.05	3.10	0.00	119.65	0.00
2010.875	37	13	121	0.41	13	0.30	0.43	0.00	0.04	0.04	0.03	8.77	0.36	0.13	0.04	0.05	3.16	0.00	120.73	0.00
2011.000	38	13	122	0.42	13	0.31	0.47	0.01	0.04	0.04	0.03	8.93	0.39	0.13	0.04	0.05	3.22	0.01	121.82	0.00
2011.125	38	13	123	0.43	13	0.33	0.52	0.01	0.04	0.04	0.04	9.10	0.42	0.13	0.04	0.05	3.28	0.01	122.94	0.00
2011.250	38	13	124	0.44	13	0.35	0.57	0.01	0.05	0.05	0.04	9.27	0.44	0.14	0.05	0.05	3.35	0.01	124.08	0.00
2011.375	39	13	126	0.44	13	0.36	0.63	0.01	0.05	0.05	0.05	9.44	0.47	0.14	0.05	0.05	3.42	0.01	125.23	0.00
2011.500	39	13	127	0.45	13	0.38	0.69	0.01	0.06	0.06	0.06	9.62	0.50	0.14	0.06	0.06	3.49	0.01	126.41	0.00
2011.625	40	13	128	0.46	13	0.40	0.75	0.01	0.06	0.06	0.06	9.80	0.53	0.14	0.06	0.06	3.56	0.01	127.62	0.00
2011.750	40	13	129	0.47	13	0.42	0.82	0.01	0.07	0.07	0.07	9.99	0.56	0.15	0.07	0.06	3.63	0.01	128.84	0.00
2011.875	41	13	130	0.48	13	0.44	0.89	0.01	0.08	0.08	0.08	10.19	0.60	0.15	0.08	0.06	3.71	0.01	130.09	0.00
2012.000	41	13	132	0.49	13	0.45	0.96	0.01	0.08	0.08	0.09	10.39	0.63	0.15	0.08	0.06	3.78	0.01	131.37	0.00
2012.125	42	13	133	0.50	13	0.47	1.04	0.01	0.09	0.09	0.10	10.60	0.67	0.16	0.09	0.07	3.87	0.01	132.66	0.00
2012.250	42	13	134	0.51	13	0.49	1.13	0.01	0.10	0.10	0.11	10.81	0.71	0.16	0.10	0.07	3.95	0.01	133.99	0.00
2012.375	42	13	136	0.52	13	0.52	1.22	0.01	0.10	0.10	0.12	11.03	0.75	0.17	0.10	0.07	4.03	0.01	135.34	0.00
2012.500	43	13	137	0.54	13	0.54	1.31	0.01	0.11	0.11	0.14	11.25	0.79	0.17	0.11	0.07	4.12	0.01	136.72	0.00
2012.625	43	13	138	0.55	13	0.56	1.41	0.02	0.12	0.12	0.15	11.49	0.84	0.17	0.12	0.08	4.21	0.02	138.12	0.00
2012.750	44	13	140	0.56	13	0.58	1.52	0.02	0.13	0.13	0.16	11.73	0.89	0.18	0.13	0.08	4.31	0.02	139.56	0.00
2012.875	45	13	141	0.57	13	0.60	1.63	0.02	0.14	0.14	0.18	11.98	0.94	0.18	0.14	0.08	4.41	0.02	141.03	0.00
2013.000	45	13	143	0.59	13	0.63	1.75	0.02	0.15	0.15	0.20	12.23	0.99	0.19	0.15	0.08	4.51	0.02	142.52	0.00

Table 8.7: Dynamic Simulation Results for Technical Risks System (continued)

Time (Year)	**ANP Inputs*(%)**														**T_{V1}**	**T_{V4}**	**T_{V5}**	**T_{V8}**	**T_{V9}**	**T_{V12}**
															06	06	08	03	04	13
	SD Simulation Outputs (%)																			
	P_{R2}	T_{V2}	T_{V3}	T_{V6}	T_{V7}	T_{V10}	T_{V11}	T_{V13}	T_{V14}	T_{V15}	T_{V16}	T_{V17}	T_{V18}	T_{V19}	T_{20}	T_{V21}	T_{V22}	T_{V23}	T_{V24}	T_{V25}
2013.125	46	13	144	0.60	13	0.65	1.87	0.02	0.16	0.16	0.22	12.50	1.04	0.19	0.16	0.09	4.61	0.02	144.05	0.00
2013.250	46	13	146	0.61	13	0.68	2.00	0.02	0.17	0.17	0.24	12.77	1.10	0.20	0.17	0.09	4.72	0.02	145.61	0.00
2013.375	47	13	148	0.63	13	0.70	2.14	0.02	0.18	0.18	0.26	13.05	1.16	0.20	0.18	0.10	4.83	0.02	147.21	0.00
2013.500	47	13	149	0.64	13	0.73	2.29	0.03	0.20	0.20	0.28	13.34	1.22	0.21	0.20	0.10	4.95	0.03	148.84	0.00
2013.625	48	13	151	0.66	13	0.76	2.44	0.03	0.21	0.21	0.31	13.64	1.29	0.21	0.21	0.10	5.06	0.03	150.51	0.00
2013.750	49	13	153	0.67	13	0.78	2.61	0.03	0.23	0.23	0.33	13.96	1.36	0.22	0.23	0.11	5.19	0.03	152.21	0.00
2013.875	49	13	154	0.69	13	0.81	2.78	0.03	0.24	0.24	0.36	14.28	1.43	0.23	0.24	0.11	5.32	0.03	153.96	0.00
2014.000	50	13	156	0.71	13	0.84	2.96	0.03	0.26	0.26	0.39	14.61	1.51	0.23	0.26	0.12	5.45	0.03	155.74	0.00
2014.125	51	13	158	0.73	13	0.87	3.15	0.04	0.27	0.27	0.42	14.96	1.59	0.24	0.27	0.12	5.59	0.04	157.57	0.00
2014.250	51	13	160	0.74	13	0.90	3.35	0.04	0.29	0.29	0.46	15.32	1.67	0.25	0.29	0.13	5.73	0.04	159.44	0.00
2014.375	52	13	161	0.76	13	0.94	3.56	0.04	0.31	0.31	0.49	15.69	1.76	0.25	0.31	0.13	5.88	0.04	161.35	0.00
2014.500	53	13	164	0.78	13	0.97	3.79	0.04	0.33	0.33	0.53	16.07	1.86	0.26	0.33	0.14	6.03	0.04	163.32	0.00
2014.625	53	13	166	0.80	13	1.00	4.02	0.05	0.35	0.35	0.57	16.47	1.95	0.27	0.35	0.14	6.19	0.05	165.32	0.00
2014.750	54	13	168	0.83	13	1.04	4.27	0.05	0.38	0.38	0.62	16.88	2.06	0.28	0.38	0.15	6.35	0.05	167.38	0.00
2014.875	55	13	170	0.85	13	1.08	4.53	0.05	0.40	0.40	0.66	17.31	2.17	0.29	0.40	0.16	6.53	0.05	169.49	0.00
2015.000	56	13	172	0.87	13	1.12	4.81	0.06	0.42	0.42	0.71	17.76	2.28	0.30	0.42	0.17	6.71	0.06	171.66	0.00

** Refer to Table 6.11: Summary of final ANP decision making priority results for all risks on page 169.*

Table 8.8: Summary of Dynamic Simulation Results for Technical Risks System Model

ANP/SD Simulation Results

Code	**Risk factor**	***ANP inputs (%)**
T_{V1}:	Ambiguity of project scope/ Scope change	06
T_{V4}:	Project modification	06
T_{V5}:	Project cost estimate problems	08
T_{V8}:	Engineering and design change	03
T_{V9}:	Supply chain breakdown	04
T_{V12}:	Inadequate site investigation	13
P_{R2}:	Technical risks	30

		SD Simulation Outputs (%)					
		Min	*Max*	*Mean*	*Median*	*StDev*	*(Norm)*
P_{R2}	Technical risks	30.00	55.69	40.48	39.28	7.41	18.31
T_{V2}:	Ground conditions problems	13.00	13.00	13.00	13.00	0.00	0.00
T_{V3}:	Project complexity	100.36	172.02	129.94	126.77	20.69	15.92
T_{V6}:	Modification to project design	0.27	0.87	0.49	0.45	0.17	34.47
T_{V7}:	Technical difficulties in utilities diversions	13.00	13.00	13.00	13.00	0.00	0.00
T_{V10}:	Risks of project time overrun	0.00	1.09	0.43	0.38	0.31	71.90
T_{V11}:	Risks of project cost overrun	0.00	4.76	1.24	0.69	1.35	108.70
T_{V13}:	Cost of delay in utility diversion	0.00	0.06	0.01	0.01	0.02	110.46
T_{V14}:	Cost of rework	0.00	0.42	0.11	0.06	0.12	110.46
T_{V15}:	Error generation	0.00	0.42	0.11	0.06	0.12	110.46
T_{V16}:	Project quality deficiency	0.00	0.71	0.15	0.06	0.20	128.29
T_{V17}:	Project scope.	6.02	17.76	10.37	9.62	3.40	32.21
T_{V18}:	Escalation to project cost overrun	0.00	2.28	0.71	0.50	0.63	89.64
T_{V19}:	Escalation to project time overrun	0.08	0.30	0.16	0.14	0.06	37.94
T_{V20}:	Rework	0.00	0.42	0.11	0.06	0.12	110.46
T_{V21}:	Technical certainties	0.03	0.17	0.07	0.06	0.04	56.56
T_{V22}:	Technical uncertainties	2.11	6.71	3.79	3.49	1.31	34.47
T_{V23}:	Time to divert underground utilities	0.00	0.06	0.01	0.01	0.02	110.46
T_{V24}:	Work to do	100.00	171.66	129.58	126.41	20.69	15.97
T_{V25}:	Worksite coordination problems	0.00	0.00	0.00	0.00	0.00	167.24

*Current simulation runs Time (Year) for technical risk model = 2008 to 2015, * Refer to Table 6.11: Summary of final ANP decision making priority results for all risks on page 169.*

- ***Analysis of the Simulation Results for the Level of Risk Impact on Project Objectives***

The level of technical risk impacts on the objectives of the case study transportation megaprojects are described as being mainly risks of project time and cost overruns and project quality deficiency. As indicated on Table 8.9, the level and extent to which technical risks affect the objectives of transportation megaproject during construction are presented using a one-way analysis of variance (ANOVA) of the technical risks impact on project time, cost and quality. The aim of the one-way analysis of variance (ANOVA) is to explore whether one particular project objective experiences more technical risk impact than those of other project objectives when using an alpha of .001. If so, what will be the nature of these distinctions and if not, what will be the form of the similarities.

Table 8.9: One-Way Analysis of Variance: The Level and Extent to which Technical Risks Affect the Objectives of the Case Study Megaproject during Construction

Project objectives	**Level of Technical Risks Impact on Project Objectives (%)**				
	Mean		Std. deviation		
Time	0.43		0.31		
Cost	1.24		1.35		
Quality	0.15		0.20		
Variance	**The Extent to which Technical Risks Impact on Project Objectives (Time, Cost and Quality)**				
	Sum of squares	Degrees of freedom (df).	Mean square	F	P
Between project objectives	36.720	2	18.360	27.242	.000
Within project objectives	113.227	168	0.674		
Total	149.947	170			

Field Survey 2013

As presented in Table 8.9, the one-way analysis of variance reveals that project time, cost and quality of transportation megaprojects are impacted by technical risks. The mean scores reveal that project cost (1.24%) is affected most, followed by the project time (0.43%) and then the project quality (0.15%). Subjecting the results to one-way analysis of variance (ANOVA), the F (obtained) is 27.242 which far exceeds the F-critical value of 7.41 for this test when using an alpha of .001. Correspondingly, the observed p-value of .000 is well below the chosen alpha of .001. By either standard, it implies that the difference between the levels of technical risks impact on the objectives of the cases study project is statistically non-significant.

8.3.4. Integrated Stock and Flow Model for the Economic Risks System

Economic risk is taken into account in any field, with consequences which cannot always be foreseen or anticipated. An important objective of this section is the understanding of a megaproject’s full risk exposure to potential financial risk factors, and how the project has to mitigate such risks. Project finance relies on asset and counterparty performance, but social, political, environmental and technical events can excuse performance by parties when they are confronted with unanticipated events outside their control. That is to say, project finance is subject to strong political influence and contradictory technical opinions about the project’s economic feasibility and its associated social and environmental impacts.

This section of the report therefore does not intend to bring new facts or technical data to feed the debate. However, its contribution stems from deep analysis of the broad material already produced in literature review, through questionnaire survey and through interviews conducted with experts involved in megaproject development. The approach strives to translate available information on social, technical, political and environmental risks into economic risks, using the following steps:

i. Integrated stock and flow diagram construction
ii. Model equations formulation
iii. Model testing- structural assessment and dimensional consistency
iv. Dynamic simulation results and discussion
v. Analysis of dynamic simulation results for project objectives

- ***Integrated Stock and Flow Diagram:*** The integrated stock and flow diagram for the economic risks sub system illustrated in Figure 8.9 is developed based on the validated causal loop diagram indicated in Figure 7.11 (See Chapter 7). It is developed with material price, economic risks, risk of project time overrun, risk of project cost overrun and quality deficiency on the focus.

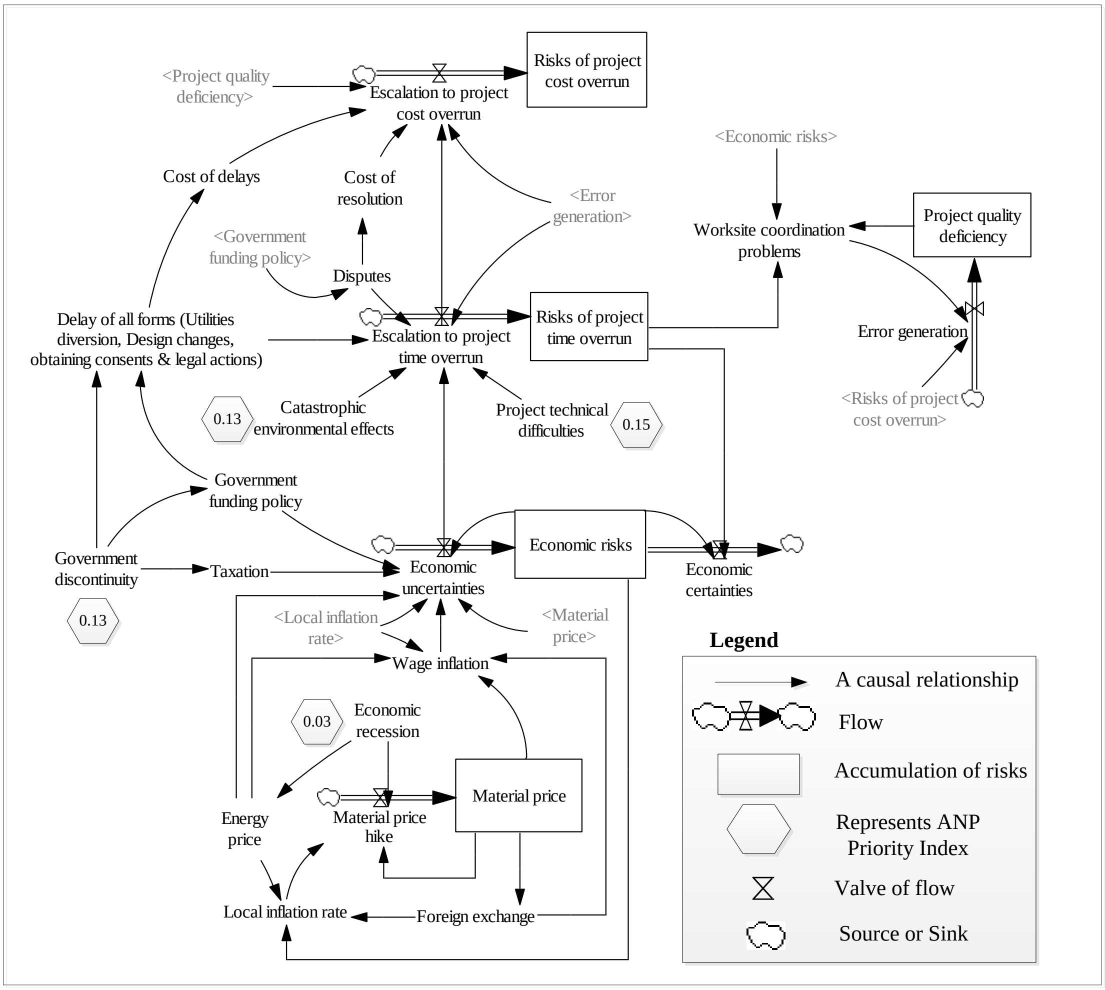


Figure 8.9: Integrated economic risks stock and flow diagram

It can be observed from Figure 8.9 that the economic recession, local inflation rate and material price have direct influence on the controlling system variable *material price hike* which stocks *material price.* The stock '*Economic risks'* is in turn influenced by several other variables through the economic uncertainties as shown. Further, it has to be noted that economic risks is affected by economic certainties. Similarly, risks of project time and cost overruns are influenced by escalation to project time overrun and escalation to project cost overrun to stock risks of project time and cost overruns respectively. Further consideration shows that a number of variables influence risks of project time and cost overruns through escalations to project time and cost overruns as detailed in the stock and flow diagram represented in Figure 8.9.

- ***Model Equation Formulation:*** The governing equations used to calculate the system parameters for this model are given in Table 8.10.

Table 8.10: Mathematical Model for the Integrated Economic Risks System Model

Code	System Variables	Equations	Measurement
P_{R3}	Economic risks	INTEG (Economic uncertainties-Economic certainties, 0.25)	Dimensionless
E_{V1}:	Government funding policy	Government discontinuity*Initial ANP value (RPI) for E_{V1} (0.17)	Dimensionless
E_{V2}:	Taxation	Government discontinuity* Initial ANP value (RPI) for E_{V2} per Unit time	Dimensionless
E_{V3}:	Government discontinuity	Initial ANP value (RPI) for E_{V3} (Constant)	
E_{V4}:	Wage inflation;	0.03*((Energy price +Foreign exchange +Local inflation rate)+(Material price per unit time))	Dimensionless/Year
E_{V5}:	Local inflation	(Economic risks/Unit time)+Energy price +Foreign exchange	Dimensionless /Year
E_{V6}:	Foreign exchange	(Material price*0.03) per Unit time	Dimensionless /Year
E_{V7}:	Material price	INTEG (Material price change hike, 0.08)	Dimensionless
E_{V8}:	Economic recession	Initial ANP value (RPI) for E_{V8}(Constant)	Dimensionless
E_{V9}:	Energy price	Economic recession*0.05	Dimensionless
E_{V10}:	Catastrophic environ. effects	Initial ANP value (RPI) for E_{V10} (Constant)	Dimensionless
E_{V11}:	Project technical difficulties	Initial ANP value (RPI) for E_{V11} (Constant)	Dimensionless
E_{V12}:	Project delays of all forms	Government funding policy * Government discontinuity*0.19	Dimensionless
E_{V13}:	Cost of delays	Delay of all forms	Dimensionless
E_{V14}:	Cost of dispute resolution	Disputes	Dimensionless
E_{V15}:	Disputes	Government funding policy	Dimensionless
E_{V16}:	Economic certainties	(Risks of project time overrun * Economic risks) per unit time	Dimensionless/Year

Field Survey 2013

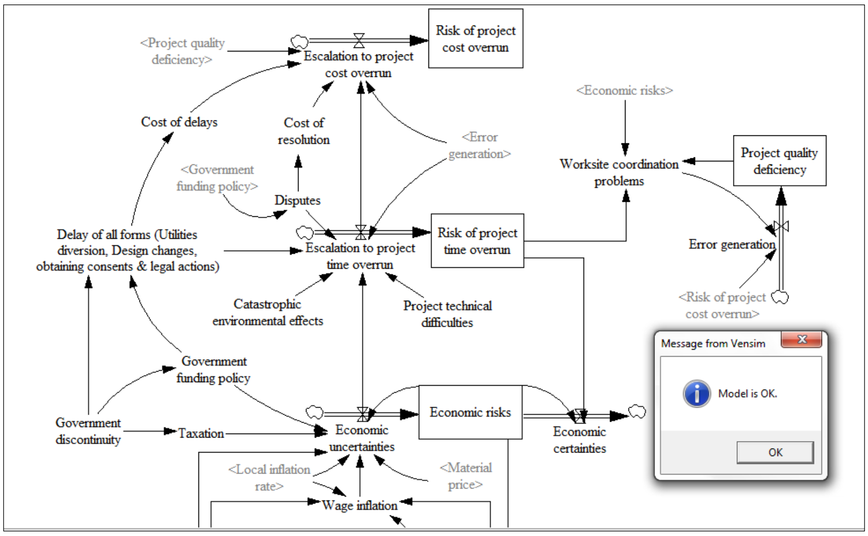
Table 8.10: Mathematical Model for the Integrated Economic Risks System Model (Continued)

Code	System Variables	Equations	Measurement
E_{V17}:	Economic uncertainties	(Economic risks +Government funding policy)*((Local inflation rate +Taxation +Wage inflation)-(Energy price + Material price/unit time))	Dimensionless/Year
E_{V18}:	Error generation	Error generation= (Risks of project cost overrun*Worksite coordination problems) per unit time	Dimensionless/Year
E_{V19}:	Escalation to project cost overrun	((Escalation to project time overrun*Error generation)*unit time)+ (Project quality deficiency /unit time) + ((Cost of delays +Cost of resolution)/ unit time))	Dimensionless /Year
E_{V20}:	Escalation to project time overrun	((Error generation +Economic uncertainties) + (Disputes/unit time)) + ((Catastrophic environmental effects* Project technical difficulties)*"Delay of all forms (Utilities diversion, Design changes, obtaining consents & legal actions))/unit time	Dimensionless /Year
E_{V21}:	Material price hike	((Material price)*(Local inflation rate + Economic recession)) per unit time	Dimensionless /Year
E_{V22}:	Project quality deficiency	INTEG ((Error generation, 0)	Dimensionless
E_{V23}:	Risks of project cost overrun	INTEG (Escalation to project cost overrun, 0)	Dimensionless
E_{V24}:	Risks of project time overrun	INTEG (Escalation to project time overrun, 0)	Dimensionless
E_{V25}:	Worksite coordination problems	(Risks of project time overrun*Project quality deficiency +Economic risks)	Dimensionless

Field Survey 2013

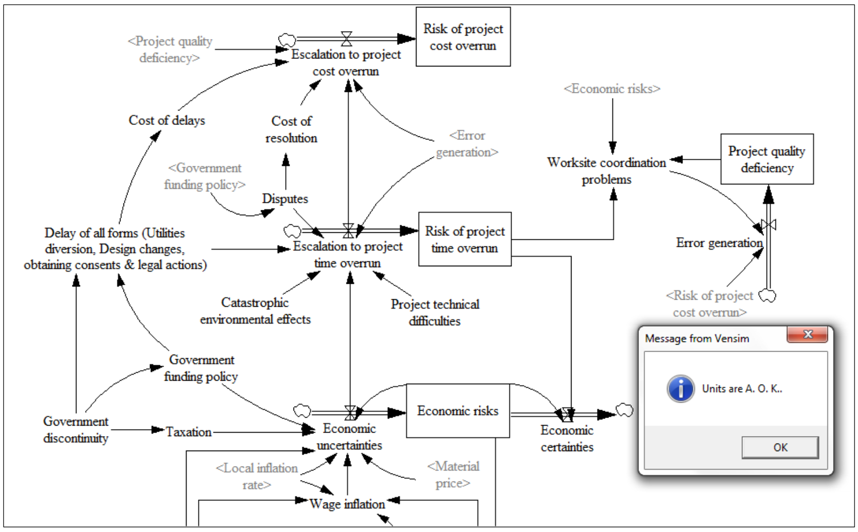
- ***Model Testing- Structural Assessment and Dimensional Consistency***

The next step was to conduct the structural assessment and dimensional consistency tests on the stock and flow model. As illustrated in Figure 8.10, messages from Vensim's built-in function indicate that the structural assessment and dimensional tests conducted on the economic risks model are consistent.



Model is OK.

Figure 8.10a: Structural Assessment Test for Economic Risks Stock and Flow Model



Units are A. O. K..

Figure 8.10b: Dimensional Consistency Check for Economic Risks Stock and Flow Model

Figure 8.10: Evaluation Tests for the Economic Risks Model

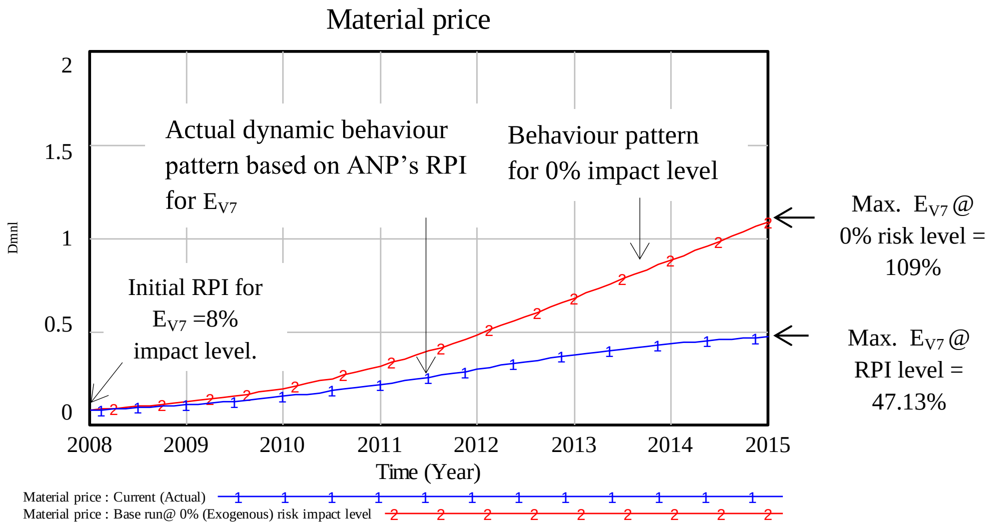
- ***Dynamic Simulation Results and Discussion:***

Simulation parameters support the dynamic hypothesis (stock and flow diagram) by given them real values, which are necessary for conducting simulation. It is to be noted that, in system dynamics simulation, it is the trend analysis which is given importance and numbers do not have much significance, however, the numbers should be, as far as possible, close to the real life situations. In the context of the economic risks modeling, Table 8.11 has been produced to indicate the model parameters, ANP inputs and the dynamic simulation outputs under the following time bounds:

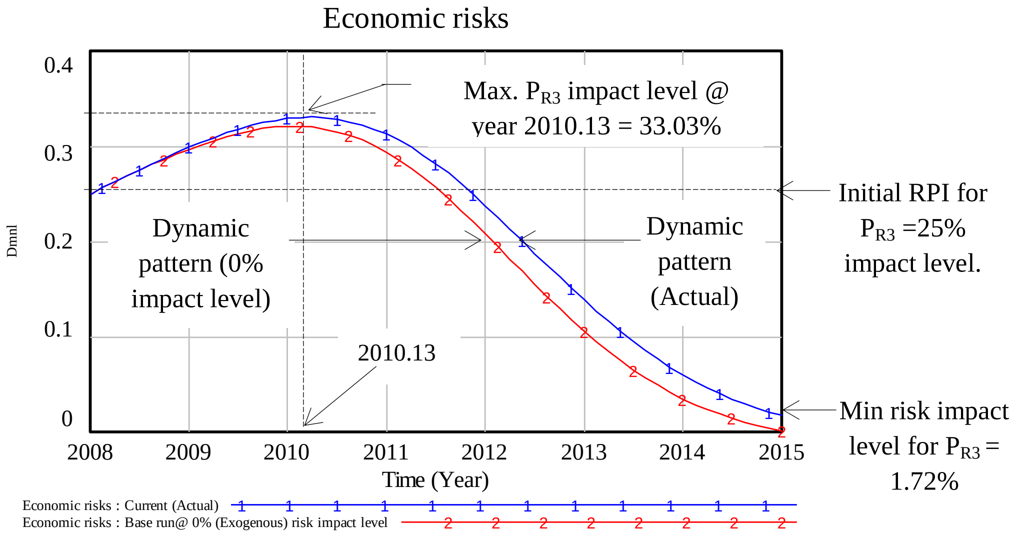
i. The initial time for the simulation = 2008, Units: Year
ii. The final time for the simulation= 2015, Units: Year
iii. The time step for the simulation = 0.125, Units: Year

Basically, the dynamic simulation was performed to study the influences of exogenous parameters (economic recession, government discontinuity, catastrophic environmental effects and project technical difficulties) on economic risks, risks of project time and cost overruns and project quality deficiency and hence, the values are fixed as 0% for no influence and 100% for current (actual) risk priority index level obtained from the ANP pairwise calculations. Figure 8.11 shows the dynamic simulation patterns of the stock variables indicating the behaviour trends for material price, economic risks, risks of time and cost overruns and project quality deficiency. The dynamic simulation outputs for all system variables within the economic risks model are also represented in Tables 8.11 and 8.12 respectively.

With no influence from the exogenous system variables in the system, the initial dynamic pattern (base run) in Figure 8.11a turns to increase steadily. However, when the values change to the actual ANP risk priority indexes, it can be observed that after two years, the material price stabilized between the fourth quarter of 2011 and the first quarter of 2012 before declining slowly from the first quarter of 2012 till the end of 2014. This is so because as no works commenced; higher will be the time period for material prices to be stabilized from the developer's point of view. But when construction proceeds, the larger will be the volume of works completed as a result, lower will be the material price level when contractor-supplier relations improved.

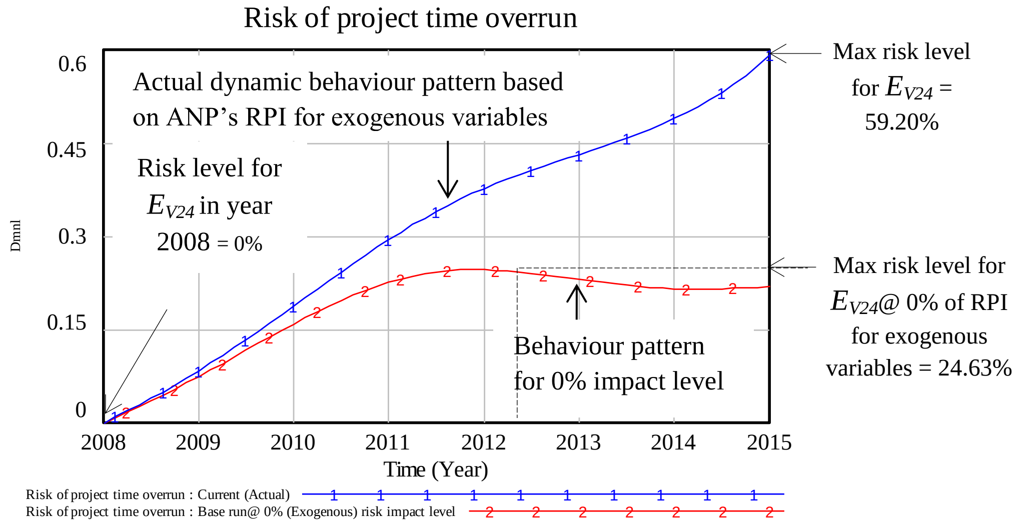


a: Baserun and actual scenario simulation patterns for material price



b: Baserun and actual scenario simulation patterns for economic risks

Figure 8.11: Dynamic Simulation Patterns for Stock Entities in the Economic Risks Model



Risk of project time overrun

Actual dynamic behaviour pattern based on ANP's RPI for exogenous variables

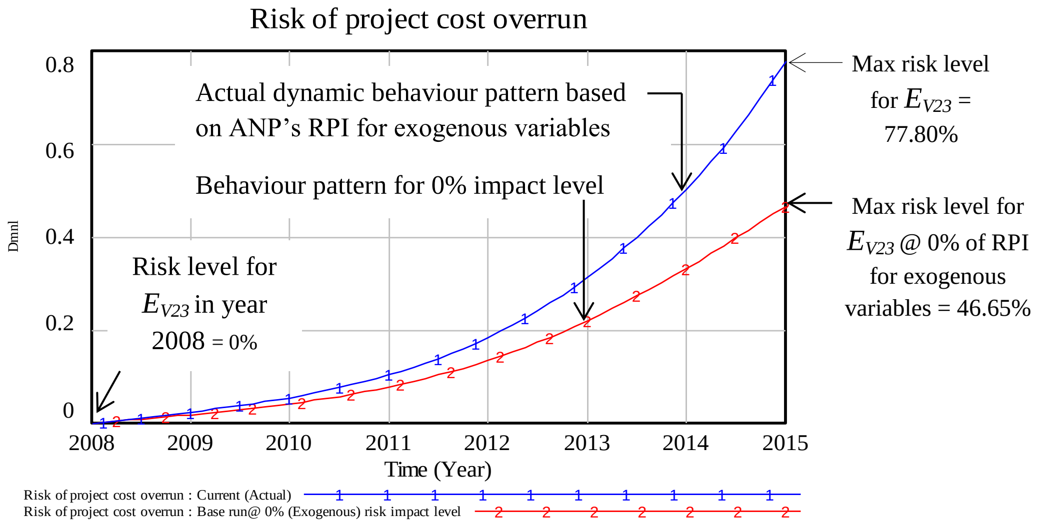
Risk level for E_{V24} in year 2008 = 0%

Behaviour pattern for 0% impact level

Max risk level for E_{V24} = 59.20%

Max risk level for E_{V24}@ 0% of RPI for exogenous variables = 24.63%

c: Baserun and actual scenario simulation patterns for risks of project time overrun



Risk of project cost overrun

Actual dynamic behaviour pattern based on ANP's RPI for exogenous variables

Behaviour pattern for 0% impact level

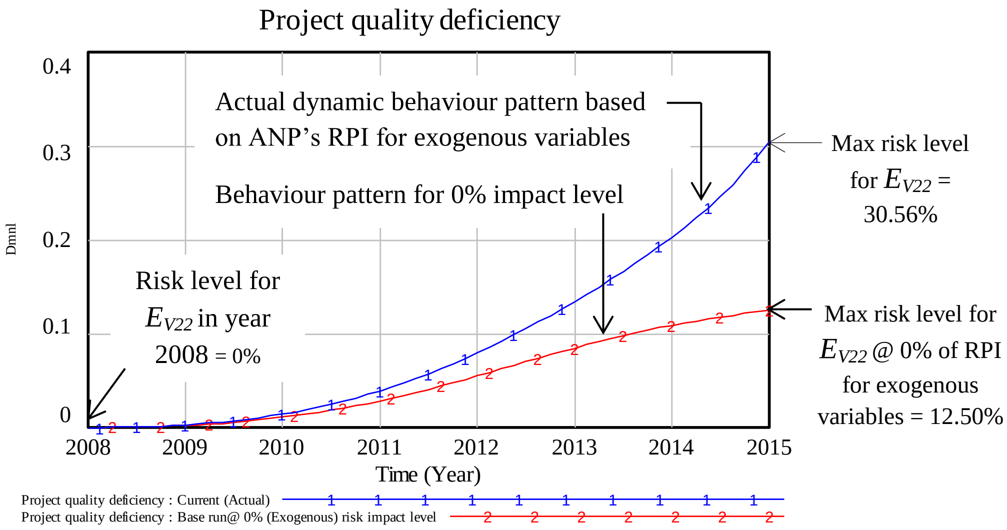
Risk level for E_{V23} in year 2008 = 0%

Max risk level for E_{V23} = 77.80%

Max risk level for E_{V23} @ 0% of RPI for exogenous variables = 46.65%

d: Baserun and actual scenario simulation patterns for risks of project cost overrun

Figure 8.11: Dynamic Simulation Patterns for Stock Entities in the Economic Risks Model (Continued)



e: Baserun and actual scenario simulation patterns for project quality deficiency

Figure 8.11: Dynamic Simulation Patterns for Stock Entities in the Economic Risks Model (Continued)

Also, it can be observed in Figure 8.11b that, the dynamic pattern of economic risks (P_{R3}) simulation graph increased steadily to reach a maximum point of 33.03% at year 2010.13 before declining to a minimum value of 1.72% in year 2015. It is important to note that, even with no influence level of exogenous system variables, the level of economic risks impact was as close to 32% in 2010.13 but with a minimum impact level of 0% in year 2015. From a holistic point of view, whether values of exogenous economic risk variables are changed or not for scenarios purposes, the overall dynamic patterns for risks of project time and cost overruns and project quality deficiency will seem to increase to a considerable impact level, which will then become a critical point to the megaproject developer. This is where the experience of a project manager and his/her ability to plan for effective risks assessment will come into play. Therefore, SDANP based simulation should only substantiate or aid managerial decisions.

Table 8.11: Dynamic Simulation Results for the Economic Risks System

Time (Year)	***ANP Inputs (%)**													
	Risk code	P_{R3}	E_{V1}	E_{V2}	E_{V3}	E_{V4}	E_{V5}	E_{V6}	E_{V7}	E_{V8}	E_{V9}	E_{V10}	E_{V11}	E_{V12}
	Risks priority index (%)	25	17	03	13	03	03	03	08	03	05	13	15	19

Time (Year)	**SD Simulation Outputs (%)**																					
	P_{R3}	E_{V1}	E_{V2}	E_{V4}	E_{V5}	E_{V6}	E_{V7}	E_{V9}	E_{V12}	E_{V13}	E_{V14}	E_{V15}	E_{V16}	E_{V17}	E_{V18}	E_{V19}	E_{V20}	E_{V21}	E_{V22}	E_{V23}	E_{V24}	E_{V25}
2008.000	25.00	2.21	0.39	1.01	25.39	0.24	8.00	0.15	0.05	0.05	2.21	2.21	0.00	5.07	0.00	2.26	7.28	2.27	0.00	0.00	0.00	25.0
2008.125	25.63	2.21	0.39	1.04	26.03	0.25	8.28	0.15	0.05	0.05	2.21	2.21	0.23	5.30	0.07	2.27	7.58	2.41	0.00	0.28	0.91	25.6
2008.250	26.27	2.21	0.39	1.07	26.67	0.26	8.58	0.15	0.05	0.05	2.21	2.21	0.49	5.52	0.15	2.29	7.88	2.55	0.01	0.57	1.86	26.3
2008.375	26.90	2.21	0.39	1.10	27.31	0.27	8.90	0.15	0.05	0.05	2.21	2.21	0.76	5.75	0.23	2.31	8.19	2.70	0.03	0.85	2.84	26.9
2008.500	27.52	2.21	0.39	1.13	27.95	0.28	9.24	0.15	0.05	0.05	2.21	2.21	1.06	5.97	0.31	2.35	8.49	2.86	0.06	1.14	3.87	27.5
2008.625	28.13	2.21	0.39	1.16	28.57	0.29	9.60	0.15	0.05	0.05	2.21	2.21	1.39	6.18	0.40	2.40	8.80	3.03	0.10	1.43	4.93	28.1
2008.750	28.73	2.21	0.39	1.19	29.18	0.30	9.98	0.15	0.05	0.05	2.21	2.21	1.73	6.38	0.50	2.46	9.09	3.21	0.15	1.73	6.03	28.7
2008.875	29.31	2.21	0.39	1.22	29.77	0.31	10.38	0.15	0.05	0.05	2.21	2.21	2.10	6.57	0.60	2.53	9.38	3.40	0.21	2.04	7.17	29.3
2009.000	29.87	2.21	0.39	1.25	30.35	0.32	10.80	0.15	0.05	0.05	2.21	2.21	2.49	6.75	0.70	2.62	9.66	3.60	0.28	2.36	8.34	29.9
2009.125	30.41	2.21	0.39	1.28	30.89	0.34	11.25	0.15	0.05	0.05	2.21	2.21	2.90	6.90	0.82	2.72	9.93	3.81	0.37	2.68	9.55	30.4
2009.250	30.90	2.21	0.39	1.31	31.41	0.35	11.73	0.15	0.05	0.05	2.21	2.21	3.33	7.03	0.94	2.83	10.18	4.04	0.47	3.02	10.79	31.0
2009.375	31.37	2.21	0.39	1.34	31.88	0.37	12.23	0.15	0.05	0.05	2.21	2.21	3.78	7.13	1.06	2.97	10.40	4.27	0.59	3.38	12.06	31.4
2009.500	31.78	2.21	0.39	1.37	32.32	0.38	12.77	0.15	0.05	0.05	2.21	2.21	4.25	7.19	1.20	3.11	10.60	4.51	0.72	3.75	13.36	31.9
2009.625	32.15	2.21	0.39	1.40	32.70	0.40	13.33	0.15	0.05	0.05	2.21	2.21	4.72	7.22	1.34	3.28	10.77	4.76	0.87	4.14	14.68	32.3
2009.750	32.47	2.21	0.39	1.43	33.03	0.42	13.93	0.15	0.05	0.05	2.21	2.21	5.20	7.20	1.48	3.47	10.90	5.02	1.04	4.55	16.03	32.6
2009.875	32.72	2.21	0.39	1.45	33.30	0.44	14.55	0.15	0.05	0.05	2.21	2.21	5.69	7.14	1.64	3.67	10.99	5.28	1.23	4.98	17.39	32.9
2010.000	32.90	2.21	0.39	1.48	33.50	0.46	15.21	0.15	0.05	0.05	2.21	2.21	6.17	7.02	1.80	3.89	11.04	5.55	1.43	5.44	18.77	33.2

** Refer to Table 6.11: Summary of final ANP decision making priority results for all risks on page 169.*

Table 8.11: Dynamic Simulation Results for the Economic Risks System (continued)

Time (Year)	***ANP Inputs (%)**																					
	Risk code									P_{R3}	E_{V1}	E_{V2}	E_{V3}	E_{V4}	E_{V5}	E_{V6}	E_{V7}	E_{V8}	E_{V9}	E_{V10}	E_{V11}	E_{V12}
	Risks priority index (%)									25	17	03	13	03	03	03	08	03	05	13	15	19
	SD Simulation Outputs (%)																					
	P_{R3}	E_{V1}	E_{V2}	E_{V4}	E_{V5}	E_{V6}	E_{V7}	E_{V9}	E_{V12}	E_{V13}	E_{V14}	E_{V15}	E_{V16}	E_{V17}	E_{V18}	E_{V19}	E_{V20}	E_{V21}	E_{V22}	E_{V23}	E_{V24}	E_{V25}
2010.125	33.0	2.21	0.39	1.50	33.6	0.48	15.9	0.15	0.05	0.05	2.21	2.21	6.65	6.85	1.98	4.14	11.0	5.83	1.66	5.93	20.15	33.3
2010.250	33.0	2.21	0.39	1.53	33.7	0.50	16.6	0.15	0.05	0.05	2.21	2.21	7.11	6.63	2.15	4.40	11.0	6.10	1.90	6.44	21.53	33.4
2010.375	33.0	2.21	0.39	1.55	33.6	0.52	17.4	0.15	0.05	0.05	2.21	2.21	7.55	6.34	2.34	4.69	10.9	6.38	2.17	6.99	22.90	33.5
2010.500	32.8	2.21	0.39	1.57	33.5	0.55	18.2	0.15	0.05	0.05	2.21	2.21	7.96	6.00	2.53	5.00	10.7	6.64	2.46	7.58	24.26	33.4
2010.625	32.6	2.21	0.39	1.59	33.3	0.57	19.0	0.15	0.05	0.05	2.21	2.21	8.34	5.60	2.73	5.33	10.5	6.91	2.78	8.21	25.61	33.3
2010.750	32.2	2.21	0.39	1.61	33.0	0.60	19.9	0.15	0.05	0.05	2.21	2.21	8.68	5.14	2.93	5.69	10.3	7.16	3.12	8.87	26.92	33.1
2010.875	31.8	2.21	0.39	1.62	32.6	0.62	20.8	0.15	0.05	0.05	2.21	2.21	8.97	4.64	3.14	6.07	9.99	7.39	3.49	9.58	28.21	32.8
2011.000	31.3	2.21	0.39	1.64	32.1	0.65	21.7	0.15	0.05	0.05	2.21	2.21	9.20	4.09	3.35	6.47	9.65	7.61	3.88	10.3	29.46	32.4
2011.125	30.6	2.21	0.39	1.65	31.4	0.68	22.7	0.15	0.05	0.05	2.21	2.21	9.39	3.50	3.56	6.90	9.27	7.80	4.30	11.2	30.66	31.9
2011.250	29.9	2.21	0.39	1.66	30.7	0.71	23.6	0.15	0.05	0.05	2.21	2.21	9.51	2.88	3.77	7.34	8.87	7.97	4.75	12.0	31.82	31.4
2011.375	29.0	2.21	0.39	1.66	29.9	0.74	24.6	0.15	0.05	0.05	2.21	2.21	9.56	2.25	3.98	7.82	8.44	8.11	5.22	12.9	32.93	30.8
2011.500	28.1	2.21	0.39	1.67	29.1	0.77	25.7	0.15	0.05	0.05	2.21	2.21	9.56	1.61	4.18	8.31	8.01	8.22	5.71	13.9	33.99	30.1
2011.625	27.1	2.21	0.39	1.67	28.1	0.80	26.7	0.15	0.05	0.05	2.21	2.21	9.49	0.98	4.38	8.83	7.57	8.29	6.24	15.0	34.99	29.3
2011.750	26.1	2.21	0.39	1.67	27.1	0.83	27.7	0.15	0.05	0.05	2.21	2.21	9.37	0.35	4.58	9.38	7.14	8.33	6.79	16.0	35.93	28.5
2011.875	24.9	2.21	0.39	1.67	26.0	0.86	28.8	0.15	0.05	0.05	2.21	2.21	9.19	-0.24	4.76	9.94	6.73	8.33	7.36	17.2	36.83	27.7
2012.000	23.8	2.21	0.39	1.67	24.8	0.89	29.8	0.15	0.05	0.05	2.21	2.21	8.95	-0.80	4.94	10.5	6.36	8.28	7.95	18.5	37.67	26.8
2012.125	22.6	2.21	0.39	1.67	23.6	0.92	30.8	0.15	0.05	0.05	2.21	2.21	8.67	-1.31	5.11	11.1	6.01	8.21	8.57	19.8	38.46	25.8
2012.250	21.3	2.21	0.39	1.66	22.4	0.96	31.9	0.15	0.05	0.05	2.21	2.21	8.35	-1.77	5.28	11.8	5.71	8.09	9.21	21.2	39.21	24.9
2012.375	20.0	2.21	0.39	1.66	21.2	0.99	32.9	0.15	0.05	0.05	2.21	2.21	8.00	-2.18	5.43	12.4	5.46	7.94	9.87	22.7	39.93	24.0
2012.500	18.8	2.21	0.39	1.65	19.9	1.02	33.9	0.15	0.05	0.05	2.21	2.21	7.62	-2.53	5.58	13.1	5.26	7.76	10.6	24.2	40.61	23.0
2012.625	17.5	2.21	0.39	1.64	18.7	1.04	34.8	0.15	0.05	0.05	2.21	2.21	7.22	-2.81	5.72	13.8	5.12	7.55	11.2	25.8	41.27	22.1
2012.750	16.2	2.21	0.39	1.63	17.5	1.07	35.8	0.15	0.05	0.05	2.21	2.21	6.81	-3.03	5.86	14.5	5.04	7.32	12.0	27.6	41.91	21.3
2012.875	15.0	2.21	0.39	1.63	16.3	1.10	36.7	0.15	0.05	0.05	2.21	2.21	6.38	-3.20	6.00	15.3	5.01	7.07	12.7	29.4	42.54	20.4
2013.000	13.8	2.21	0.39	1.62	15.1	1.13	37.6	0.15	0.05	0.05	2.21	2.21	5.96	-3.30	6.14	16.0	5.04	6.80	13.4	31.3	43.16	19.6

Table 8.11: Dynamic Simulation Results for the Economic Risks System (continued)

***ANP Inputs (%)**

Risk code	P_{R3}	E_{V1}	E_{V2}	E_{V3}	E_{V4}	E_{V5}	E_{V6}	E_{V7}	E_{V8}	E_{V9}	E_{V10}	E_{V11}	E_{V12}
Risks priority index	25	17	03	13	03	03	03	08	03	05	13	15	19

SD Simulation Outputs (%)

Time (Year)	P_{R3}	E_{V1}	E_{V2}	E_{V4}	E_{V5}	E_{V6}	E_{V7}	E_{V9}	E_{V12}	E_{V13}	E_{V14}	E_{V15}	E_{V16}	E_{V17}	E_{V18}	E_{V19}	E_{V20}	E_{V21}	E_{V22}	E_{V23}	E_{V24}	E_{V25}
2013.125	12.7	2.21	0.39	1.61	14.0	1.15	38.4	0.15	0.05	0.05	2.21	2.21	5.54	-3.36	6.28	16.8	5.13	6.51	14.2	33.3	43.8	18.9
2013.250	11.5	2.21	0.39	1.60	12.9	1.18	39.2	0.15	0.05	0.05	2.21	2.21	5.13	-3.37	6.44	17.6	5.28	6.23	15.0	35.4	44.4	18.2
2013.375	10.5	2.21	0.39	1.60	11.8	1.20	40.0	0.15	0.05	0.05	2.21	2.21	4.73	-3.34	6.62	18.4	5.48	5.93	15.8	37.6	45.1	17.6
2013.500	9.47	2.21	0.39	1.59	10.8	1.22	40.8	0.15	0.05	0.05	2.21	2.21	4.34	-3.28	6.81	19.3	5.75	5.64	16.6	39.9	45.8	17.1
2013.625	8.52	2.21	0.39	1.58	9.91	1.24	41.5	0.15	0.05	0.05	2.21	2.21	3.96	-3.19	7.04	20.2	6.06	5.35	17.5	42.3	46.5	16.6
2013.750	7.62	2.21	0.39	1.58	9.04	1.26	42.1	0.15	0.05	0.05	2.21	2.21	3.60	-3.08	7.31	21.1	6.44	5.07	18.4	44.8	47.3	16.3
2013.875	6.79	2.21	0.39	1.57	8.22	1.28	42.8	0.15	0.05	0.05	2.21	2.21	3.26	-2.95	7.62	22.1	6.88	4.80	19.3	47.5	48.1	16.1
2014.000	6.01	2.21	0.39	1.57	7.46	1.30	43.4	0.15	0.05	0.05	2.21	2.21	2.94	-2.80	7.99	23.1	7.40	4.54	20.2	50.2	48.9	15.9
2014.125	5.30	2.21	0.39	1.56	6.76	1.32	43.9	0.15	0.05	0.05	2.21	2.21	2.64	-2.65	8.43	24.2	7.99	4.29	21.2	53.1	49.8	15.9
2014.250	4.63	2.21	0.39	1.56	6.12	1.33	44.5	0.15	0.05	0.05	2.21	2.21	2.36	-2.50	8.96	25.3	8.67	4.05	22.3	56.1	50.8	16.0
2014.375	4.03	2.21	0.39	1.56	5.53	1.35	45.0	0.15	0.05	0.05	2.21	2.21	2.09	-2.35	9.59	26.6	9.45	3.83	23.4	59.3	51.9	16.2
2014.500	3.47	2.21	0.39	1.56	4.99	1.36	45.5	0.15	0.05	0.05	2.21	2.21	1.84	-2.20	10.4	27.9	10.4	3.63	24.6	62.6	53.1	16.5
2014.625	2.97	2.21	0.39	1.56	4.49	1.38	45.9	0.15	0.05	0.05	2.21	2.21	1.61	-2.05	11.3	29.4	11.4	3.44	25.9	66.1	54.4	17.1
2014.750	2.51	2.21	0.39	1.56	4.05	1.39	46.3	0.15	0.05	0.05	2.21	2.21	1.40	-1.91	12.4	31.1	12.7	3.27	27.3	69.8	55.8	17.8
2014.875	2.09	2.21	0.39	1.56	3.65	1.40	46.7	0.15	0.05	0.05	2.21	2.21	1.20	-1.78	13.7	33.1	14.2	3.11	28.8	73.7	57.4	18.7
2015.000	1.72	2.21	0.39	1.56	3.29	1.41	47.1	0.15	0.05	0.05	2.21	2.21	1.02	-1.65	15.4	35.3	16.0	2.96	30.6	77.8	59.2	19.8

** Refer to Table 6.11: Summary of final ANP decision making priority results for all risks on page 169.*

Table 8.12: Summary of the Dynamic Simulation Results for the Economic Risks System Model

ANP/SD Simulation Results							
Code	**System Variables**	***ANP Inputs (%)**					
E_{V3}:	Government discontinuity (change)	13					
E_{V8}:	Economic recession	03					
E_{V10}:	Catastrophic environmental effects;	13					
E_{V11}:	Project technical difficulties	15					
		SD Simulation Outputs (%)					
		Min	Max	Mean	Median	StDev	Norm
P_{R3}	Economic risks	1.72	33.0	21.51	26.07	10.73	49.86
E_{V1}:	Change in government funding policy	2.21	2.21	2.21	2.21	0.00	0.00
E_{V2}:	Taxation	0.39	0.39	0.39	0.39	0.00	0.00
E_{V4}:	Wage inflation;	1.01	1.67	1.50	1.57	0.19	12.41
E_{V5}:	Local inflation	3.29	33.7	22.46	26.67	10.37	46.17
E_{V6}:	Foreign exchange	0.24	1.41	0.80	0.77	0.39	49.42
E_{V7}:	Material price	8.00	47.1	26.58	25.65	13.14	49.42
E_{V9}:	Energy price	0.15	0.15	0.15	0.15	0.00	0.00
E_{V12}:	Project delays of all forms	0.05	0.05	0.05	0.05	0.00	0.00
E_{V13}:	Cost of delays	0.05	0.05	0.05	0.05	0.00	0.00
E_{V14}:	Cost of dispute resolution	2.21	2.21	2.21	2.21	0.00	0.00
E_{V15}:	Disputes	2.21	2.21	2.21	2.21	0.00	0.00
E_{V16}:	Economic certainties	0.00	9.56	5.13	5.13	3.06	59.58
E_{V17}:	Economic uncertainties	-3.4	7.22	1.82	1.61	4.19	230.7
E_{V18}:	Error generation	0.00	15.4	4.56	4.18	3.61	79.23
E_{V19}:	Escalation to project cost overrun	0.023	0.35	0.115	0.083	9.29	80.49
E_{V20}:	Escalation to project time overrun	5.01	16.0	8.59	8.67	0.0244	28.42
E_{V21}:	Material price hike	2.27	8.33	5.54	5.55	1.94	35.03
E_{V22}:	Project quality deficiency	0.00	30.6	8.88	5.71	8.90	100.3
E_{V23}:	Risks of project cost overrun	0.00	77.8	22.36	13.91	21.85	97.72
E_{V24}:	Risks of project time overrun	0.00	59.2	30.74	33.99	17.02	55.35
E_{V25}:	Worksite coordination problems	15.9	33.5	25.62	26.90	6.29	24.56

*Current simulation runs Time (Year) for the economic risks model = 2008 to 2015, * Refer to Table 6.11: Summary of final ANP decision making priority results for all risks on page 169.*

- ***Analysis of the Simulation Results for the Level of Risk Impact on Project Objectives***

Up to this point, dynamic simulations have been performed to reveal the level of economic risks impacts on project performance, hence risks of project time and cost overruns and quality deficiency. However, does one particular project objective experience more of economic risks impact than those of other project objectives? If so, what is the nature of these distinctions and if not, what is the form of the similarities? To provide answers to these questions, one-way analysis (ANOVA) was used to explore these distinctions using an alpha of .001.

Table 8.13: One-Way Analysis of Variance: The Level and Extent to which Economic Risks Affect the Objectives of the Case Study Megaproject during Construction

Project Objectives	Level of Economic Risks Impact on Project Objectives (%)				
	Mean		Std. Deviation		
Time	30.74		17.02		
Cost	22.36		21.84		
Quality	8.88		8.90		
Variance	The Extent to which Economic Risks Impact on Project Objectives				
	Sum of squares	Degrees of freedom (df).	Mean square	F	P
Between project objectives	13862.771	2	6931.386	24.143	.000
Within project objectives	48232.202	168	287.096		
Total	62094.974	170			

Field Survey 2013.

As presented in Table 8.13, the one-way analysis of variance reveals that project time, cost and quality of the case study transportation megaprojects are impacted by economic risks. The mean scores reveal that project time (30.74%) is affected most, followed by the project cost (22.36%) and then the project quality (8.88%). Subjecting the results to one-way analysis of variance (ANOVA), the F (obtained) is 24.143 which far exceeds the F-critical value of 7.41 for this test when using an alpha of .001. Correspondingly, the observed p-value of .000 is well below the chosen alpha of .001. By either standard, it implies that the difference between the levels of economic risks impact on the objectives of the cases study project is statistically non-significant.

8.3.5. Integrated Stock and Flow Model for Environmental Risks System

The main line of approach in this section is to focus on the environmental risk impact generated by transportation megaprojects in the construction phase and the resulting effects such as environmental risks, risks of project time and cost overruns and project quality deficiency. We restricted ourselves to two main areas of environmental issues from works and unfavourable climatic conditions. The variables under each of these areas considered have been grouped from the ANP risk priority index weighting viewpoint, by strictly maintaining the combination of effect and respondents' categories and age of working experiences based on a questionnaire survey and interviews conducted with professionals on Edinburgh Tram Network project. The level of influence the case study megaproject under construction has in relation to these two main areas is represented in Figure 8.12. It was developed with environmental risks, risks of project time overrun, risks of project cost overrun and project quality deficiency on the focus and was constructed based on the validated causal loop diagram indicated in Figure 7.14. The parameters which are currently deemed useful for the environmental risks model are provided in Table 7.5.

The approached devised to assess risks in this subsystem is based on the following steps:

i. Integrated stock and flow diagram construction
ii. Model equations formulation
iii. Model testing- structural assessment and dimensional consistency
iv. Dynamic simulation and discussion
v. Analysis of dynamic simulation results for project objectives

- ***Integrated Stock and Flow Diagram Construction:*** As illustrated in Figure 8.12, the environmental risks and unfavourable climatic conditions have direct influence on the controlling variable *environmental uncertainties* which stocks *environmental risks,* while environmental issues from works have influence on both social issues and environmental uncertainties. It can be noted that the stock '*environmental risks'* and the inflow environmental uncertainties form a feedback loop wich reinforces the risk effects in the system. Further, it has to be noted that environmental risks are affected by environmental certainties.

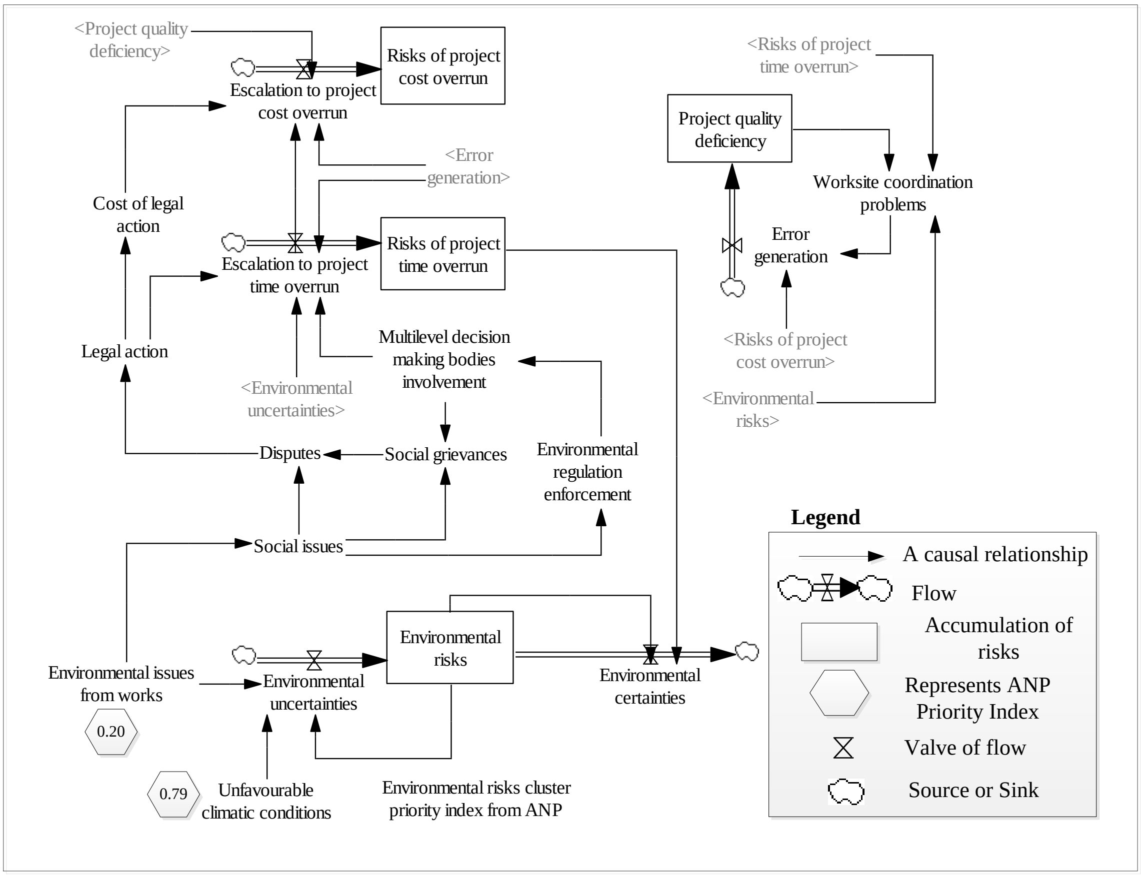


Figure 8.12: Integrated Stock and Flow Diagram for Environmental Risks System

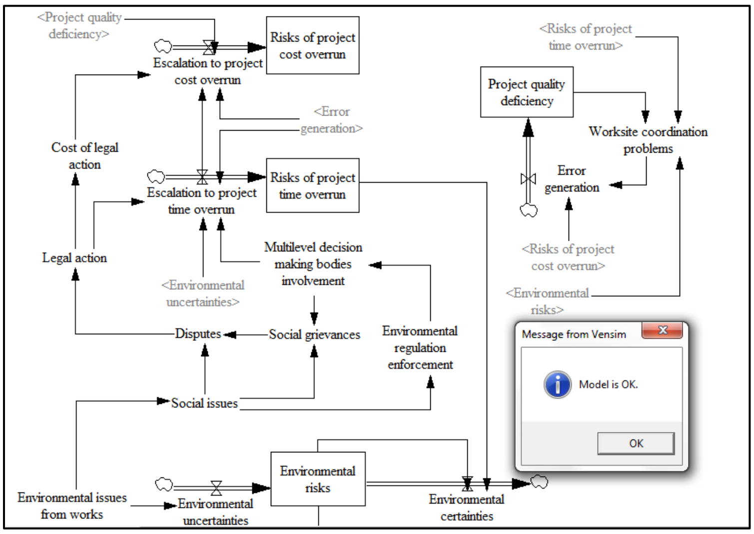
Similarly, risks of project time and cost overruns are influenced by escalation to project time overrun and escalation to project cost overrun to stock risks of project time and cost overruns respectively. Further consideration shows that a number of the system variables such as legal actions, error generation and others influence risks of project time and cost overruns through escalations to project time and cost overruns as detailed in the stock and flow diagram illustrated in Figure 8.12.

- ***Model Equation Formulation***: The governing equations used to calculate the system parameters for the environmental risks model are given in Table 8.14.

Table 8.14: Mathematical model for integrated environmental risks system model

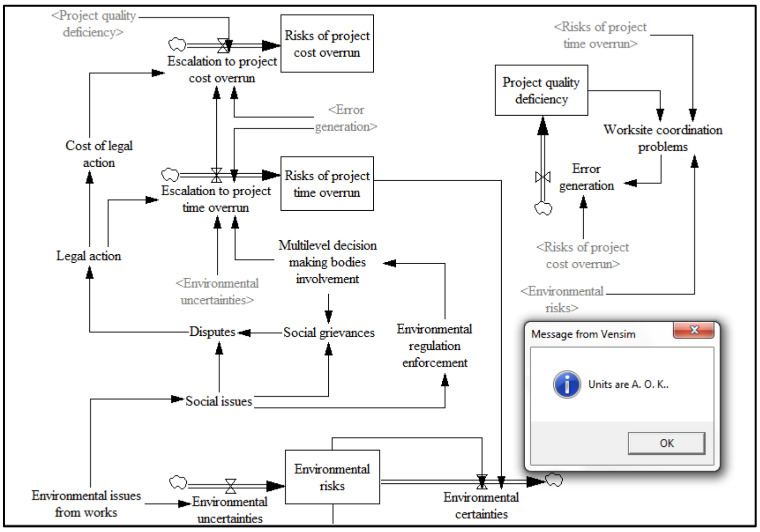
Code	System Variables	Equations	Measurement
P_{R4}:	Environmental risks	INTEG (Environmental uncertainties-Environmental certainties, Environmental risks cluster priority index from ANP)	Dimensionless
E_{NV1}:	Environmental Issues	Constant (Initial ANP value for $\mathbf{E_{NV1}}$)	
E_{NV2}:	Climatic conditions		
E_{NV3}:	Cost of legal action	Legal action	Dimensionless
E_{NV4}:	Disputes	Social grievances*Social issues* Initial ANP value for E_{NV4}	Dimensionless
E_{NV5}:	Environmental regulation enforcement	Social issues	Dimensionless
E_{NV6}:	Environmental certainties	(Risks of project time overrun*Environmental risks) per Unit Time	Dimensionless/ Year
E_{NV7}:	Environmental uncertainties	((Environmental risks)*(Unfavourable climatic conditions*Environmental issues from works)) per Unit Time	Dimensionless/ Year
E_{NV8}:	Error generation	(Worksite coordination problems*Risks of project cost overrun) per Unit Time	Dimensionless/ Year
E_{NV9}:	Escalation to project cost overrun	(Escalation to project time overrun * Error generation* Unit Time Project quality deficiency +Cost of legal action) per Unit Time	Dimensionless /Year
E_{NV10}:	Escalation to project time overrun	(Error generation*Legal action + Environmental uncertainties)+(Multilevel decision making bodies involvement) per Unit Time	Dimensionless/ Year
E_{NV11}:	Legal action	Disputes	Dimensionless
E_{NV12}:	Multi decision making bodies involvement	Environmental regulation enforcement* Initial ANP value for E_{NV12}	Dimensionless
E_{NV13}:	Project quality deficiency	INTEG (Error generation, 0)	Dimensionless
E_{NV14}:	Risks of project cost overrun	INTEG (Escalation to project cost overrun, 0)	Dimensionless
E_{NV15}:	Risks of project time overrun	INTEG (Escalation to project time overrun, 0)	Dimensionless
E_{NV16}:	Social issues	Environmental issues from works+0.04	Dimensionless
E_{NV17}:	Social grievances	(Social issues)/(Multilevel decision making bodies involvement)*0.06	Dimensionless
E_{NV18}:	Worksite coordination problems	(Risks of project time overrun*Project quality deficiency + Environmental risks)	Dimensionless

- ***Model Testing:*** Tests conducted on the environmental risks model before simulations are performed are illustrated in Figure 8.13. As shown in Figure 8.13, the messages from the Vensim's built-in function indicate that the structural assessment and dimensional tests conducted on the environmental risks model are consistent.



Model is OK.

Figure 8.13a: Structural Assessment Test for the Environmental Risks Stock Model

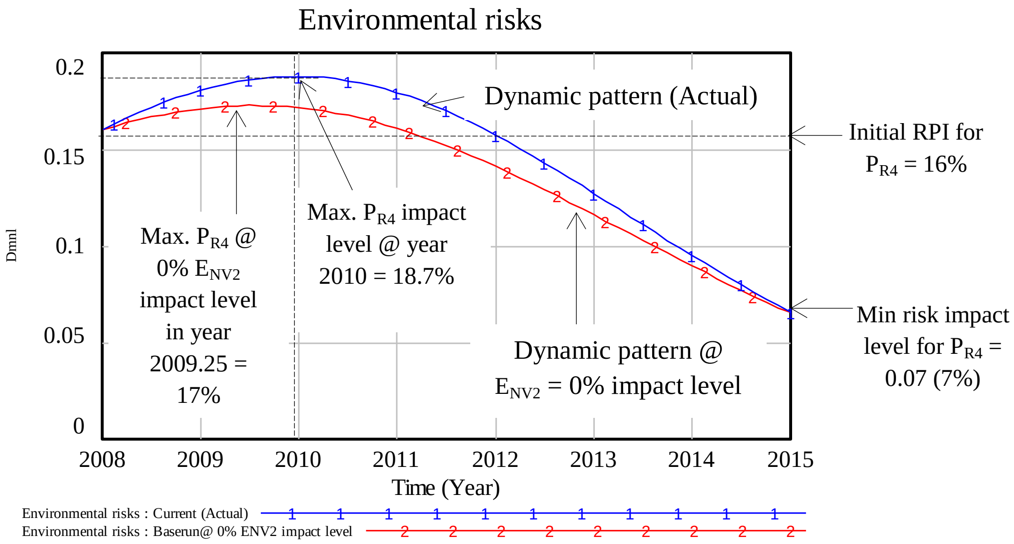


Units are A. O. K..

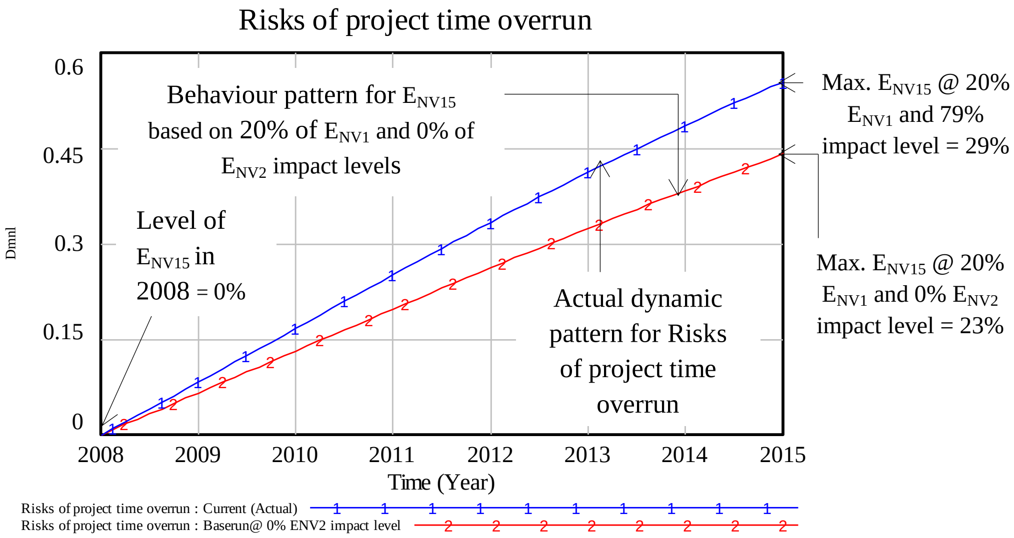
Figure 8.13b: Dimensional Consistency Check for the Environmental Risks Stock Model

Figure 8.13: Evaluation Tests for the Environmental Risks Model

- ***Dynamic Simulation Results and Discussion:*** The trend of the dynamic simulation patterns of the various stocks in the environmental risks sub-model is discussed in this section. The focus of the discussion is on the analysis of the SD output graphs in Figure 8.14. However, physical numbers generated by Vensim's built-in functions which indicate the minimum, maximum, mean, median and standard deviation values for the model parameters were also discussed. Summaries of the dynamic results are presented in Tables 8.15 and 8.16 respectively.

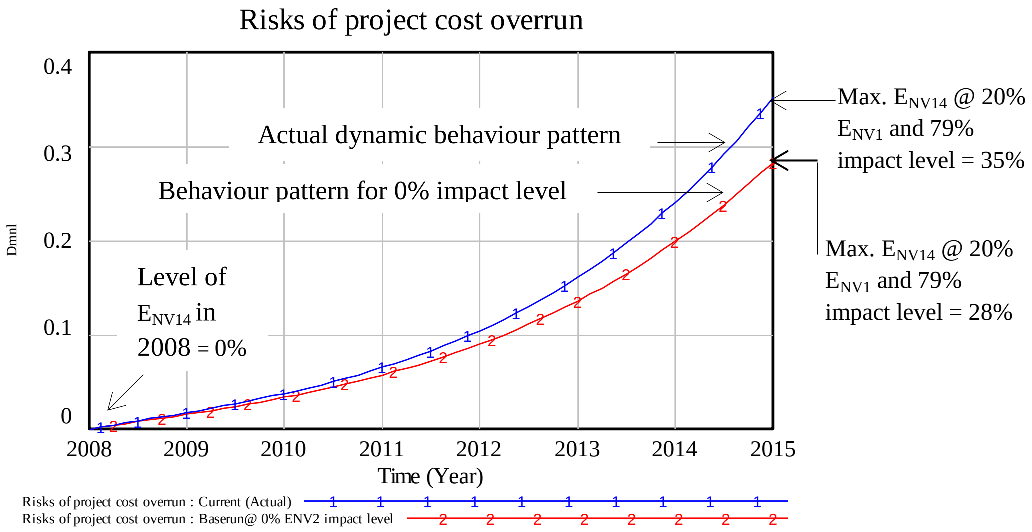


a: Baserun and actual scenario simulation patterns for environmental risks

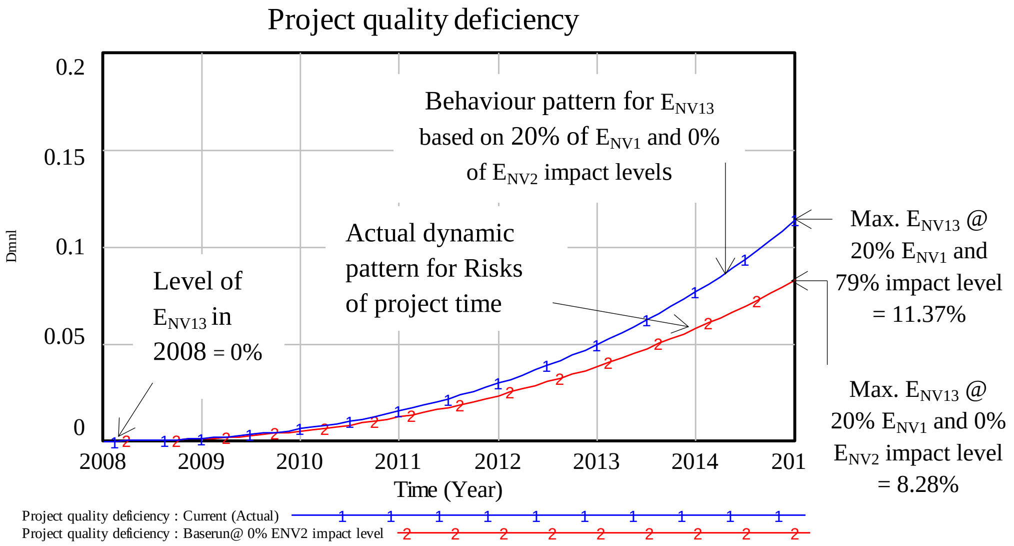


b: Baserun and actual scenario simulation patterns for risks of project time overrun

Figure 8.14: Dynamic Patterns for Stock Entities in the Environmental risks model



c: Baserun and actual scenario simulation patterns for risks of project cost overrun



d: Baserun and actual scenario simulation patterns for project quality deficiency

Figure 8.14: Dynamic Patterns for Stock Entities in the Environmental risks model (Continued)

Considering Figure 8.14a, baserun for the dynamic simulation was performed using 0% risk impact level for unfavorable climatic conditions and 20% risk impact level for environmental issues from works. Simulating with the initial 0% risk impact level is based on experts' responses during an interview conducted on ETNP which revealed that there were favorable climatic conditions at the time physical construction commenced. With such good climatic conditions and a 20% impact level for environmental issues from works such as noise from heavy construction machinery and equipment, traffic and road diversion, the dynamic pattern (base run) in Figure 8.14a turns to decay gradually. But when values of ANP's RPI for both unfavorable climatic conditions (79%) and the environmental issues from works (20%) were used for the dynamic simulation, the environmental risks pattern turns to exponential form until after 27 months (2008 to 2010.25) before declining steadily.

In Figure 8.14b, 8.14c and 8.14d, the level of impacts of environmental issues from works on the public or people living along the project routes will compel involvement of environmental regulatory bodies (local and regional) and other decision making bodies to enforce environmental laws and to prevent further damages to the public, eco-system and the natural environment. Where the impacts seem to be serious, contractors may be faced by various disputes and be compelled to halt activities through legal means which will lead to risks of project time and cost overruns and quality deficiency.

As indicated in Figures 8.14b, 8.14c and 8.14d, the dynamic patterns suggest that risks of project time and cost overruns and project quality deficiency turn to exponential forms as a result of impacts of environmental issues from works and unfavourable climatic conditions which interact with variables like social issues, disputes, environmental regulatory involvement, multi-level decision making bodies involvement, legal actions , worksite coordination problems and error generation within the system to affect project time, cost and quality. The level of impacts generated by these parameters over the period of seven years (2008-2015) are summarized and indicated in Table 8.15 and 8.16 respectively.

Table 8.15: Dynamic Simulation Results for Environmental risks System

Time (Year)	***ANP Inputs (%)**																
	Risk code											P_{R4}	**E_{NV1}**	**E_{NV2}**	**E_{NV12}**	**E_{NV16}**	**E_{NV17}**
	Risks priority index (%)											16	20	79	23	04	06
	SD Simulation Outputs (%)																
	P_{R4}	E_{NV3}	E_{NV4}	E_{NV5}	E_{NV6}	E_{NV7}	E_{NV8}	E_{NV9}	E_{NV10}	E_{NV11}	E_{NV12}	E_{NV13}	E_{NV14}	E_{NV15}	E_{NV16}	E_{NV17}	E_{NV18}
2008.000	16.0	1.69	1.69	24	0.00	2.53	0.00	1.69	8.05	1.69	5.52	0.00	0.00	0.0	24.0	26.1	16.0
2008.125	16.3	1.69	1.69	24	0.16	2.58	0.03	1.69	8.10	1.69	5.52	0.00	0.21	1.0	24.0	26.1	16.3
2008.250	16.6	1.69	1.69	24	0.34	2.63	0.07	1.70	8.15	1.69	5.52	0.00	0.42	2.0	24.0	26.1	16.6
2008.375	16.9	1.69	1.69	24	0.51	2.67	0.11	1.71	8.19	1.69	5.52	0.01	0.64	3.0	24.0	26.1	16.9
2008.500	17.2	1.69	1.69	24	0.70	2.71	0.15	1.73	8.24	1.69	5.52	0.03	0.85	4.1	24.0	26.1	17.2
2008.625	17.4	1.69	1.69	24	0.89	2.75	0.19	1.75	8.28	1.69	5.52	0.04	1.07	5.1	24.0	26.1	17.4
2008.750	17.7	1.69	1.69	24	1.08	2.79	0.23	1.78	8.31	1.69	5.52	0.07	1.28	6.1	24.0	26.1	17.7
2008.875	17.9	1.69	1.69	24	1.28	2.82	0.27	1.81	8.35	1.69	5.52	0.10	1.51	7.2	24.0	26.1	17.9
2009.000	18.1	1.69	1.69	24	1.48	2.85	0.31	1.85	8.38	1.69	5.52	0.13	1.73	8.2	24.0	26.1	18.1
2009.125	18.2	1.69	1.69	24	1.69	2.88	0.36	1.89	8.41	1.69	5.52	0.17	1.96	9.3	24.0	26.1	18.3
2009.250	18.4	1.69	1.69	24	1.89	2.91	0.40	1.94	8.43	1.69	5.52	0.21	2.20	10.3	24.0	26.1	18.4
2009.375	18.5	1.69	1.69	24	2.10	2.92	0.45	1.99	8.45	1.69	5.52	0.26	2.44	11.4	24.0	26.1	18.5
2009.500	18.6	1.69	1.69	24	2.31	2.94	0.50	2.05	8.47	1.69	5.52	0.32	2.69	12.4	24.0	26.1	18.7
2009.625	18.7	1.69	1.69	24	2.52	2.95	0.55	2.12	8.48	1.69	5.52	0.38	2.95	13.5	24.0	26.1	18.7
2009.750	18.7	1.69	1.69	24	2.73	2.96	0.60	2.19	8.49	1.69	5.52	0.45	3.21	14.5	24.0	26.1	18.8
2009.875	18.8	1.69	1.69	24	2.93	2.97	0.66	2.27	8.50	1.69	5.52	0.53	3.49	15.6	24.0	26.1	18.9
2010.000	18.8	1.69	1.69	24	3.13	2.97	0.71	2.36	8.50	1.69	5.52	0.61	3.77	16.7	24.0	26.1	18.9

** Refer to Table 6.11: Summary of final ANP decision making priority results for all risks on page 169.*

Table 8.15: Dynamic Simulation Results for Environmental risks System (continued)

Time (Year)	***ANP Inputs (%)**																
	Risk code											P_{R4}	**E_{NV1}**	**E_{NV2}**	**E_{NV12}**	**E_{NV16}**	**E_{NV17}**
	Risks priority index (%)											16	20	79	23	04	06
	SD Simulation Outputs (%)																
	P_{R4}	E_{NV3}	E_{NV4}	E_{NV5}	E_{NV6}	E_{NV7}	E_{NV8}	E_{NV9}	E_{NV10}	E_{NV11}	E_{NV12}	E_{NV13}	E_{NV14}	E_{NV15}	E_{NV16}	E_{NV17}	E_{NV18}
2010.125	18.8	1.69	1.69	24	3.33	2.96	0.77	2.46	8.50	1.69	5.52	0.70	4.07	17.7	24.0	26.1	18.9
2010.250	18.7	1.69	1.69	24	3.52	2.96	0.83	2.56	8.49	1.69	5.52	0.80	4.37	18.8	24.0	26.1	18.9
2010.375	18.6	1.69	1.69	24	3.70	2.95	0.88	2.66	8.48	1.69	5.52	0.90	4.69	19.8	24.0	26.1	18.8
2010.500	18.6	1.69	1.69	24	3.88	2.93	0.94	2.78	8.47	1.69	5.52	1.01	5.03	20.9	24.0	26.1	18.8
2010.625	18.4	1.69	1.69	24	4.05	2.91	1.00	2.90	8.45	1.69	5.52	1.13	5.37	22.0	24.0	26.1	18.7
2010.750	18.3	1.69	1.69	24	4.21	2.89	1.07	3.03	8.43	1.69	5.52	1.25	5.74	23.0	24.0	26.1	18.6
2010.875	18.1	1.69	1.69	24	4.36	2.86	1.13	3.17	8.40	1.69	5.52	1.39	6.12	24.1	24.0	26.1	18.5
2011.000	17.9	1.69	1.69	24	4.51	2.83	1.19	3.32	8.37	1.69	5.52	1.53	6.51	25.1	24.0	26.1	18.3
2011.125	17.7	1.69	1.69	24	4.64	2.80	1.26	3.47	8.34	1.69	5.52	1.68	6.93	26.2	24.0	26.1	18.2
2011.250	17.5	1.69	1.69	24	4.76	2.77	1.33	3.63	8.31	1.69	5.52	1.83	7.36	27.2	24.0	26.1	18.0
2011.375	17.3	1.69	1.69	24	4.87	2.73	1.39	3.81	8.27	1.69	5.52	2.00	7.82	28.3	24.0	26.1	17.8
2011.500	17.0	1.69	1.69	24	4.97	2.68	1.46	3.98	8.23	1.69	5.52	2.17	8.29	29.3	24.0	26.1	17.6
2011.625	16.7	1.69	1.69	24	5.06	2.64	1.53	4.17	8.18	1.69	5.52	2.36	8.79	30.3	24.0	26.1	17.4
2011.750	16.4	1.69	1.69	24	5.14	2.59	1.60	4.37	8.14	1.69	5.52	2.55	9.31	31.3	24.0	26.1	17.2
2011.875	16.1	1.69	1.69	24	5.20	2.54	1.67	4.57	8.09	1.69	5.52	2.75	9.86	32.4	24.0	26.1	17.0
2012.000	15.7	1.69	1.69	24	5.25	2.49	1.74	4.79	8.04	1.69	5.52	2.96	10.43	33.4	24.0	26.1	16.7
2012.125	15.4	1.69	1.69	24	5.29	2.43	1.82	5.01	7.98	1.69	5.52	3.17	11.03	34.4	24.0	26.1	16.5
2012.250	15.0	1.69	1.69	24	5.32	2.38	1.89	5.24	7.93	1.69	5.52	3.40	11.65	35.4	24.0	26.1	16.2
2012.375	14.7	1.69	1.69	24	5.33	2.32	1.97	5.48	7.87	1.69	5.52	3.64	12.31	36.4	24.0	26.1	16.0
2012.500	14.3	1.69	1.69	24	5.34	2.26	2.05	5.73	7.81	1.69	5.52	3.88	12.99	37.3	24.0	26.1	15.7
2012.625	13.9	1.69	1.69	24	5.33	2.20	2.12	6.00	7.75	1.69	5.52	4.14	13.71	38.3	24.0	26.1	15.5
2012.750	13.5	1.69	1.69	24	5.31	2.14	2.21	6.27	7.69	1.69	5.52	4.41	14.46	39.3	24.0	26.1	15.2
2012.875	13.1	1.69	1.69	24	5.28	2.07	2.29	6.55	7.63	1.69	5.52	4.68	15.24	40.3	24.0	26.1	15.0
2013.000	12.7	1.69	1.69	24	5.24	2.01	2.37	6.84	7.57	1.69	5.52	4.97	16.06	41.2	24.0	26.1	14.8

Table 8.15: Dynamic Simulation Results for Environmental risks System (continued)

Time (Year)	***ANP Inputs (%)**																
	Risk code											P_{R4}	**E_{NV1}**	**E_{NV2}**	**E_{NV12}**	**E_{NV16}**	**E_{NV17}**
	Risks priority index (%)											16	20	79	23	04	06
	SD Simulation Outputs (%)																
	P_{R4}	E_{NV3}	E_{NV4}	E_{NV5}	E_{NV6}	E_{NV7}	E_{NV8}	E_{NV9}	E_{NV10}	E_{NV11}	E_{NV12}	E_{NV13}	E_{NV14}	E_{NV15}	E_{NV16}	E_{NV17}	E_{NV18}
2013.125	12.3	1.69	1.69	24	5.19	1.95	2.46	7.14	7.51	1.69	5.52	5.26	16.92	42.2	24.0	26.1	14.5
2013.250	11.9	1.69	1.69	24	5.13	1.88	2.55	7.45	7.44	1.69	5.52	5.57	17.81	43.1	24.0	26.1	14.3
2013.375	11.5	1.69	1.69	24	5.06	1.82	2.64	7.78	7.38	1.69	5.52	5.89	18.74	44.0	24.0	26.1	14.1
2013.500	11.1	1.69	1.69	24	4.99	1.75	2.74	8.11	7.32	1.69	5.52	6.22	19.71	44.9	24.0	26.1	13.9
2013.625	10.7	1.69	1.69	24	4.90	1.69	2.84	8.46	7.26	1.69	5.52	6.56	20.73	45.9	24.0	26.1	13.7
2013.750	10.3	1.69	1.69	24	4.81	1.63	2.95	8.82	7.20	1.69	5.52	6.92	21.78	46.8	24.0	26.1	13.5
2013.875	9.9	1.69	1.69	24	4.72	1.56	3.06	9.19	7.13	1.69	5.52	7.29	22.89	47.7	24.0	26.1	13.4
2014.000	9.5	1.69	1.69	24	4.61	1.50	3.18	9.58	7.07	1.69	5.52	7.67	24.04	48.6	24.0	26.1	13.2
2014.125	9.1	1.69	1.69	24	4.50	1.44	3.31	9.99	7.02	1.69	5.52	8.07	25.23	49.4	24.0	26.1	13.1
2014.250	8.7	1.69	1.69	24	4.39	1.38	3.44	10.41	6.96	1.69	5.52	8.48	26.48	50.3	24.0	26.1	13.0
2014.375	8.4	1.69	1.69	24	4.27	1.32	3.59	10.85	6.90	1.69	5.52	8.91	27.78	51.2	24.0	26.1	12.9
2014.500	8.0	1.69	1.69	24	4.15	1.26	3.74	11.30	6.84	1.69	5.52	9.36	29.14	52.0	24.0	26.1	12.9
2014.625	7.6	1.69	1.69	24	4.03	1.20	3.92	11.78	6.79	1.69	5.52	9.83	30.55	52.9	24.0	26.1	12.8
2014.750	7.3	1.69	1.69	24	3.91	1.15	4.10	12.28	6.74	1.69	5.52	10.31	32.02	53.8	24.0	26.1	12.8
2014.875	6.9	1.69	1.69	24	3.78	1.09	4.31	12.81	6.69	1.69	5.52	10.83	33.56	54.6	24.0	26.1	12.8
2015.000	6.6	1.69	1.69	24	3.65	1.04	4.53	13.36	6.64	1.69	5.52	11.37	35.16	55.4	24.0	26.1	12.9

** Refer to Table 6.11: Summary of final ANP decision making priority results for all risks on page 169.*

Table 8.16: Summary of the Dynamic Simulation Results for Environmental Risks System

ANP/SD simulation results

Code	**System Variables**	***ANP inputs (%)**
E_{NV1}:	Environmental issues from works	20
E_{NV2}:	Unfavourable climatic conditions	79
E_{NV12}:	Multi decision making bodies involvement	23
E_{NV16}:	Social issues	04
E_{NV17}:	Social grievances	06
P_{R4}:	Environmental risks	16

		SD Simulation Outputs (%)					
		Min	*Max*	*Mean*	*Median*	*StDev*	*(Norm)*
P_{R4}:	Environmental risks	6.59	18.78	14.86	14.86	16.39	3.85
E_{NV3}:	Cost of legal action	1.69	1.69	1.69	1.69	1.69	0.00
E_{NV4}:	Disputes	1.69	1.69	1.69	1.69	1.69	0.00
E_{NV5}:	Environmental regulation enforcement	24.00	24.00	24.00	24.00	24.00	0.00
E_{NV6}:	Environmental certainties	0.00	5.34	3.72	3.72	4.27	1.61
E_{NV7}:	Environmental uncertainties	1.04	2.97	2.35	2.35	2.59	0.61
E_{NV8}:	Error generation	0.00	4.53	1.67	1.67	1.46	1.24
E_{NV9}:	Escalation to project cost overrun	1.69	13.36	5.17	5.17	3.98	3.42
E_{NV10}:	Escalation to project time overrun	6.64	8.50	7.90	7.90	8.14	0.59
E_{NV11}:	Legal action	1.69	1.69	1.69	1.69	1.69	0.00
E_{NV12}:	Multi decision making bodies involvement	5.52	5.52	5.52	5.52	5.52	0.00
E_{NV13}:	Project quality deficiency	0.00	11.37	3.35	3.35	2.17	3.34
E_{NV14}:	Risks of project cost overrun	0.00	35.16	11.42	11.42	8.29	9.88
E_{NV15}:	Risks of project time overrun	55.4	28.7	29.3	16.5	57.6	55.4
E_{NV16}:	Social issues	24.00	24.00	24.00	24.00	24.00	0.00
E_{NV17}:	Social grievances	26.09	26.09	26.09	26.09	26.09	0.00
E_{NV18}:	Worksite coordination problems	12.81	18.89	16.34	16.34	16.90	2.14

*Current simulation runs Time (Year) for environmental risks model = 2008 to 2015, * Refer to Table 6.11: Summary of final ANP decision making priority results for all risks on page 169.*

Source: Field Work 2013

- ***Analysis of Dynamic Simulation Results for Project Objectives:***

The findings of the dynamic simulation results are explored in relation to the level of impacts of environmental risks on the objectives of transportation megaprojects identified as being mainly risks of project time and cost overruns and project quality deficiency. Table 8.17 presents a one-way analysis of variance (ANOVA) of the level of environmental risks impact on project time, cost and quality. The aim of the one-way analysis of variance (ANOVA) is to explore whether one particular project objective experience more of environmental risks impact than those of other project objectives using an alpha of .001. If so, what will be the nature of these distinctions and if not, what will be the form of the similarities.

Table 8.17: One-Way Analysis of Variance: The Level and Extent to which Environmental Risks Affect the Objectives of the Case Study Megaproject during Construction

Project Objectives	Level of Environmental Risks Impact on Project Objectives				
	Mean		*Std. deviation*		
Time	29.3		57.6		
Cost	11.42		8.29		
Quality	3.35		2.17		
Variance	The Extent to which Environmental Risks Impact on Project Objectives				
	Sum of squares	Degrees of freedom (df).	Mean square	F	P
Between project objectives	19106.609	2	9553.304	73.678	.000
Within project objectives	21783.508	168	129.664		
Total	40890.116	170			

Filed Survey 2013

As presented in Table 8.17, the one-way analysis of variance reveals that project time, cost and quality of transportation megaprojects are all impacted by the environmental risks. The mean scores reveal that project time (29.3%) is affected most, followed by the project cost (11.42%) and then project quality (3.35%). Subjecting the results to one-way analysis of variance (ANOVA), the F (obtained) is 73.678 which far exceeds the F-critical value of 7.41 for this test when using an alpha of .001. Correspondingly, the observed p-value of .000 is well below the chosen alpha of .001. By either standard, it implies that the difference between the levels of environmental risks impact on the objectives of the cases study project is statistically non-significant.

8.3.6. Integrated Stock and Flow Model for Political Risks System

Generally, political risk can be viewed as the use of political authority in a way that threatens a megaproject company's value. Two types of political risks are relevant to companies doing business internationally: industry- or firm specific political risk and country-specific political risk. Mass anti-government protests may not pose a political threat to a firm if they do not affect: (a) Government policies towards the megaproject development and (b) the company's current or future operations or value. However, changes in the legal framework governing contracts could have a significant negative impact on the company.

Regardless of the source, a megaproject developer attempting to understand potential political risk must recognize the difference between (a) political issues that can affect corporate performance, and (b) dramatic situations that have no financial impact on the company. In addition, the megaproject developers should understand the potential reputation damage, and associated costs, related to political risk.

For a better understanding of this section of the report, the under listed approach were used to translate available information on political risks into an integrated SDANP stock and flow model using the following steps:

i. Integrated stock and flow diagram construction
ii. Model equations formulation
iii. Model testing- structural assessment and dimensional consistency
iv. Dynamic simulation results and discussion
v. Analysis of dynamic simulation results for project objectives

- ***Integrated Stock and Flow Diagram Construction:*** Figure 8.15 illustrates the integrated political risks stock and flow diagram. It was developed based on the validated cause-effective (Dynamic hypothesis) diagram presented in Figure 7.17 and with political support, political risks, risk of project time overrun, risk of project cost overrun and quality deficiency as the focus. As illustrated in Figure 8.15, the model parameters represent only some of the most critical political risk factors facing the developer of the case study megaproject (Edinburgh Tram Network Project) at the time of this research. Although the model boundary chart presented in

Table 7.6: System boundary for political risks sub-system did not try to list all risks, the wide variety of political risk factors it included provides the relevant issues facing the developer of Edinburgh Tram Network Project (ETNP).

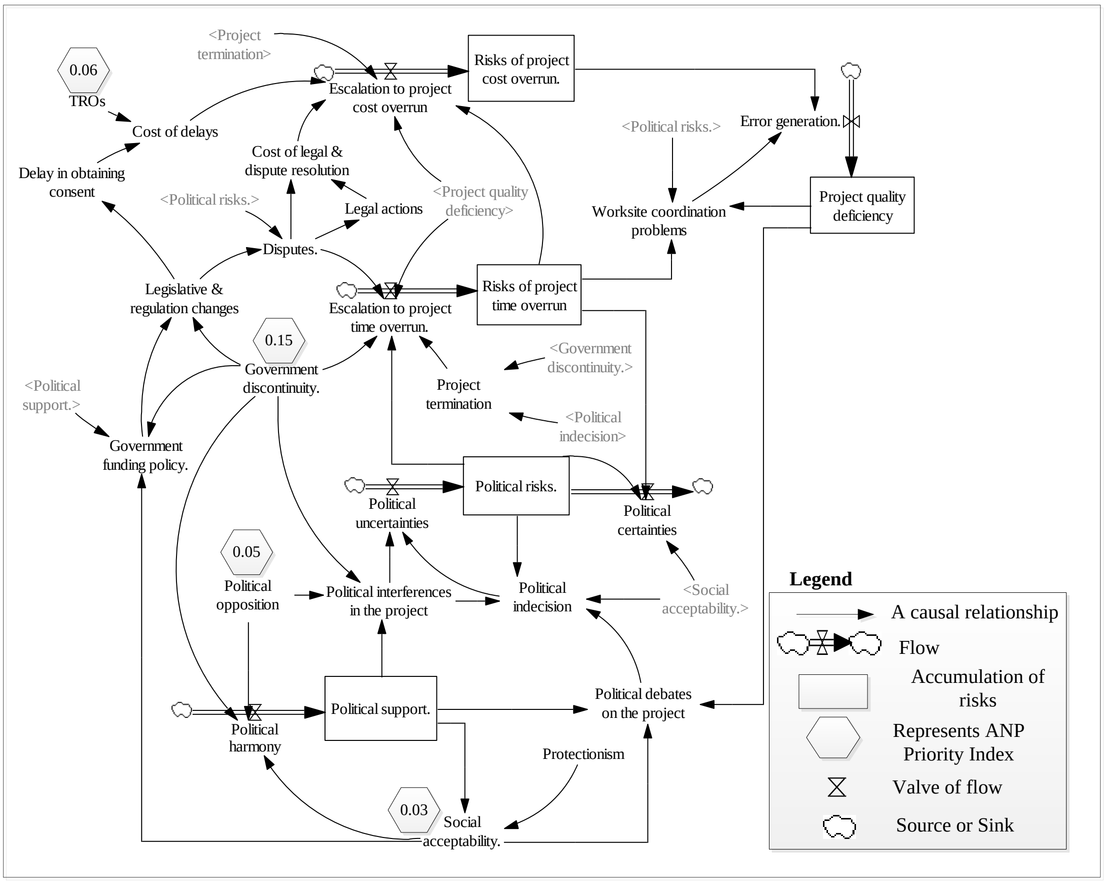


Figure 8.15: Integrated Stock and Flow Diagram for the Political Risks Model

The notation of the model follows the methodology of Forrester (1961). There are three different entities on the model: levels, rates and auxiliaries. Levels are indicated by the rectangular boxes, rates are noted by the signal flow meters and auxiliaries are shown without boxes. The sources and sinks of risks are shown as ‘pools’. The straight and curved solid lines indicate information flow among the various components of the system.

As Figure 8.15 indicates, four exogenous parameters with ANP RPIs represented in hexagonal boxes influence the level of risks in the system. The first parameter ‘TROs’ refers to the percentage of change to traffic management and related restrictions placed to road usage or even part of it. ‘Government discontinuity’ refers to the degree of change to political actors representing the megaproject owner when discontinuities of governmental or sovereign authorities of the national government occur in office. ‘Political opposition’ refers to instinctive opposition to the project as a result of lack of full knowledge of the project and its associated safety risks. ‘Protectionism’ is the economic policy of restraining trade between nations, through methods such as tariffs on imported goods, restrictive quotas, a variety of other government regulations designed to discourage imports and to prevent foreign take-over of native markets and companies. The result of this could either be unfair bidding or competitiveness.

It can be observed from Figure 8.15 that, government discontinuity; political opposition and social acceptability have direct influence on the controlling factor ‘political harmony’ which stocks political support. The stock ‘political risks’ is in turn influenced by variables such as political interference, and political indecision through the political uncertainties as shown. Further, it has to be noted that ‘political risks’ is affected by its outflow ‘political certainties’.

Similarly, risks of project time and cost overruns are influenced by escalation to project time overrun and escalation to project cost overrun to stock risks of project time and cost overruns respectively. Further consideration showed that a number of variables influence risks of project time and cost overruns through escalations to project time and cost overruns as detailed in the stock and flow diagram presented in Figure 8.15.

- ***Model Equation Formulation:*** The next step of the SD methodology is the development of the model equation (mathematical model); usually presented as a stock-flow diagram that captures the model structure and the interrelationships among the system variables (Sterman 2000). The integrated stock-flow diagram is translated to a system of differential equations, which is then solved via Vensim’s built-in simulation functions to support the analysis. The embedded mathematical equations are divided into two main categories: stock equations, relating the accumulations within the system to the net flow rates, and rate equations, defining the flows among the stocks as functions of time. All equations of the political risk sub model are deduced from Figure 8.15: and presented in Table 8.18.

The entire mathematical model is a non-linear model of fifth order. The initial values for the stock parameters are equal to zero apart from the initial value of *political support and political risks* which are based on the Risk Priority Indexes derived from the ANP's pairwise calculation.

Table 8.18: Mathematical Model for the Integrated Political Risks Model

Code	**System Variables**	**Equations**	**Measurement**
P_{R5}	Political risks	INTEG (Political uncertainties-Political certainties, Initial ANP value for P_{R5})	Dimensionless
P_{V1}:	Government funding policy	(Social acceptability + Political support) / Government discontinuity	Dimensionless
P_{V2}:	Political opposition	Constant	Dimensionless
P_{V3}:	Government discontinuity	Constant	Dimensionless
P_{V4}:	Political support	Political support.= INTEG (Political harmony, Initial ANP value for P_{V4})	Dimensionless
P_{V5}:	Political indecision (decision)	Social acceptability / (Political interferences in the project*Political debates on the project + Political risks)	Dimensionless
P_{V6}:	Project termination	Government discontinuity * Political indecision	Dimensionless
P_{V7}:	Delay in obtaining consent	"Legislative & regulation changes"	Dimensionless
P_{V8}:	Legislative/regulatory changes	Government discontinuity *Government funding policy	Dimensionless
P_{V9}:	Cost of delays	Delay in obtaining consent*TROs	Dimensionless
P_{V10}:	Cost of legal/dispute resolution	Disputes +Legal actions	Dimensionless
P_{V11}:	Disputes	Legislative & regulation changes * Political risks	Dimensionless
P_{V12}:	Error generation	(Worksite coordination problems * Risks of project cost overrun) per Unit time	Dimensionless /Year

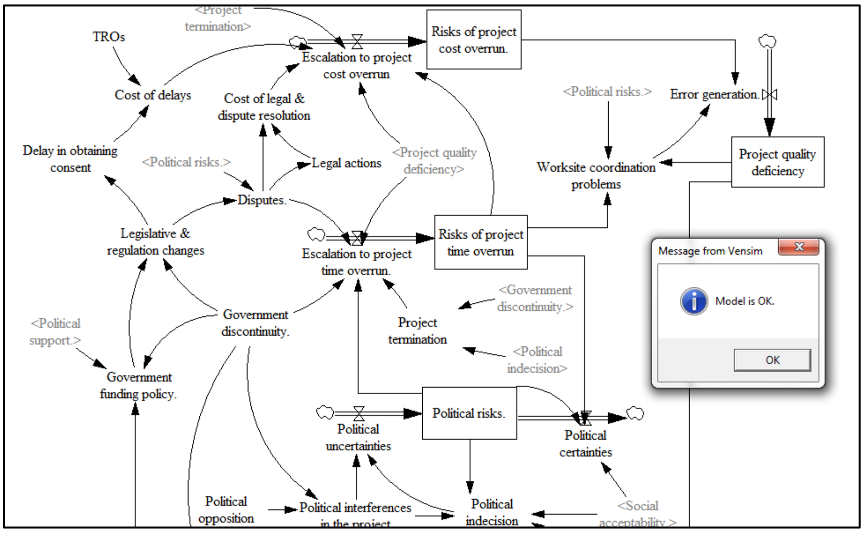
Source: Field Survey 2013

Table 8.18: Mathematical Model for the Integrated Political Risks Model (Continued)

Code	System Variables	Equations	Measurement
P_{V13}:	Escalation to project cost overrun	Risks of project time overrun* Project quality deficiency*(Cost of delays /Unit time) + (Cost of legal & dispute resolution+ Project termination)/Unit time	Dimensionless /Year
P_{V14}:	Escalation to project time overrun.	((Project quality deficiency*Political risks) per Unit time)) + ((Government discontinuity* Disputes) per Unit time)) + Project termination per Unit time	Dimensionless /Year
P_{V15}:	Legal actions	Disputes	Dimensionless
P_{V16}:	Political certainties	Social acceptability / Risks of project time overrun + Political risks	Dimensionless /Year
P_{V17}:	Political debates on the project	((Project quality deficiency) / (Political support + Social acceptability))*Unit time	Dimensionless
P_{V18}:	Political harmony	(Social acceptability / (Government discontinuity + Political opposition)) per Unit time	Dimensionless /Year
P_{V19}:	Political interferences in the project	(Political opposition + Government discontinuity) - (Political support per Unit time)	Dimensionless
P_{V20}:	Political uncertainties	(Political interferences in the project + Political indecision) per Unit time	Dimensionless /Year
P_{V21}:	Project quality deficiency	INTEG (Error generation, 0)	Dimensionless
P_{V22}:	Risks of project cost overrun.	INTEG (Escalation to project cost overrun, 0)	Dimensionless
P_{V23}:	Risks of project time overrun	INTEG (Escalation to project time overrun, 0)	Dimensionless
P_{V24}:	Social acceptability.	Political support * Protectionism	Dimensionless
P_{V25}:	Worksite coordination problems	Risks of project time overrun + Project quality deficiency + Political risks	Dimensionless

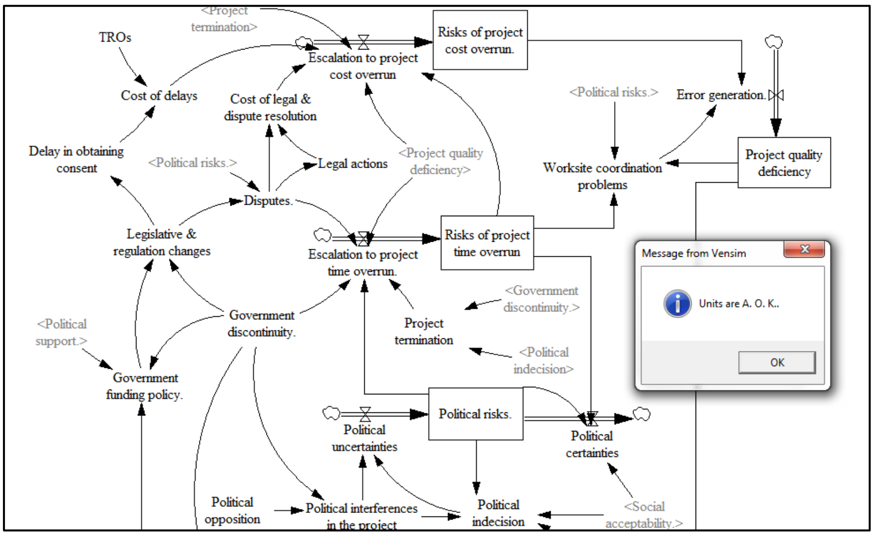
Source: Field Survey 2013

- ***Model Testing:*** Tests conducted on the political risks model before simulations were performed are illustrated in Figure 8.16. As the Figure 8.16 indicates, the messages from Vensim's built-in function show that the structural assessment and dimensional tests conducted on the environmental risks model are OK and hence, consistent.



Model is OK.

Figure 8.16a: Structural assessment test for political risks stock and flow model

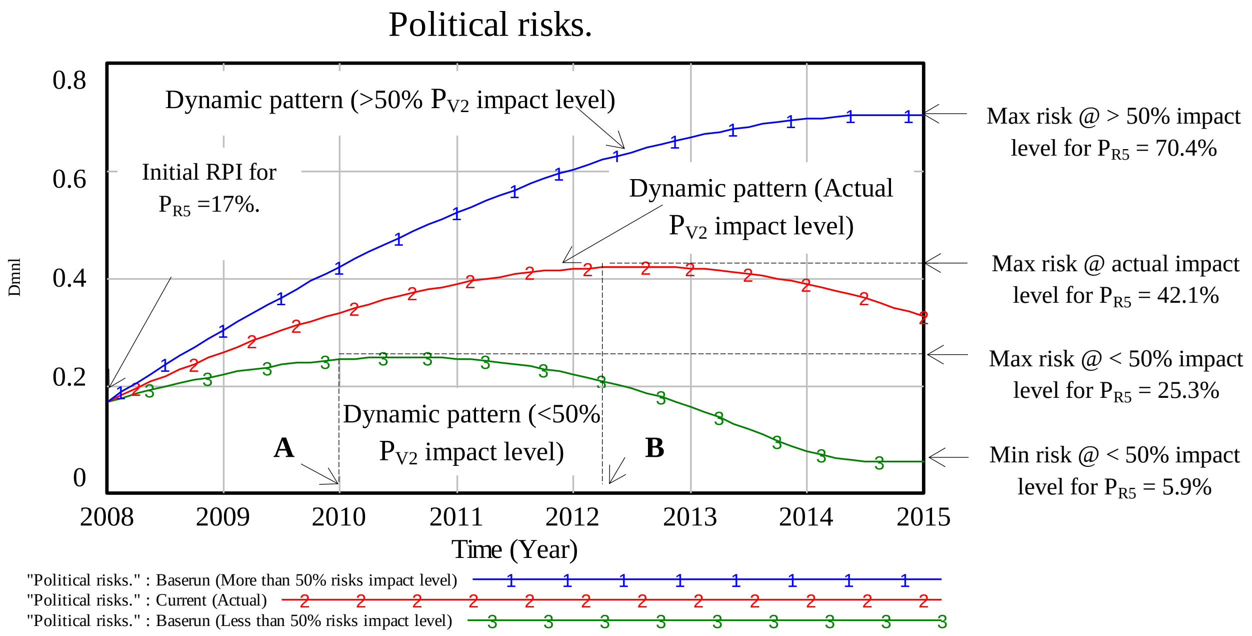


Units are A. O. K..

Figure 8.16b: Dimensional Consistency Check for the Political Risks Stock Model

Figure 8.16: Evaluation Tests for the Political Risks Model

- ***Dynamic Simulation Results and Discussion:*** This section presents the trend of a series of dynamic simulation patterns for political support, political risks, risks of project time overrun, risks of project cost overrun and project quality deficiency under two assumptions. First, simulation is performed by using the RPIs obtained from ANP's pairwise calculations and second, parameter values for exogenous system variables are set to different values so that variation in the values of the system parameters can cause a change in the dynamic behaviour of the model (in this case, +/- 50% to the ANP RPIs). The simulation results indicating the behaviour patterns of the stock risk entities are therefore shown in Figure 8.17.

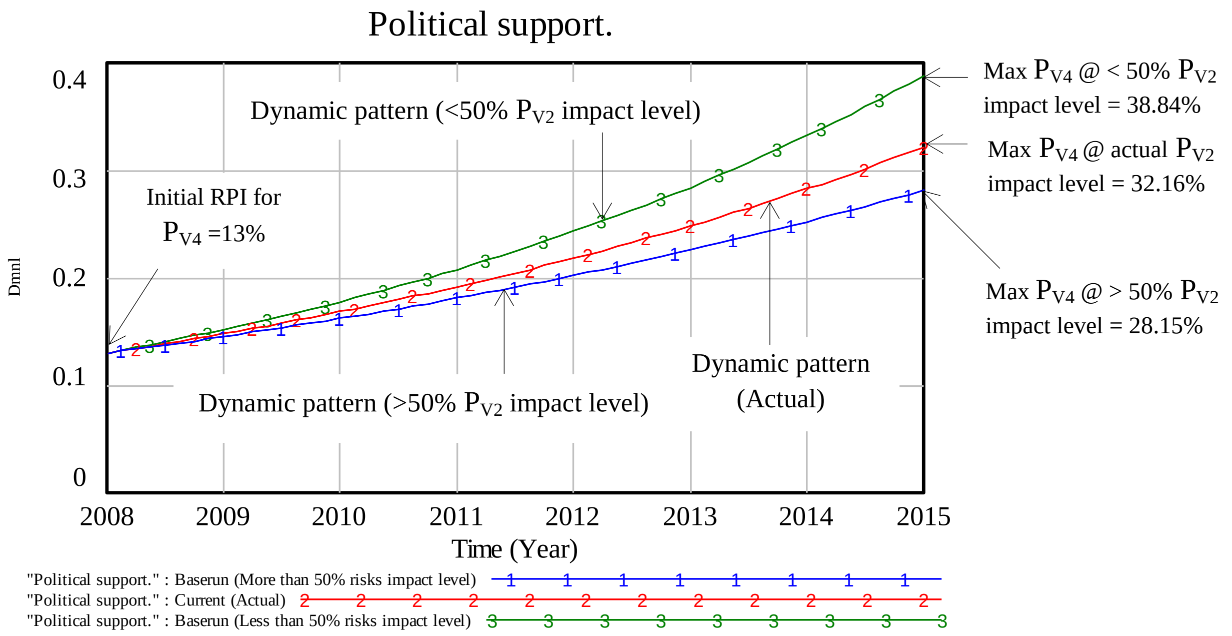


Note: Letters 'A and B' represent years 2010 and 2012.25 respectively

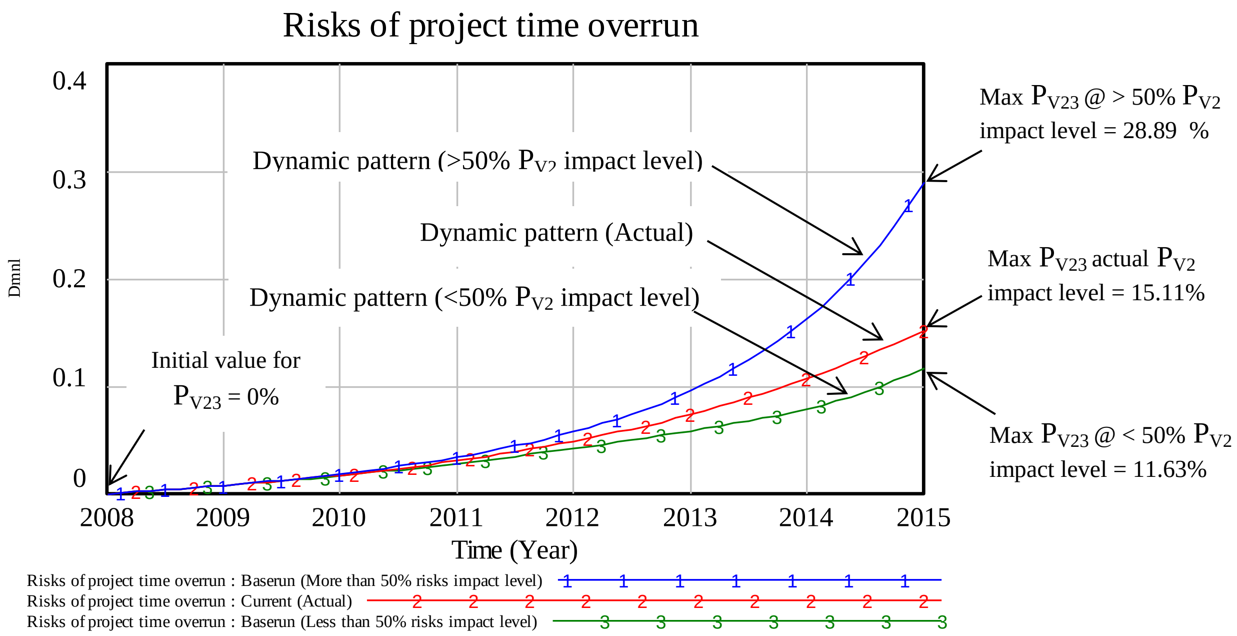
a: Scenario simulation patterns for political risks

Figure 8.17: Dynamic Simulation Patterns for Stock Entities in the Political Risks Model

As Figure 8.17a indicates, the state of the system for the 'Current (Actual)' run (represented in red line) for the political risks graph grows exponentially until the year 2012.25 before declining gradually to the end of year 2014. The pattern for the base run (less than 50% risk impact level) represented as a green line also grows gradually until year 2010 before declining (exponential decay) until the end of year 2014. The exponential decay of political risks at this point suggests that the net level of political support will increase as indicated in Figure 8.17b. Similarly, an observed mode of behaviour for the base run (more than 50% risk impact level) indicated by the blue line grows exponentially. As direct consequences of that growth, the level of political support to the project falls as indicated in Figure 8.17b.

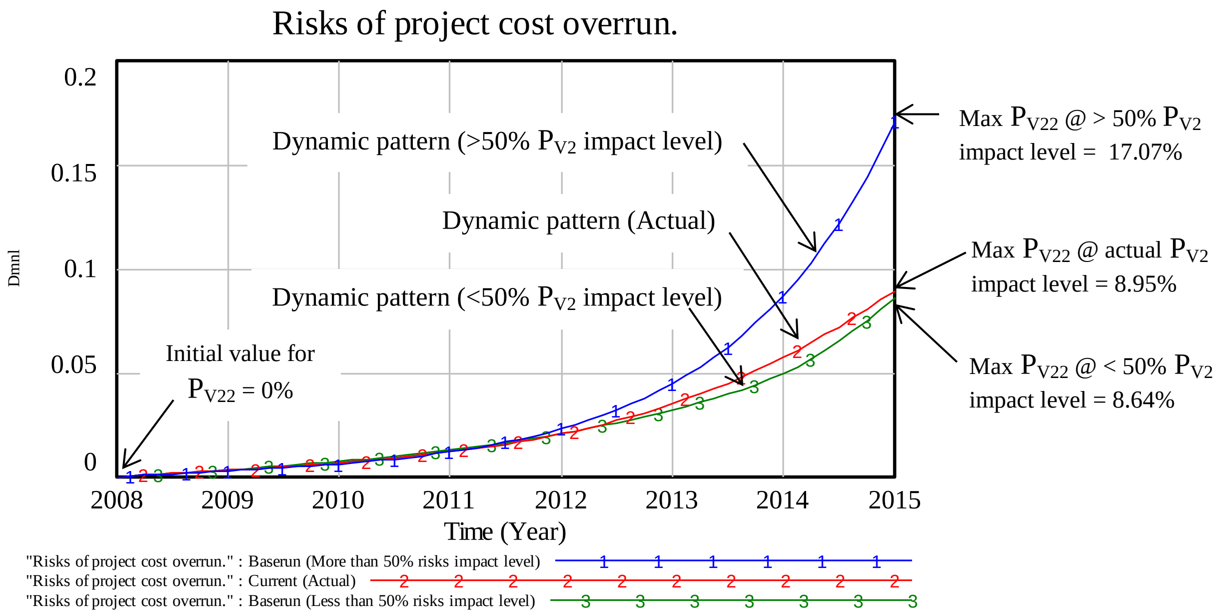


b: Scenario simulation patterns for political support

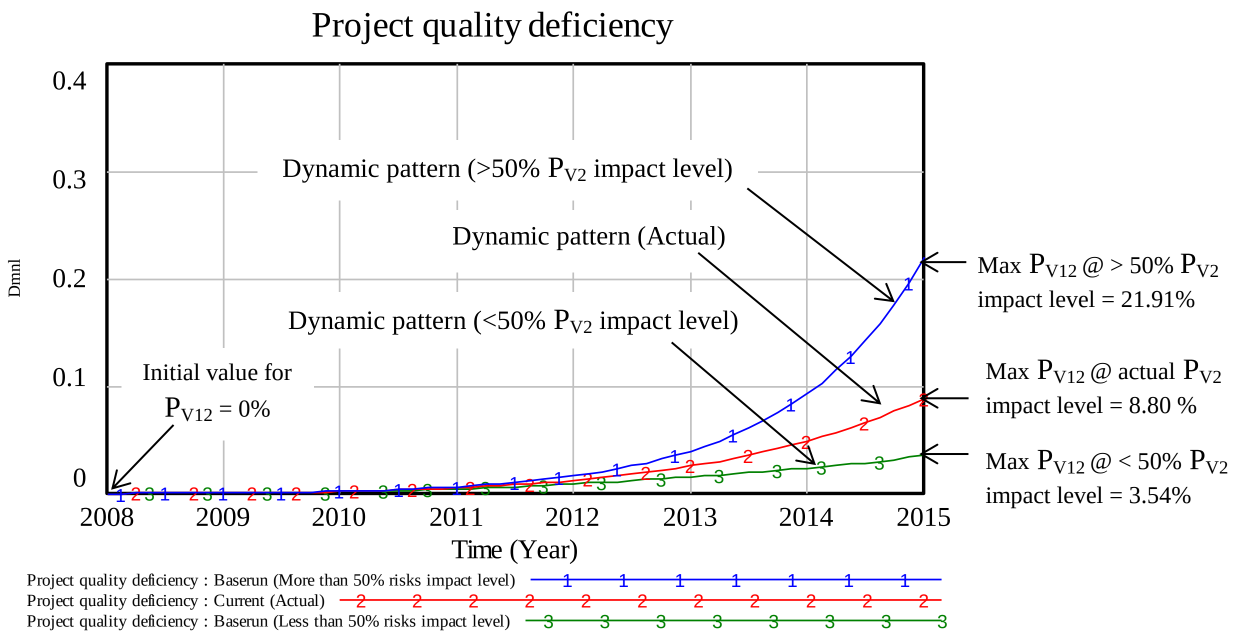


c: Scenario simulation patterns for risks of project time overrun

Figure 8.17: Dynamic Simulation Patterns for Stock Entities in the Political Risks Model (Continued)



d: Scenario simulation patterns for risks of project cost overrun



e: Scenario simulation patterns for project quality deficiency

Figure 8.17: Dynamic Simulation Patterns for Stock Entities in the Political Risks Model (Continued)

Despite the dynamic characteristics of political support, there is not, at any moment, a limit to the risks of project time and cost overruns and quality deficiencies as illustrated in Figures 8.17c to 8.17e which if improved causes risks of time and cost overruns to fall and project quality to improve. The behaviour patterns of these three risks arise through the nonlinear interactions of political risk variables with one another within the system. This suggests that decision making concerning project delays, budget overruns and quality deficiencies for the case study megaproject at the construction phase must be focused by the project managers on nonlinearities of political risk interactions within the project environment. As indicated by the simulated patterns in Figure 8.17 and the results represented in Tables 8.19 and 8.20, even if there is a significant level of political support to the case study megaproject, there is still the need for dynamic political risk assessment to reduce such risks.

Table 8.19: Dynamic Simulation Results for Political Risks System

Time (Year)	***ANP Inputs (%)**																							
	Risk code																	P_{R5}	P_{V2}	P_{V3}	P_{V4}	P_{V9}	P_{V10}	
	Risks priority index																	17	8	15	13	3	6	
	SD Simulation Outputs (%)																							
	P_{R5}	P_{V1}	P_{V4}	P_{V5}	P_{V6}	P_{V7}	P_{V8}	P_{V9}	P_{V10}	P_{V11}	P_{V12}	P_{V13}	P_{V14}	P_{V15}	P_{V16}	P_{V17}	P_{V18}	P_{V19}	P_{V20}	P_{V21}	P_{V22}	P_{V23}	P_{V24}	P_{V25}
2008.000	17.0	89.2	13.0	2.29	0.34	13.4	13.4	0.80	4.55	2.28	0.00	0.34	0.69	2.3	2.29	0.00	1.70	10.0	12.3	0.00	0.00	0.00	0.39	17.00
2008.125	18.3	90.7	13.2	2.17	0.33	13.6	13.6	0.82	4.97	2.48	0.01	0.33	0.70	2.5	2.16	0.00	1.72	9.79	12.0	0.00	0.04	0.09	0.40	18.34
2008.250	19.5	92.2	13.4	2.07	0.31	13.8	13.8	0.83	5.39	2.69	0.02	0.32	0.71	2.7	2.05	0.01	1.75	9.57	11.6	0.00	0.08	0.17	0.40	19.65
2008.375	20.7	93.7	13.7	1.98	0.30	14.1	14.1	0.84	5.81	2.91	0.03	0.31	0.73	2.9	1.96	0.02	1.78	9.35	11.3	0.00	0.12	0.26	0.41	20.94
2008.500	21.9	95.2	13.9	1.90	0.29	14.3	14.3	0.86	6.24	3.12	0.04	0.31	0.76	3.1	1.87	0.04	1.81	9.13	11.0	0.01	0.16	0.35	0.42	22.21
2008.625	23.0	96.8	14.1	1.84	0.28	14.5	14.5	0.87	6.68	3.34	0.05	0.31	0.78	3.3	1.80	0.07	1.84	8.91	10.7	0.01	0.20	0.45	0.42	23.45
2008.750	24.1	98.4	14.3	1.78	0.27	14.8	14.8	0.89	7.11	3.56	0.06	0.31	0.80	3.6	1.74	0.11	1.87	8.68	10.5	0.02	0.24	0.55	0.43	24.67
2008.875	25.2	100	14.6	1.73	0.26	15.0	15.0	0.90	7.56	3.78	0.07	0.31	0.83	3.8	1.69	0.16	1.90	8.44	10.2	0.02	0.28	0.65	0.44	25.87
2009.000	26.3	102	14.8	1.69	0.25	15.2	15.2	0.91	8.00	4.00	0.09	0.31	0.86	4.0	1.64	0.22	1.93	8.20	9.89	0.03	0.32	0.75	0.44	27.04
2009.125	27.3	103	15.0	1.65	0.25	15.5	15.5	0.93	8.45	4.23	0.10	0.32	0.89	4.2	1.60	0.28	1.96	7.96	9.61	0.04	0.36	0.86	0.45	28.19
2009.250	28.3	105	15.3	1.62	0.24	15.7	15.7	0.94	8.91	4.45	0.12	0.33	0.93	4.5	1.57	0.36	1.99	7.72	9.34	0.06	0.40	0.97	0.46	29.32
2009.375	29.3	107	15.5	1.59	0.24	16.0	16.0	0.96	9.36	4.68	0.13	0.34	0.96	4.7	1.54	0.44	2.03	7.47	9.06	0.07	0.44	1.09	0.47	30.42
2009.500	30.2	108	15.8	1.57	0.23	16.3	16.3	0.98	9.82	4.91	0.15	0.35	1.00	4.9	1.51	0.54	2.06	7.22	8.78	0.09	0.48	1.21	0.47	31.50
2009.625	31.1	110	16.0	1.54	0.23	16.5	16.5	0.99	10.3	5.14	0.17	0.37	1.04	5.1	1.48	0.64	2.09	6.96	8.50	0.11	0.52	1.33	0.48	32.55
2009.750	32.0	112	16.3	1.53	0.23	16.8	16.8	1.01	10.7	5.37	0.19	0.39	1.08	5.4	1.46	0.76	2.13	6.70	8.22	0.13	0.57	1.46	0.49	33.58
2009.875	32.8	114	16.6	1.51	0.23	17.1	17.1	1.02	11.2	5.60	0.21	0.41	1.12	5.6	1.44	0.89	2.16	6.43	7.94	0.15	0.62	1.59	0.50	34.58
2010.000	33.7	116	16.8	1.50	0.22	17.3	17.3	1.04	11.7	5.84	0.24	0.43	1.16	5.8	1.43	1.03	2.20	6.16	7.66	0.18	0.67	1.73	0.51	35.56

** Refer to Table 6.11: Summary of final ANP decision making priority results for all risks on page 169.*

Table 8.19: Dynamic Simulation Results for Political Risks System (continued)

Time (Year)	*ANP Inputs (%)																							
	Risk code																	P_{R5}	P_{V2}	P_{V3}	P_{V4}	P_{V9}	P_{V10}	
	Risks priority index																	17	8	15	13	3	6	
	SD Simulation Outputs (%)																							
	P_{R5}	P_{V1}	P_{V4}	P_{V5}	P_{V6}	P_{V7}	P_{V8}	P_{V9}	P_{V10}	P_{V11}	P_{V12}	P_{V13}	P_{V14}	P_{V15}	P_{V16}	P_{V17}	P_{V18}	P_{V19}	P_{V20}	P_{V21}	P_{V22}	P_{V23}	P_{V24}	P_{V25}
2010.125	34.4	118	17.1	1.5	0.2	17.6	17.6	1.06	12.1	6.07	0.26	0.45	1.21	6.1	1.41	1.18	2.23	5.89	7.37	0.21	0.72	1.88	0.51	36.51
2010.250	35.2	119.4	17.4	1.5	0.2	17.9	17.9	1.07	12.6	6.30	0.29	0.48	1.25	6.3	1.40	1.35	2.27	5.61	7.09	0.24	0.78	2.03	0.52	37.44
2010.375	35.9	121.4	17.7	1.5	0.2	18.2	18.2	1.09	13.1	6.53	0.32	0.51	1.30	6.5	1.39	1.52	2.31	5.32	6.80	0.28	0.84	2.19	0.53	38.35
2010.500	36.6	123.4	18	1.5	0.2	18.5	18.5	1.11	13.5	6.76	0.35	0.54	1.35	6.8	1.39	1.72	2.34	5.04	6.51	0.32	0.90	2.35	0.54	39.22
2010.625	37.2	125.4	18.3	1.5	0.2	18.8	18.8	1.13	14.0	7.00	0.39	0.57	1.40	7.0	1.38	1.92	2.38	4.74	6.21	0.36	0.97	2.52	0.55	40.08
2010.750	37.8	127.4	18.6	1.5	0.2	19.1	19.1	1.15	14.5	7.22	0.43	0.61	1.46	7.2	1.37	2.15	2.42	4.44	5.91	0.41	1.04	2.69	0.56	40.91
2010.875	38.4	129.5	18.9	1.5	0.2	19.4	19.4	1.17	14.9	7.45	0.47	0.65	1.52	7.5	1.37	2.39	2.46	4.14	5.61	0.46	1.12	2.88	0.57	41.71
2011.000	38.9	131.6	19.2	1.5	0.2	19.7	19.7	1.18	15.4	7.68	0.51	0.69	1.58	7.7	1.37	2.64	2.50	3.83	5.31	0.52	1.20	3.07	0.57	42.49
2011.125	39.4	133.8	19.5	1.5	0.2	20.1	20.1	1.20	15.8	7.90	0.56	0.74	1.64	7.9	1.37	2.92	2.54	3.52	5.00	0.5	1.28	3.26	0.58	43.24
2011.250	39.9	135.9	19.8	1.5	0.2	20.4	20.4	1.22	16.3	8.12	0.61	0.79	1.70	8.1	1.37	3.21	2.58	3.20	4.69	0.65	1.38	3.47	0.59	43.97
2011.375	40.3	138.1	20.1	1.5	0.2	20.7	20.7	1.24	16.7	8.34	0.66	0.84	1.77	8.3	1.37	3.53	2.62	2.88	4.38	0.73	1.48	3.68	0.60	44.67
2011.500	40.6	140.4	20.5	1.5	0.2	21.1	21.1	1.26	17.1	8.56	0.72	0.89	1.84	8.6	1.38	3.86	2.67	2.55	4.06	0.81	1.58	3.90	0.61	45.35
2011.625	41	142.7	20.8	1.5	0.2	21.4	21.4	1.28	17.5	8.77	0.78	0.95	1.91	8.8	1.38	4.22	2.71	2.22	3.74	0.90	1.69	4.13	0.62	46.00
2011.750	41.3	145.0	21.1	1.5	0.2	21.8	21.8	1.31	18.0	8.98	0.84	1.01	1.99	9.0	1.39	4.60	2.75	1.88	3.41	1.00	1.81	4.37	0.63	46.64
2011.875	41.5	147.4	21.5	1.6	0.2	22.1	22.1	1.33	18.4	9.18	0.92	1.08	2.07	9.2	1.40	5.0	2.80	1.54	3.09	1.11	1.94	4.62	0.64	47.24
2012.000	41.7	149.8	21.8	1.6	0.2	22.5	22.5	1.35	18.8	9.38	0.99	1.15	2.15	9.4	1.40	5.43	2.85	1.19	2.75	1.22	2.07	4.88	0.65	47.83
2012.125	41.9	152.2	22.2	1.6	0.2	22.8	22.8	1.37	19.1	9.57	1.07	1.22	2.24	9.6	1.41	5.88	2.89	0.83	2.42	1.34	2.22	5.15	0.67	48.39
2012.250	42.0	154.7	22.5	1.6	0.2	23.2	23.2	1.39	19.5	9.75	1.16	1.30	2.32	9.8	1.42	6.37	2.94	0.47	2.08	1.48	2.37	5.43	0.68	48.93
2012.375	42.1	157.2	22.9	1.6	0.2	23.6	23.6	1.42	19.9	9.93	1.25	1.38	2.42	99.	1.44	6.8	2.99	0.10	1.73	1.62	2.53	5.72	0.69	49.44
2012.500	42.1	159.8	23.3	1.7	0.3	24	24	1.44	20.2	10.1	1.35	1.47	2.51	10.1	1.45	7.42	3.04	-0.3	1.39	1.78	2.70	6.02	0.70	49.94
2012.625	42.1	162.4	23.7	1.7	0.3	24.4	24.4	1.46	20.5	10.3	1.46	1.55	2.61	10.3	1.46	8.00	3.08	-0.7	1.04	1.95	2.89	6.33	0.71	50.42
2012.750	42.1	165.0	24.0	1.7	0.3	24.8	24.8	1.49	20.8	10.4	1.57	1.65	2.72	10.4	1.48	8.60	3.14	-1.0	0.68	2.13	3.08	6.66	0.72	50.87
2012.875	42	167.7	24.4	1.8	0.3	25.2	25.2	1.51	21.1	10.6	1.69	1.74	2.82	10.6	1.50	9.24	3.19	-1.4	0.32	2.33	3.29	7.00	0.73	51.31
2013.000	41.8	170.5	24.8	1.8	0.3	25.6	25.6	1.53	21.4	10.7	1.81	1.84	2.93	10.7	1.5	9.92	3.24	-1.8	0.0	2.54	3.51	7.35	0.74	51.72

Table 8.19: Dynamic Simulation Results for Political Risks System (continued)

Time (Year)	***ANP Inputs (%)**																							
	Risk code																	P_{R5}	P_{V2}	P_{V3}	P_{V4}	P_{V9}	P_{V10}	
	Risks priority index																	17	8	15	13	3	6	
	SD Simulation Outputs (%)																							
	$\mathbf{P}_{R5}$	P_{V1}	P_{V4}	P_{V5}	P_{V6}	P_{V7}	P_{V8}	P_{V9}	P_{V10}	P_{V11}	P_{V12}	P_{V13}	P_{V14}	P_{V15}	P_{V16}	P_{V17}	P_{V18}	P_{V19}	P_{V20}	P_{V21}	P_{V22}	P_{V23}	P_{V24}	P_{V25}
2013.125	41.6	173	25.2	1.8	0.3	26	26	1.56	21.6	10.8	1.95	1.95	3.05	10.8	1.53	10.6	3.29	-2.2	-0.4	2.76	3.74	7.72	0.76	52.12
2013.250	41.4	176	25.6	1.9	0.3	26.4	26.4	1.58	21.9	10.9	2.09	2.06	3.17	10.9	1.55	11.4	3.34	-2.6	-0.8	3.01	3.98	8.10	0.77	52.51
2013.375	41.1	179	26.1	1.9	0.3	26.8	26.8	1.61	22.0	11.0	2.24	2.17	3.29	11.0	1.58	12.2	3.4	-3.1	-1.1	3.27	4.24	8.50	0.78	52.87
2013.500	40.8	182	26.5	2.0	0.3	27.3	27.3	1.64	22.9	11.1	2.40	2.28	3.41	11.1	1.60	13.0	3.45	-3.5	-1.5	3.55	4.51	8.91	0.79	53.22
2013.625	40.4	185	26.9	2.0	0.3	27.7	27.7	1.66	22.4	11.2	2.57	2.40	3.54	11.2	1.62	13.9	3.51	-3.9	-1.9	3.85	4.79	9.33	0.81	53.56
2013.750	39.9	186	27.4	2.1	0.3	28.2	28.2	1.69	22.5	11.3	2.74	2.52	3.67	11.3	1.65	14.8	3.57	-4.4	-2.3	4.17	5.09	9.77	0.82	53.88
2013.875	39.5	191	27.8	2.2	0.3	28.6	28.6	1.72	22.6	11.3	2.93	2.64	3.80	11.3	1.68	15.8	3.63	-4.8	-2.7	4.51	5.41	10.2	0.83	54.20
2014.000	38.9	194	28.3	2.2	0.3	29.1	29.1	1.75	22.6	11.3	3.13	2.77	3.93	11.3	1.71	16.8	3.69	-5.3	-3.0	4.88	5.74	10.7	0.85	54.50
2014.125	38.3	197	28.7	2.3	0.4	29.6	29.6	1.77	22.7	11.3	3.33	2.90	4.07	11.3	1.74	17.8	3.75	-5.7	-3.4	5.27	6.08	11.2	0.86	54.79
2014.250	37.7	200	29.2	2.4	0.4	30.1	30.1	1.80	22.7	11.3	3.55	3.02	4.20	11.3	1.77	18.9	3.81	-6.2	-3.8	5.69	6.45	11.7	0.88	55.07
2014.375	37	204	29.7	2.5	0.4	30.6	30.6	1.83	22.6	11.3	3.78	3.15	4.34	11.3	1.81	20.1	3.87	-6.7	-4.2	6.13	6.82	12.2	0.89	55.34
2014.500	36.2	207	30.1	2.6	0.4	31.1	31.1	1.86	22.5	11.3	4.0	3.28	4.47	11.2	1.85	21.3	3.93	-7.1	-4.5	6.60	7.22	12.8	0.90	55.61
2014.625	35.4	210	30.6	2.7	0.4	31.6	31.6	1.89	22.4	11.2	4.26	3.41	4.60	11.2	1.88	22.5	4.00	-7.6	-4.9	7.10	7.63	13.3	0.92	55.87
2014.750	34.6	214	31.1	2.9	0.4	32.1	32.1	1.92	22.2	11.1	4.52	3.53	4.73	11.1	1.93	23.8	4.06	-8.1	-5.3	7.64	8.05	13.9	0.93	56.13
2014.875	33.7	217	31.6	3.0	0.5	32.6	32.6	1.96	22.0	11.0	4.79	3.66	4.86	11.0	1.97	25.2	4.13	-8.6	-5.6	8.20	8.50	14.5	0.95	56.39
2015.000	32.7	221	32.2	3.2	0.5	33.1	33.1	1.99	21.7	10.8	5.07	3.78	4.99	10.8	2.02	26.6	4.19	-9.2	-6.0	8.80	8.95	15.1	0.96	56.65

** Refer to Table 6.11: Summary of final ANP decision making priority results for all risks on page 169.*

Table 8.20: Summary of the Dynamic Simulation Results for the Political Risks System Model

ANP/SD Simulation Results							
Code	**System Variables**	***ANP inputs (%)**					
P_{V2}:	Political opposition	08					
P_{V3}:	Government discontinuity	15					
P_{V9}:	Protectionism	03					
P_{V10}:	Delay in obtaining temporary Traffic Regulation Orders (TROs)	06					
		SD Simulation Outputs (%)					
		Min	Max	Mean	Median	StDev	(Norm)
P_{R5}	Political risks	17.0	42.1	35.2	37.7	7.04	20.0
P_{V1}:	Government funding policy	89.3	220.8	145.4	140.4	38.4	26.4
P_{V4}:	Political support	13.0	32.2	21.2	20.5	5.6	26.4
P_{V5}:	Political indecision (decision)	1.47	3.18	1.84	1.69	0.42	22.9
P_{V6}:	Project termination	0.22	0.48	0.28	0.25	0.06	22.9
P_{V7}:	Delay in obtaining consent/approval	13.4	33.1	21.8	21.1	5.76	26.4
P_{V8}:	Legislative & regulatory changes	13.4	33.1	21.8	21.1	5.76	26.4
P_{V9}:	Cost of delays	0.80	1.99	1.31	1.26	0.35	26.4
P_{V10}:	Cost of legal & dispute resolution	4.55	22.7	15.9	17.1	5.94	37.5
P_{V11}:	Disputes	2.28	11.3	7.93	8.56	2.97	37.5
P_{V12}:	Error generation	0.00	5.07	1.32	0.72	1.42	108
P_{V13}:	Escalation to project cost overrun	0.31	3.78	1.32	0.89	1.07	81.0
P_{V14}:	Escalation to project time overrun.	0.69	4.99	2.21	1.84	1.30	58.7
P_{V15}:	Legal actions	2.28	11.33	7.93	8.56	2.97	37.5
P_{V16}:	Political certainties	1.37	2.29	1.60	1.51	0.23	14.3
P_{V17}:	Political debates on the project	0.00	26.6	7.02	3.86	7.62	109
P_{V18}:	Political harmony	1.70	4.19	2.76	2.67	0.73	26.4
P_{V19}:	Political interferences in the project	-9.16	10.0	1.82	2.55	5.60	307.
P_{V20}:	Political uncertainties	-5.97	12.3	3.66	4.06	5.33	146
P_{V21}:	Project quality deficiency	0.00	8.80	1.95	0.81	2.41	123
P_{V22}:	Risks of project cost overrun.	0.00	8.95	2.56	1.58	2.50	97.4
P_{V23}:	Risks of project time overrun	0.00	15.1	5.14	3.90	4.33	84.1
P_{V24}:	Social acceptability.	0.39	0.96	0.64	0.61	0.17	26.4
P_{V25}:	Worksite coordination problems	17.0	56.7	42.3	45.4	11.7	27.6

*Current simulation runs Time (Year) for Political Risk Model = 2008 to 2015, * Refer to Table 27: Summary of final ANP decision making priority results for all risks.*

Source: Field Work 2013

- ***Analysis of Dynamic Simulation Results for Project Objectives:***

The findings of the dynamic simulation results are explored in relation to the level of impacts of political risks on the objectives of the case study megaproject identified as been mainly risks of project time and cost overruns and project quality deficiency. Table 8.21 presents a one-way analysis of variance (ANOVA) of the level of political risks impact on project time, cost and quality. The aim of the one-way analysis of variance (ANOVA) is to explore whether one particular project objective experience more of risks impact than those of other project objectives using an alpha of .001. If so, what will be the nature of these distinctions and if not, what will be the form of the similarities.

Table 8.21: One-Way Analysis of Variance: The Level and Extent to which Political Risks Affect the Objectives of the Case Study Megaproject during Construction

Project Objectives	Level of Political Risks Impact on Megaproject Objectives (%)	
	Mean	*Std. deviation*
Time	5.14	4.33
Cost	2.56	2.50
Quality	1.95	2.41

Variance	The Extent to which Political Risks Impact on Project Objectives				
	Sum of squares	Degrees of freedom (df).	Mean square	F	P
Between project objectives	326.590	2	163.295	15.666	.000
Within project objectives	1751.192	168	10.424		
Total	2077.782	170			

Source: Field work 2013

As presented in Table 8.21, the one-way analysis of variance reveals that project time, cost and quality of transportation megaprojects are all impacted by political risks. The mean scores reveal that project time is affected most, followed by the project cost and then the project quality. Subjecting the results to one-way analysis of variance (ANOVA), the F (obtained) is 15.666 which far exceeds the F-critical value of 7.41 for this test when using an alpha of .001. Correspondingly, the observed p-value of .000 is well below the chosen alpha of .001. By either standard, it implies that the difference between the levels of political risks impact on the objectives of the cases study project is statistically non-significant.

8.4: Summary

Realistic 'project time, cost and quality' has become increasingly important during megaproject development. They serve as crucial benchmarks for assessing the performance of megaprojects and the efficiency of the principal contractor (Chan and Kumaraswamy, 2002). In this section of the research, potential risk variables which cause transportation megaprojects to underperform in the construction phase and problems likely to confront the current and future transportation megaprojects were classified and modelled in five (Social, Technical, Economic, Environmental and Political) sub systems. The idea is to develop a proactive megaproject dynamic system tool to assess transportation megaprojects in which potential problems are fully anticipated.

A case study of tram network construction in Edinburgh, Scotland (UK) has been taken to explain how the ANP and the SD methodology can be integrated and used as an approach and tool to assess risks in transportation megaproject in the construction phase for managerial decision against project delays, over budgets and quality deficiency in megaproject development over time.

Table 8.22: Summary of Dynamic Simulation Result for Risks Impact on ETNP

Risks	**Level of Risk Impact on Project Performance (%)**			
	Cost	Time	Quality	Total Impact
Social	12	6	1	19
Technical	1.24	0.43	0.15	1.82
Economic	22.36	30.74	8.88	61.98
Environmental	11.43	29.3	3.35	44.08
Political	2.56	5.14	1.95	9.65
Total Impact	**49.59**	**71.61**	**15.33**	**136.53**

Source: Field Work 2013

The new approach was used to produce dynamic simulations and graphs to reveal the level of impacts of STEEP risks on project cost, time and quality for Edinburgh Tram Project over time. Table 8.22 illustrates a summary of the dynamic simulation results indicating the level of STEEP risks impact on project cost, time and quality on ETNP during construction. As Table 8.22 indicates, the total level of STEEP risks impact on

ETNP with respect to cost is 49.59%, and for time and quality, 71.61% and 15.33% respectively. In addition, findings of the dynamic simulation results were further explored by subjecting the results to a one-way analysis of variance (ANOVA). The aim of the ANOVA is to explore whether one particular project objective experiences more risks impact than those of other project objectives, and if so, what will be the nature of these distinctions and if not, what will be the form of the similarities. The results indicated non-significant differences between the levels of all risks impact on the objectives of the cases study project. Detail results of the extent to which the STEEP risks impacted on cost, time and quality are represented in Tables 8.5, 8.9, 8.13, 8.17 and 8.21.

It must be noted that, in the new approach, numbers are not very important as the researcher is basically interested in studying the behaviour and trend of the dynamic system. However, the model must pass the reality check, so that the inputs of the ANP's RPIs into the system dynamics simulations can be proven realistic. The next chapter "Validation of the SDANP models" laid emphasis on different ways in which a model may be validated before its results can be accepted.

CHAPTER NINE: MODEL VALIDATION

9.1: Introduction

In Chapter 8, the SDANP models for assessing the dynamics of risks in transportation megaprojects were developed and major observations made from their simulated behaviour modes which replicate the existing problem entities (risks of project time and cost overruns and project quality deficiency) of Edinburgh Tram Network Project (ETNP) the construction phase in Scotland, UK.

This chapter is about the major aspects of the model validation. It presents the final process that is to be carried out using the system dynamics methodology to address the research objective 4 stated in Section 1.3.2 of Chapter I. The chapter is organized around six major sections, namely: Introduction; Model Validation Process; Validation Scheme for the Integrated System Models; data validity; policy analysis and design and finally, a brief summary of the chapter.

9.1.1: Philosophical Aspects of Model Validity

Validation of dynamic simulation models is one of the most vital phases in the process of modelling real systems. However, as is true for scientific theories in general, dynamic model validation also faces the problem that ‘correctness’ of a model cannot be proven. That means validation and verification of models is impossible (Sterman, 2010). The word ‘verify’ derived from the Latin word “*verus”* means “truth” and is defined by the Webster dictionary as “*to establish the truth, accuracy, or reality of.*” While “valid” is defined as “*well-grounded or justifiable.”*

By these definitions, it can be said that a model can only deliver correct results in a specific setting (reproduce the behaviour of the original) and cannot constitute proof that it will work correctly in all or even other circumstances. As Forrester (1961, p.123) states: “*The validity (or significance) of a model should be judged by its suitability for a* *particular purpose. A model is sound and defendable if it accomplishes what is expected of it…. Validity, as an abstract concept divorced from purpose, has no useful meaning.*" With regards to objective criteria for model validity, Forrester further states that: *"Any "objective" model-validation procedure rests eventually at some lower level on a judgement or faith that either the procedure or its goals are acceptable without objective proof."* Greenberger, Crenson, and Crissey (1976, p70-71) emphasized that: *"No model has ever been or ever will be thoroughly validated… "Useful", illuminating," "convincing," or "inspiring confidence" are more apt descriptors applying to models than "valid."* Sterman (2010, p. 846) confirmed this to conclude that: *"Some modellers have long recognized the impossibility of validation in the sense of establishing the truth."*

The author therefore does not speak of the "correctness" of the dynamic megaproject model (MegaDS) for transportation projects and its sub models in this research but only of their validity relative to their purposes in risk descriptions and assessment. This validity can be established by extensive scenario trials, but it is only true until evidence to the contrary appears.

9.2: Model Validation Process

Figure 9.1 illustrates a simpler form for the model validation process. The 'problem entity' is the system (real or proposed – for example for this research, a Dynamic Systems Approach to Risk Assessment in Megaprojects is considered as a problem entity) to be modelled. The 'conceptual model' is the mathematical- verbal representation (influence or causal loop diagram) of the problem entity developed for a particular study; and the 'computerised model' is the conceptual model implemented on a computer (dynamic simulation model). The inferences about the problem entity are obtained by conducting simulations on the computerised model in the experimentation phase.

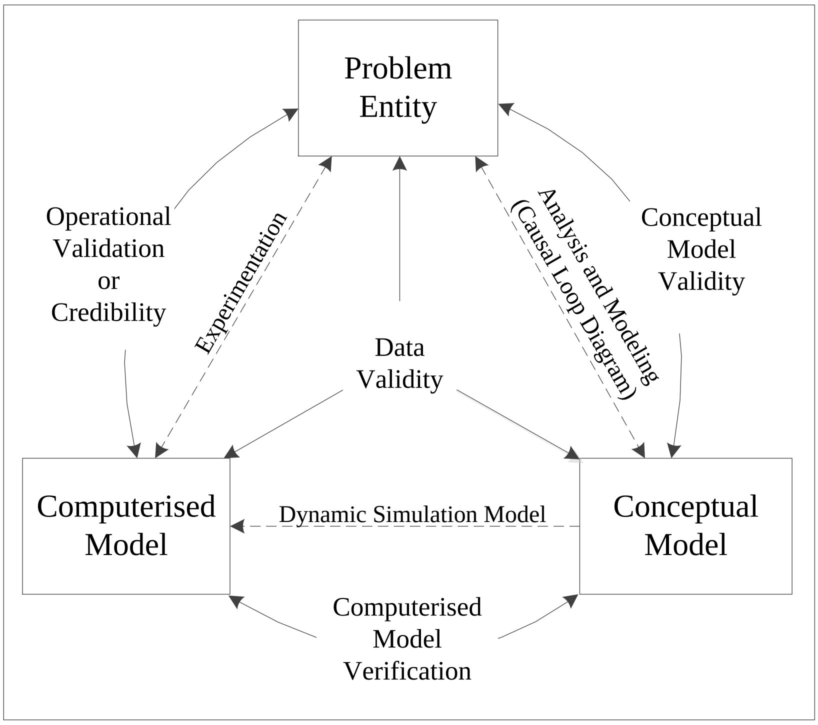


Figure 9.1: Model Validation Process

There are three steps in deciding if a simulation is an accurate representation of the actual system considered, namely, verification, validation and credibility (Garzia and Garzia 1990 and Law, 2003). Sargent (2003) defines ‘Conceptual model validation’ as the process of determining that the theories and assumptions underlying the conceptual model are correct and that the model representation of the problem entity is “reasonable” for the intended purpose of the model. ‘Computerised model verification’ is the process of determining that the model implementation accurately depicts the developers’ conceptual description of the model and the solution to the model (AIAA, 1998). ‘Operational validation’ is defined as determining that the model’s output behaviour has adequate exactness for the model’s intended purpose over the domain of the model’s intended applicability (Sargent, 2003). Operational validity determines the model credibility. ‘Data validity’ ensures that the data necessary for model building, model evaluation and conducting the model experiments to solve the problem are adequate and correct (Love and Back, 2000).

9.3: Methods for Testing and Validating the Integrated System Models

In order to show that the MegaDS model systems represent the original system well enough for the model purpose, validity was demonstrated with respect to a wide variety of specific system dynamics tests promoted by Forrester and Senge (1980) which are adopted and modified from Sterman (2010, esp. pp. 859-861) to uncover flaws and improve the models. Table 9.1 summarises the main tests used to build confidence in the models and the question addressed by each test.

It is necessary to distinguish three systems (Real, Model and Hypothesized) that are mentioned in Table 9.1. The *real system* includes existing components, interactions, causal linkages between these components and the resulting behaviour of the system in reality. However, in most cases limited knowledge about the real system is known. The *model system* is the abstract system built by the modeller to simulate the real system, which can help megaproject managers, engineers and consultants in decision-making processes. The *hypothesized system* is the counterpart of the real system, which is constructed from the dynamic hypotheses models for the purpose of validation. The hypothesized system is created by and from the available knowledge of experts and/or the experiences of the stakeholders with the real system through the process of observation and reasoning.

Table 9.1: Tests for Building Confidence in the Integrated SDANP Models

Dynamic Model Tests	Question Addressed by the Test
1. Model Structure	
Structure Verification	Is the hypothesized model system structure consistent with relevant descriptive knowledge of the real system?
Parameter Verification	Are the parameters consistent with relevant descriptive (and numerical, when available) knowledge of the system?
Boundary Adequacy (Structure)	Are the important concepts for addressing the problems endogenous to the model?
Dimensional Consistency	Is each equation dimensionally consistent without the use of parameters having no real-world counterpart?
Extreme Conditions	Does each equation make sense even when its inputs take on extreme values?

Source: Adopted and modified from Sterman (2010, esp. pp. 859-861)

Table 9.1: Tests for Building Confidence in the Integrated SDANP Models (Continued)

Dynamic Model Tests	Question Addressed by the Test
2. Model Behaviour	
Behaviour Reproduction	Does the model endogenously generate the symptoms of the problem, behaviour modes, phasing, frequencies, and other characteristics of the real system?
Behaviour Anomaly	Does anomalous behaviour arise if an assumption of the model is deleted?
Family Member	Can the model reproduce the behaviour of the examples of the systems in the same class as the model (e.g., can the environmental risks model generate similar behaviour when similar megaprojects are executed in similar cities in the UK and Europe)?
Surprise Behaviour	Does the model point to the existence of a previously unrecognised mode of behaviour in the real system?
Extreme Policy	Does the model behave properly when subjected to extreme policies or test inputs?
Behavioural Boundary Adequacy	Is the behaviour of the model sensitive to the addition or alteration of structure to represent plausible alternative theories?
Behaviour Sensitivity	Is the behaviour of the model sensitivity to plausible variations in parameters?
Statistical Character	Does the output of the model system have the same statistical character as the “output” of the real system?
3. Policy Implication	
System Improvement	Is the performance of the real system improved through the use of the model?
Behaviour Prediction	Does the model correctly describe the results of a new policy?
Boundary Adequacy (Policy)	Are the policy recommendations sensitive to the addition or alteration of the structure to represent plausible alternatives theories?
Policy Sensitivity	Are the policy recommendations sensitive to plausible variations in parameters?

Source: Adopted and modified from Sterman (2010, esp. pp. 859-861)

9.3.1: Importance of the Integrated System Model Objective

The objective of the MegaDS model is to assess the dynamics of risk in transportation megaprojects and its impact on project performance with respect to time, cost and quality at the construction phase overtime. The risks considered are: Social risks (P_{R1}), Technical risks (P_{R2}), Economic risks (P_{R3}), Environmental risks (P_{R4}), and Political risks (P_{R4}).

9.3.2: Validating the Model Structure

All the tests listed in Table 9.1 have been applied to evaluate the structural validity of the MegaDS sub models: models constructed to understand the dynamics of STEEP risks on transportation megaprojects in the construction phase. These tests by no means are exhaustive but constitute the core of tests for the structural validity of the integrated SDANP simulation models. The purpose of these models is to describe and assess the impact of risks on project objectives of a transportation megaproject in Edinburgh (UK) at the construction phase over time (the simulations runs from 2008 to 2015). MegaDS is a dynamic general disequilibrium representation of STEEP risks identified in ETNP. Although illustration of the applicability of structural validity tests to MegaDS being demonstrated in this research is on risks assessment in megaprojects, it can also be applicable to any simulation model built to support policy decision making in similar complex dynamic systems with uncertain data.

9.3.2.1: Tests of Suitability

- **Structure Verification**

The structural verification is of fundamental importance in the overall validation process. For the structural verification of STEEP models, two approaches were applied. First, available knowledge about the real system (Data from Edinburgh Tram Network Project) was utilized during the construction of the model, and second, literature regarding risks in transportation megaprojects, as given in Tables 2.4 and 2.6 of chapter 2. The causal relationships developed in the models, which were based on the available knowledge about the real system, provided a sort of ‘empirical’ structural validation. Also, literature regarding risks in transportation megaprojects domain served as a ‘theoretical’ structural validation for this research.

- **Parameter Verification**

The values assigned to the parameters of STEEP models are sourced from the existing knowledge (literature and project documents) and questionnaire survey conducted on Edinburgh Tram Network Project.

Table 9.2: Parameters in the STEEP Models

Model Name	**Parameters**			
	Code	Variable	Description (Variable type)	Assigned values (%)
S*o*RM	P_{R1}	Social risks	Stock	13
	S_{V1}	Social grievances	Stock	06
	S_{V7}	Social Issues	Exogenous	04
T*e*RM	P_{R2}	Technical risks	Stock	30
	T_{V1}	Ambiguity of project scope	Exogenous	06
	T_{V5}	Cost estimation problems	Exogenous	08
	T_{V6}	Unforeseen modification to project	Exogenous	06
	T_{V8}	Engineering & design changes	Exogenous	03
	T_{V9}	Supply chain breakdown	Exogenous	04
	T_{V12}	Inadequate site investigation	Exogenous	13
E*c*RM	P_{R3}	Economic risks	Stock	25
	E_{V3}	Government discontinuity	Exogenous	13
	E_{V7}	Material price	Stock	08
	E_{V8}	Economic recession	Exogenous	03
	E_{V10}	Catastrophic environmental effects;	Exogenous	13
	E_{V11}	Project technical difficulties	Exogenous	15
E*n*RM	P_{R4}	Environmental risks	Stock	16
	E_{NV1}	Environmental issues from works	Exogenous	20
	E_{NV2}	Unfavourable climatic conditions	Exogenous	79
P*o*RM	P_{R5}	Political risks	Stock	17
	P_{V2}	Political opposition	Exogenous	08
	P_{V3}	Government discontinuity	Exogenous	15
	P_{V9}	Protectionism	Exogenous	03
	P_{V10}	Delay in obtaining temporary Traffic Regulation Orders (TROs)	Exogenous	06

Source: Field Survey 2013

Thereafter, data estimation was performed to derive numerical values for each parameter using Weighted Quantitative Scores (WQS) and the ANP pairwise calculations. The estimated values for the parameters using the WQS and the ANP are the Risk Priority Indexes (RPIs). For illustration purposes, Table 9.2 lists the stock and exogenous parameters and their RPIs used in constructing the STEEP model.

- **Boundary Adequacy**

The purpose of this test is to determine the important concepts for addressing the problems that are endogenous to the MegaDS sub models and to check for significant changes when boundary assumptions are relaxed **(**Sterman 2000). As indicated in

Tables 7.2 to 7.6 (chapter no. 7, section 7.1.3.1), the system boundary for risks (STEEP) sub models present system elements consistent with the purpose of MegaDS model which were developed based on relevant sources such as literature review, interviews, expert opinions and questionnaire survey conducted on Edinburgh Tram Network Project.

As indicated in the integrated stock diagrams (See Figures 8.2, 8.6, 8.9, 8.12 and 8.15 in chapter 8), all elements relating to risks of project time overrun, risks of project cost overrun and project quality deficiency are represented endogenously. Only elements such as social issues for the social risks sub model (Figure 8.2), Ambiguity of project scope, Unforeseen modification to project, Cost estimation problems, Engineering & design changes, Supply chain breakdown and Inadequate site investigation for the technical risks sub model (Figures 8.6), Government discontinuity, Economic recession, Catastrophic environmental effects; and Project technical difficulties for the economic risks sub model (Figures 8.9), Environmental issues from works and Unfavourable climatic conditions for the environmental risks sub model (Figures 8.31), and Political opposition, Government discontinuity, Protectionism and Delay in obtaining temporary Traffic Regulation Orders (TROs) for the political risks sub model (Figures 8.15) are indicated as exogenous system. During simulation, the boundary adequacy was checked by modifying the endogenous risk element to exogenous and then to excluded. The reason was to observe the dynamic changes of the model outputs over time when the system boundary is extended so that policies can be analysed and recommended.

- **Dimensional Consistency**

Mathematical equations involving dimensional quantities are correct only if the operations presented on both sides of the equation agree not only in terms of the numerical value of the quantities but also in terms of their units of measurement (dimensions). In formulating the equations for the STEEP models, the requirements of the dimensional consistency were used to:

i. Check the validity of the model equations;
ii. Determine correct conversion factors, and
iii. Formulate model equations

In checking the equations, a built-in function in the Vensim software was used to ensure that (1) the mathematical expression used is legitimate, and that (2) units on both sides of the equations agree after performing the mathematical operations. Where there was no agreement, the two possibilities considered were: (a) the expression may be correct except for a conversion variable, or (b) the expression may be completely illegitimate. After the dimensional analysis, it was noted that, not only are the values of the elements in the models based on the existing knowledge of the real system, but they are also dimensionally consistent.

- **Extreme Conditions**

The sub models of the MegaDS model has been tested against extreme values. For example, the actual construction period for the case study megaproject is 78 months (Between December, 2008 and July, 2014). However, simulation for the models varied from 0 to 84 months (Between 2008 and 2015). Beyond 78 months, there was no significant change of behaviour. Also, the structures of the models and outputs were plausible for extreme and unlikely combinations of levels of variables in the system. In the integrated sub models, exogenous variables for each model were set at a high and low of +/-50% to test their robustness to extreme conditions. Outputs of individual models showed realistic trends and hence indicated no significant change in behaviours beyond the normal trend.

9.3.3: Validating the Model Behaviour

9.3.3.1: Behaviour Reproduction Test.

As stated by Sterman (2010), the purpose of the behaviour reproduction test, are to:

a. Produce the model behaviour of interest in the system qualitatively and quantitatively;
b. Generate endogenously the symptoms of difficulty motivating the study, and
c. Generate the various modes of the model behaviour observed in the real system.

Figure 9.2 shows the baseline (Current run) output from the system with all variables at their baseline levels. Since this research contains a number of these figures, the forthcoming discussion will explain the dynamic behaviour of the STEEP risks and how they are organized. At the bottom of Figure 9.2, there are a number of system variable names: 1) Social risks; 2) Technical risks; 3) Economic risks, 4) Environmental risks and 5) Political risks. Each of the traces of these risks on the graph, labelled 1 through 5, represents each of their respective displayed variables. The scale on the left side of the graph (Y-axis) shows the scales for each of the traces. The X-axis presents the time scale in years. The time scope for the simulation is between year 2008 and year 2015, so the X-axis ends at seven years. In the baseline (Current run) condition shown in Figure 9.2, the various patterns represent the desired level of impacts these risks have on the project performance of the case study megaproject at the construction phase with respect to time, cost and quality and are in tune with the real life situations.

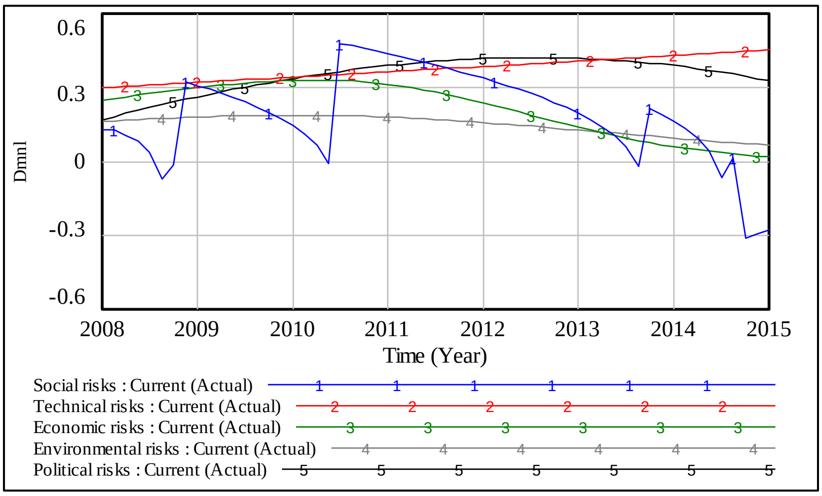


Figure 9.2: Behaviour Reproduction Test for the Level of STEEP Risks Impacts on the System (All Variables at Baseline Levels)

9.3.3.2: Sensitivity Analysis

System dynamics models are generally not sensitive to changes in parameters and behavioral relationships. Sensitivity analysis is performed to test the robustness of the model by ensuring that uncertainties and estimating errors do not significantly affect the overall behaviour of the model. Sensitivity analysis is to test the limits of the STEEP models and their ability to adjust to changes. According to Sterman (2010), a model is considered robust if its behaviour does not change drastically when a parameter or behavioural relationship is altered. In this research, the extensive tests conducted on the models revealed that, the models are not sensitive behaviourally. Visual inspection of the dynamic graphs showed that the patterns generated were similar to those generated by the Current (Actual) runs. However, the magnitude and value of the system variables changed when the values (RPIs) of the parameters were altered. There are three types of sensitivity: numerical, behaviour mode, and policy sensitivity.

- **Numerical Sensitivity Analysis**

The numerical sensitivity analysis is carried out by changing the parameters in the models such as the initial value of stocks and the value of the exogenous system variables. For each parameter, the numerical sensitivity test is conducted by reducing and increasing the value of the parameter by twenty-five percent (+/-25%). Parameters for stock and exogenous system entities of the STEEP models and their distribution functions used in screening the analysis of the entire MegaDS model are given in Table 9.3. To ascertain the sensitivity of each parameter, the dynamic simulation results of the system variables are compared with the base run (Current run) results. Summaries of these results are presented in Tables 9.4 to 9.8.

Table 9.3: Parameter Distributions of Stock and Exogenous System Entities for STEEP Risks Models

Model Name	**Code**	**Parameters**	**Description (Variable Type)**	**Assigned values (%)**	**Range (-/+25%)**	**Distribution**
S*o*RM	P_{R1}	Social risks	Stock	13	[9.7-16.3]	Uniform
	S_{V1}	Social grievances	Stock	06	[4.5-7.5]	Uniform
	S_{V7}	Social Issues	Exogenous	04	[03-05]	Uniform
T*e*RM	P_{R2}	Technical risks	Stock	30	[22.5-37.5]	Uniform
	T_{V1}	Ambiguity of project scope	Exogenous	06	[4.5-7.5]	Uniform
	T_{V5}	Cost estimation problems	Exogenous	08	[6-10]	Uniform
	T_{V6}	Unforeseen modification to project	Exogenous	06	[4.5-7.5]	Uniform
	T_{V8}	Engineering & design changes	Exogenous	03	[2.3-3.8]	Uniform
	T_{V9}	Supply chain breakdown	Exogenous	04	[03-05]	Uniform
	T_{V12}	Inadequate site investigation	Exogenous	13	[9.7-16.3]	Uniform
E*c*RM	P_{R3}	Economic risks	Stock	25	[18.8-31.3]	Uniform
	E_{V3}	Government discontinuity	Exogenous	13	[9.7-16.3]	Uniform
	E_{V7}	Material price	Stock	08	[6-10]	Uniform
	E_{V8}	Economic recession	Exogenous	03	[2.3-3.8]	Uniform
	E_{V10}	Catastrophic environmental effects	Exogenous	13	[9.7-16.3]	Uniform
	E_{V11}	Project technical difficulties	Exogenous	15	[11.3-18.8]	Uniform
E*n*RM	P_{R4}	Environmental risks	Stock	16	[12-20]	Uniform
	E_{NV1}	Environmental issues from works	Exogenous	20	[15-25]	Uniform
	E_{NV2}	Unfavourable climatic conditions	Exogenous	79	[59.3-98.8]	Uniform
P*o*RM	P_{R5}	Political risks	Stock	17	[12.8-21.3]	Uniform
	P_{V2}	Political opposition	Exogenous	08	[6-10]	Uniform
	P_{V3}	Government discontinuity	Exogenous	15	[11.3-18.8]	Uniform
	P_{V9}	Protectionism	Exogenous	03	[2.3-3.8]	Uniform
	P_{V10}	Delay in obtaining temporary Traffic Regulation Orders (TROs)	Exogenous	06	[4.5-7.5]	Uniform

Table 9.4: Numerical Sensitivity Test for the Social Risks Parameters

Parameter	**ANP/SD Simulation Results (%)**		
			Inputs
	Actual	Test 1 (-25%)	Test 2 (+25%)
SG	06	4.5	7.5
SI	04	03	05
SR	13	9.7	16.3

Sensitivity Simulation Outputs (%)

	Test Results (Actual)						Test 1 Results: (-25% of Actual Input)						Test 2 Results: (+25% of Actual Input)					
	Min	Max	Mean	Med	StDev	Norm	Min	Max	Mean	Med	StDev	Norm	Min	Max	Mean	Med	StDev	Norm
CDR	00	01	00	00	00	54	00	00	00	00	00	218	00	01	00	00	00	125
DEG	06	20	19	20	02	11	05	17	17	17	02	11	08	22	22	22	02	11
Disp.	06	20	19	20	02	11	05	17	17	17	02	11	08	22	22	22	02	11
ErG	00	04	01	00	01	121	00	00	00	00	00	85	00	02	00	00	00	70
EG	20	67	21	20	06	29	17	67	19	17	07	35	22	67	24	22	06	25
EPCO	00	13	06	06	04	71	00	02	01	02	01	46	00	09	03	02	02	95
EPTO	00	03	02	02	01	42	00	01	00	00	00	170	-01	04	01	01	02	119
LC	-02	14	08	08	04	51	-03	06	01	01	02	203	-03	19	06	04	07	121
MLDMBI	00	04	04	04	01	16	00	03	03	03	00	16	01	05	05	05	01	16
PMPS	00	04	04	04	01	16	00	03	03	03	00	16	01	05	05	05	01	16
PQD	00	08	01	00	02	148	00	00	00	00	00	118	00	01	00	00	00	167
RPCO	00	41	12	07	12	103	00	09	04	03	03	85	00	17	04	02	05	108
RPTO	00	13	06	06	04	71	00	02	01	02	01	46	00	09	03	02	02	95
SC	-391	262	06	14	81	142	-16	29	03	-12	67	26	-51	302	-05	-13	101	-208
SG	06	20	19	20	02	11	05	17	17	17	02	11	08	22	22	22	02	11
SR	-31	48	19	20	18	96	-4	18	-09	-11	15	-16	-0.4	63	04	-02	31	697
SU	00	01	00	00	00	71	00	00	00	00	00	46	00	00	00	00	00	96
TPAS	06	20	19	20	02	11	05	17	17	17	02	11	08	22	22	22	02	11
WCP	00	12	06	06	04	70	00	02	01	02	01	45	00	10	03	02	03	99

Table 9.5: Numerical Sensitivity Test for the Technical Risks Parameters

Parameter	**ANP/SD Simulation Results (%)**		
			Inputs
	Actual	Test 1 (-25%)	Test 2 (+25%)
TR	30	22.5	37.5
APS	06	4.5	7.5
CEP	08	06	10
UMP	06	4.5	7.5
EDC	03	2.3	3.8
SCB	04	03	05
ISI	13	9.7	16.3

	Sensitivity Simulation Outputs (%)																	
	Test Results (Actual)						Test 1 Results: (-25% of Actual Input)						Test 2 Results: (+25% of Actual Input)					
	Min	Max	Mean	Med	StDev	Norm	Min	Max	Mean	Med	StDev	Norm	Min	Max	Mean	Med	StDev	Norm
CDUD	0.00	0.06	0.01	0.01	0.0002	110.5	0.00	0.01	0.00	0.00	0.00	127.3	0.00	0.55	0.10	0.04	0.14	134.9
CR	0.00	0.42	0.11	0.06	0.12	110.5	0.00	0.07	0.02	0.01	0.02	1.027	0.00	33.6	0.61	0.23	0.83	134.9
ErG	0.00	0.42	0.11	0.06	0.12	110.5	0.00	0.07	0.02	0.01	0.02	102.7	0.00	33.6	0.61	0.23	0.83	134.9
EPCO	0.00	2.28	0.71	0.50	0.63	89.64	0.00	0.46	0.17	0.13	0.13	79.21	0.00	12.46	29.0	1.57	3.20	110.5
EPTO	0.08	0.30	0.16	0.14	0.06	37.94	0.03	0.05	0.04	0.04	0.01	195.5	0.21	20.9	0.68	0.49	0.49	72.04
GCP	13.0	13.0	13.0	13.0	0.00	0.00	9.70	9.70	9.70	9.70	0.00	0.00	16.3	16.3	16.3	16.3	0.00	0.00
MPDS	0.27	0.87	0.49	0.45	0.17	34.47	0.09	0.16	0.12	0.11	0.02	17.16	0.68	61.7	2.11	1.57	1.44	68.28
Proj.C	100.4	172	129.9	126.8	20.7	15.92	75.2	98.34	85.76	85.23	67.7	78.9	125	355.2	202.8	185.7	63.33	31.23
PQD	0.00	0.71	0.15	0.06	0.20	128.3	0.00	0.13	0.03	0.01	0.04	123.4	0.00	3.96	0.72	0.21	1.01	141.6
PC	60.2	17.76	10.4	9.62	3.34	32.21	25.4	4.35	3.32	3.26	0.53	15.85	11.8	95.35	33.90	25.82	21.90	64.59
Rwk	0.00	0.42	0.11	0.06	0.12	110.5	0.00	0.07	0.02	0.01	0.02	127.3	0.00	.336	0.61	0.23	0.83	134.9
RPCO	0.00	4.76	1.24	0.69	1.35	108.7	0.00	1.12	0.32	0.20	0.33	12.50	0.00	19.10	4.27	1.97	5.12	120.0
RPTO	0.00	1.09	0.43	0.38	0.31	71.90	0.00	0.26	0.11	0.11	0.07	65.18	0.00	4.60	1.47	1.10	12.6	85.46
TC	0.03	0.17	0.07	0.06	0.04	56.56	0.01	0.02	0.01	0.01	0.00	28.90	0.08	2.54	0.56	0.29	0.60	108.2
TDUD	13.0	13.0	13.0	13.0	0.00	0.00	9.70	9.70	9.70	9.70	0.00	0.00	16.3	16.30	16.30	16.30	0.00	0.00
TR	30.0	55.69	40.48	39.28	7.41	18.31	22.5	30.80	26.26	26.05	2.43	9.24	37.5	121.2	65.22	58.78	23.07	35.37
TU	2.11	6.71	3.79	3.49	1.31	34.47	0.90	1.61	1.20	1.18	0.21	17.16	4.14	37.88	12.92	9.61	88.2	68.28
TDUU	0.00	0.06	0.01	0.01	0.02	110.5	0.00	0.01	0.00	0.00	0.00	12.73	0.00	0.55	0.10	0.04	0.14	134.9
WTD	100	171.7	129.6	126.4	20.69	15.97	0.75	98.13	85.55	85.02	6.77	7.91	12.5	354.6	202.2	185.6	63.33	31.32
CDUD	0.00	0.00	0.00	0.00	0.00	167.2	0.00	0.00	0.00	0.00	0.00	152.1	0.00	0.22	0.02	0.00	0.05	2.031

Table 9.6: Numerical Sensitivity Test for the Economic Risks Parameters

Parameter	**ANP/SD Simulation Results (%)**		
			Inputs
	Actual	Test 1 (-25%)	Test 2 (+25%)
GD	13	9.7	16.3
ER	03	06	3.8
CER	13	9.7	16.3
PTD	15	11.3	18.8
EcR	25	18.8	31.3
MP	08	06	10

	Sensitivity Simulation Outputs (%)																	
	Test Results (Actual)						Test 1 Results: (-25% of Actual Input)						Test 2 Results: (+25% of Actual Input)					
	Min	Max	Mean	Med	StDev	Norm	Min	Max	Mean	Med	StDev	Norm	Min	Max	Mean	Med	StDev	Norm
COD	0.05	0.05	0.05	0.05	0.00	0.00	0.09	0.09	0.09	0.09	0.00	0.00	0.03	0.03	0.03	0.03	0.00	0.00
CDR	2.21	2.21	2.21	2.21	0.00	0.00	2.76	2.76	2.76	2.76	0.00	0.00	1.70	1.70	1.70	1.70	0.00	0.00
DOAF	0.05	0.05	0.05	0.05	0.00	0.00	0.09	0.09	0.09	0.09	0.00	0.00	0.03	0.03	0.03	0.03	0.00	0.00
Disp.	2.21	2.21	2.21	2.21	0.00	0.00	2.76	2.76	2.76	2.76	0.00	0.00	1.70	1.70	1.70	1.70	0.00	0.00
EC	0.00	9.56	5.13	5.13	3.06	59.58	0.00	4.41	2.71	2.85	1.32	48.82	0.00	18.98	8.60	7.66	6.42	74.71
EcR	1.72	33.03	21.51	26.07	10.73	49.86	2.73	2.22	15.76	18.85	6.45	40.93	0.53	45.48	26.14	32.33	16.27	62.25
EU	-3.4	7.22	1.82	1.61	4.19	230.7	-2.2	3.03	0.40	0.36	2.11	526.4	-4.4	14.66	4.25	2.01	7.23	169.9
EP	0.15	0.15	0.15	0.15	0.00	0.00	0.25	0.25	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ErG	0.00	15.42	4.56	4.18	3.61	79.23	0.00	7.49	3.02	2.98	2.01	66.66	0.00	25.50	5.68	4.98	5.34	94.07
EPCO	0.02	0.35	0.12	0.08	9.29	80.49	2.85	24.08	9.50	7.45	6.34	66.78	1.73	4.565	12.64	8.82	1.127	89.16
EPTO	5.01	15.97	8.59	8.67	0.02	28.42	5.15	8.57	6.19	6.19	0.75	12.07	3.57	26.14	11.65	11.82	5.54	47.54
FE	0.24	1.41	0.8	0.77	0.39	49.42	0.24	1.08	0.63	0.60	0.27	42.96	0.24	1.58	0.95	0.97	0.48	50.80
GFP	2.21	2.21	2.21	2.21	0.00	0.00	2.76	2.76	2.76	2.76	0.00	0.00	1.70	1.70	1.70	1.70	0.00	0.00
LIR	3.29	33.68	22.46	26.67	10.37	46.17	4.07	22.85	16.64	19.63	6.20	37.28	2.11	46.05	27.09	32.58	15.84	58.49
MP	8.00	47.13	26.58	25.65	13.14	49.42	8.00	36.15	20.90	20.06	8.98	42.96	8.00	52.68	31.54	32.38	16.03	50.80
MPH	2.27	8.33	5.54	5.55	1.94	35.03	1.94	5.23	4.01	4.13	0.99	24.59	1.11	11.56	6.29	6.00	3.39	53.97
PQD	0.00	30.56	8.88	5.71	8.9	100.3	0.00	20.59	6.46	4.42	6.21	96.11	0.00	37.25	10.21	6.65	10.38	101.6
RPCO	0.00	77.8	22.36	13.91	21.85	97.72	0.00	64.65	20.75	14.67	18.33	88.35	0.00	84.36	22.73	13.11	23.49	103.4
RPTO	0.00	59.2	30.74	33.99	17.02	55.37	0.00	43.01	21.66	22.55	12.54	57.90	0.00	79.75	43.67	51.82	22.68	51.95
Tax.	0.39	0.39	0.39	0.39	0.00	0.00	0.49	0.49	0.49	0.49	0.00	0.00	0.30	0.30	0.30	0.30	0.00	0.00
WI	1.01	1.67	1.5	1.57	0.19	12.41	0.83	12.5	1.15	1.23	0.13	11.13	1.19	2.09	1.79	1.79	0.23	12.92
WCP	15.87	33.47	25.62	26.9	6.29	24.56	0.11	0.224	0.179	0.195	4.04	22.59	18.0	46.17	32.63	33.38	9.92	30.41

Table 9.7: Numerical Sensitivity Test for the Environmental Risks Parameters

Parameter	**ANP/SD Simulation Results (%)**																	
																		Inputs
														Actual		Test 1 (-25%)		Test 2 (+25%)
EnvR														16		12		20
EIFW														20		15		25
UCC														79		59.3		98.8
							Sensitivity Simulation Outputs (%)											
	Test Results (Actual)						Test 1 Results: (-25% of Actual Input)						Test 2 Results: (+25% of Actual Input)					
	Min	Max	Mean	Med	StDev	Norm	Min	Max	Mean	Med	StDev	Norm	Min	Max	Mean	Med	StDev	Norm
CLA	1.70	1.70	1.70	1.70	0.00	0.00	1.30	1.30	1.30	1.30	0.00	0.00	2.00	2.00	2.00	2.00	0.00	0.00
Disp	1.70	1.70	1.70	1.70	0.00	0.00	1.30	1.30	1.30	1.30	0.00	0.00	2.00	2.00	2.00	2.00	0.00	0.00
EnC	0.00	5.30	3.70	4.30	1.60	43.3	0.00	2.60	1.80	2.20	0.80	44.5	0.00	10.2	6.70	7.30	3.00	44.4
EnRC	24.0	24.0	24.0	24.0	0.00	0.00	19.0	19.0	19.0	19.0	0.00	0.00	29.0	29.0	29.0	29.0	0.00	0.00
EnR	6.60	18.8	14.9	16.4	3.80	25.9	6.00	13.0	10.8	11.8	2.20	20.4	5.70	26.0	18.9	21.2	6.60	34.7
EnU	1.00	3.00	2.30	2.60	0.60	25.9	0.50	1.20	1.00	1.10	0.2	20.4	1.40	6.40	4.70	5.20	1.60	34.7
ErG	0.00	4.50	1.70	1.50	1.20	7.42	0.00	1.60	0.70	0.70	0.50	64.3	0.00	16.8	4.00	2.80	4.00	9.86
EPCO	1.70	13.4	5.20	4.00	3.40	66.1	1.30	6.5	3.00	2.50	1.60	52.0	2.00	30.2	9.20	6.30	7.60	83.0
EPTO	6.60	8.50	7.90	8.10	0.60	7.40	4.90	5.50	5.30	5.40	0.20	3.60	8.40	13.1	11.4	11.9	1.50	13.5
LA	1.70	1.70	1.70	1.70	0.00	0.00	1.30	1.30	1.30	1.30	0.00	0.00	2.00	2.00	2.00	2.00	0.00	0.00
MBMDI	5.50	5.50	5.50	5.50	0.00	0.00	4.40	4.40	4.40	4.40	0.00	0.00	6.70	6.70	6.70	6.70	0.00	0.00
PQD	0.00	11.4	3.40	2.20	3.30	99.5	0.00	5.10	1.60	1.10	1.50	94.9	0.00	26.7	6.80	3.90	7.30	108.1
RPCO	0.00	35.2	11.4	8.30	9.90	86.5	0.00	20.5	7.40	5.90	5.80	78.6	0.00	61.8	17.7	11.4	17.0	95.8
RPTO	0.00	55.4	28.7	29.3	16.5	57.6	0.00	37.4	19.0	19.2	11.1	58.1	0.00	80.3	42.7	44.4	24.3	56.9
SG	26.1	26.1	26.1	26.1	0.00	0.00	26.1	26.1	26.1	26.1	0.00	0.00	26.1	26.1	26.1	26.1	0.00	0.00
SI	24.0	24.0	24.0	24.0	0.00	0.00	19.0	19.0	19.0	19.0	0.00	0.00	29.0	29.0	29.0	29.0	0.00	0.00
WCP	12.8	18.9	16.3	16.9	2.10	13.1	7.90	13.0	11.3	12.0	1.70	14.8	20.0	27.2	23.3	23.4	2.20	9.30

Table 9.8: Numerical Sensitivity Test for the Political Risks Parameters

Parameter	**ANP/SD Simulation Results (%)**		
			Inputs
	Actual	Test 1 (-25%)	Test 2 (+25%)
PR	17	12.8	21.3
PO	08	06	10
GD	15	11.3	18.8
P	03	2.3	3.8
TRO	06	4.5	7.5
PS	13	9.7	16.3

	Sensitivity Simulation Outputs (%)																	
	Test Results (Actual)						Test 1 Results: (-25% of Actual Input)						Test 2 Results: (+25% of Actual Input)					
	Min	Max	Mean	Med	StDev	Norm	Min	Max	Mean	Med	StDev	Norm	Min	Max	Mean	Med	StDev	Norm
COD	0.80	1.990	1.31	1.26	0.35	26.42	0.45	1.120	0.73	0.71	0.20	26.92	1.27	3.17	2.080	2.010	0.560	26.72
CDR	4.55	22.67	15.9	17.1	5.94	37.47	2.54	12.70	8.91	9.66	3.33	37.40	7.21	36.02	25.19	2.715	9.470	37.59
DOC	13.4	33.12	21.8	21.1	5.76	26.42	9.92	24.97	16.3	15.7	4.40	26.92	16.9	42.29	27.73	26.75	7.410	26.72
Disp	2.28	11.33	7.93	8.56	2.97	37.47	1.27	6.350	4.46	4.83	1.67	37.40	3.60	18.01	12.60	13.57	4.740	37.59
ErG	0.00	5.070	1.32	0.72	1.42	107.6	0.00	0.860	0.30	0.22	0.26	86.51	0.00	36.08	6.390	2.140	8.870	138.9
EPCO	0.31	3.780	1.32	0.89	1.07	80.97	0.16	0.950	0.40	0.30	0.25	62.02	0.52	16.07	4.370	2.450	4.400	100.6
EPTO	0.69	4.990	2.21	1.84	1.30	58.73	0.34	1.440	0.82	0.76	0.36	43.76	1.22	21.17	6.220	3.980	5.370	86.32
GFP	89.3	220.8	145	140	38.4	26.42	87.8	221.0	145	139	38.9	26.92	90.0	224.9	147.5	142.3	39.41	26.72
LA	2.28	11.33	7.93	8.56	2.97	37.47	1.27	6.350	4.46	4.83	1.67	37.40	3.60	18.01	12.60	13.57	4.740	37.59
LRC	13.4	33.12	21.8	21.1	5.76	26.42	9.92	24.97	16.3	15.7	4.40	26.92	16.9	42.29	27.73	26.75	7.410	26.72
PC	1.37	2.290	1.60	1.51	0.23	14.29	1.08	1.900	1.30	1.21	0.22	17.29	1.68	2.910	1.880	1.790	0.270	14.26
PDP	0.00	26.57	7.02	3.86	7.62	108.6	0.00	8.210	2.64	1.83	2.50	94.72	0.00	96.92	19.87	7.890	25.40	127.8
PH	1.70	4.190	2.76	2.67	0.73	26.42	1.29	3.250	2.12	2.05	0.57	26.92	2.15	5.380	3.520	3.400	0.940	26.72
PI	1.47	3.180	1.84	1.69	0.42	22.90	1.12	2.400	1.41	1.28	0.32	22.70	1.87	5.210	2.440	2.150	0.740	30.33
PIP	-9.16	10.00	1.82	2.55	5.60	307.0	-7.1	7.600	1.34	1.91	4.30	320.8	-12	12.50	2.090	3.030	7.140	342.1
PR	17.0	42.14	35.2	37.7	7.04	20.01	12.8	31.73	26.4	28.1	5.28	19.97	21.3	52.54	43.95	46.97	8.730	19.87
PS	13.0	32.16	21.2	20.5	5.60	26.42	9.70	24.41	16.0	15.4	4.30	26.92	16.3	40.74	26.71	25.77	7.140	26.72
PU	-5.97	12.29	3.66	4.06	5.33	145.6	-4.7	9.340	2.75	3.06	4.09	149.1	-6.7	15.41	4.530	4.950	6.660	147.1
PQD	0.00	8.800	1.95	0.81	2.41	123.4	0.00	2.050	0.54	0.29	0.59	109.9	0.00	40.99	7.24	2.110	10.33	142.7
PT	0.22	0.480	0.28	0.25	0.06	22.90	0.13	0.270	0.16	0.15	0.04	22.70	0.35	0.980	0.460	0.400	0.140	30.33
RPCO	0.00	8.950	2.56	1.58	2.50	97.36	0.00	2.720	9.20	0.68	0.76	82.61	0.00	29.12	70.60	3.540	7.910	112.0
RPTO	0.00	15.11	5.14	3.90	4.33	84.12	0.00	5.640	2.13	1.75	1.65	77.69	0.00	41.68	11.76	7.680	11.29	96.04
SA	0.39	0.960	0.64	0.61	0.17	26.42	0.22	0.560	0.37	0.35	0.10	26.92	0.62	1.550	1.020	0.980	0.270	26.72
WCP	17.0	56.65	42.3	45.4	11.7	27.63	12.8	35.33	29.1	32.2	6.67	22.91	21.3	123.9	62.95	60.53	25.78	40.95

- **Behaviour Mode Sensitivity Analysis**

After the numerical sensitivity, behaviour mode sensitivity analysis was performed to check model behaviour and to gain more confidence in the models. Using the changes in the parameter (Stock and exogenous system variables) values, the modes of individual models were experimented with to see the resulting changes in behaviour under different parameter settings.

For example, in the social risks model, three parameters and their initial ANP's Risk Priority Indexes (RPIs) were used to explore the sensitivity of the model. The three parameters are "Social Issues," "Social Risks," and "Social Grievances." The comparative run for the social risks and the social grievances are shown in Figure 9.3. Although the three curves do not look exactly the same, changes in the parameters do not affect the general mode of behaviour of the system. All three curves for the social risks show a small decrease in the stock right after the step increase and then continue to behave in similar manner until year 2015. On the other hand, the three behaviour patterns for the social grievances show increase in stock and then a slow approach to equilibrium. The curves indicate that the faster project managers adopt proactive risk mitigation techniques, the faster the stock of social grievances will approach equilibrium.

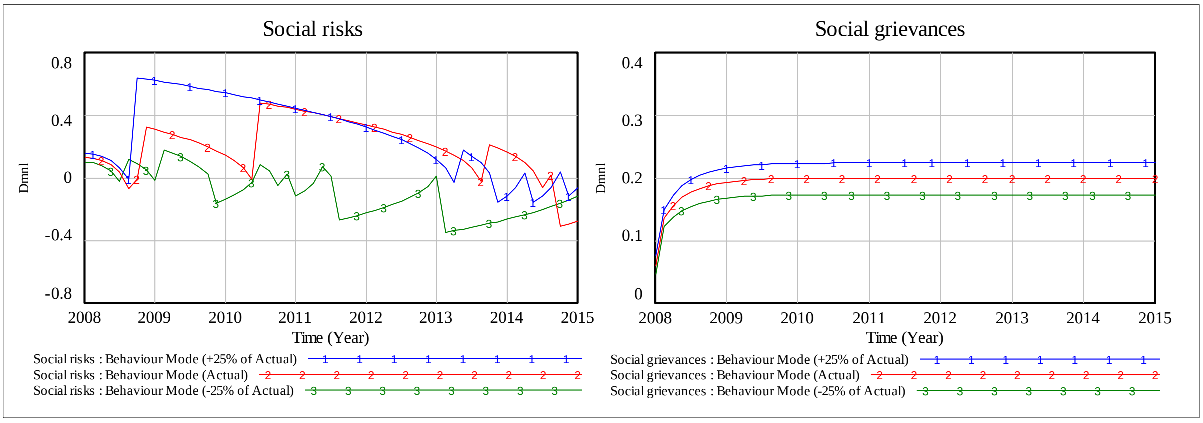


Figure 9.3: Behaviour Mode Sensitivity Graphs for Social Risks and Social Grievances

“Technical risks”; “Economic risks”; “Environmental risks” and “Political risks” are other major parameters about whose level of impacts on the performance of Edinburgh Tram Network Project are uncertain. Figures 9.4, 9.5, 9.6 and 9.7 show the comparative runs of these parameters.

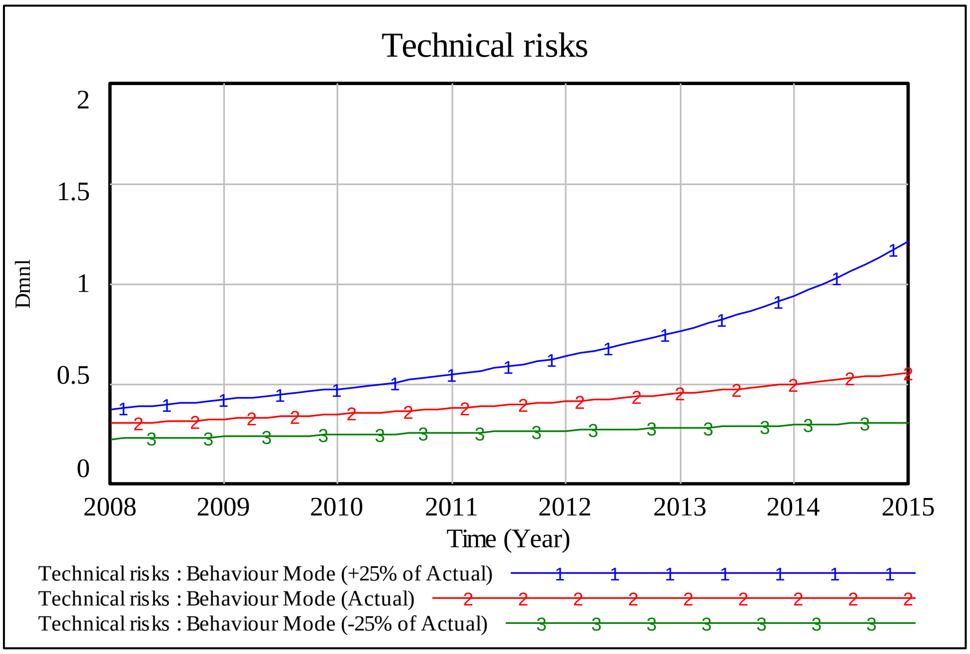


Figure 9.4: Behaviour Mode Sensitivity Graphs for Technical Risks

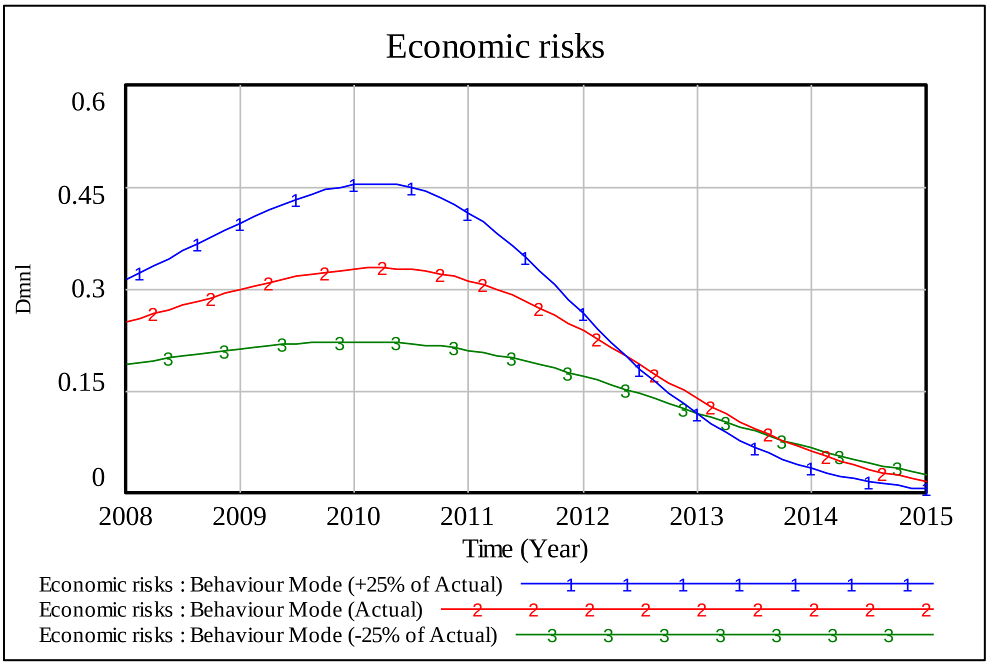


Figure 9.5: Behaviour Mode Sensitivity Graphs for Economic Risks

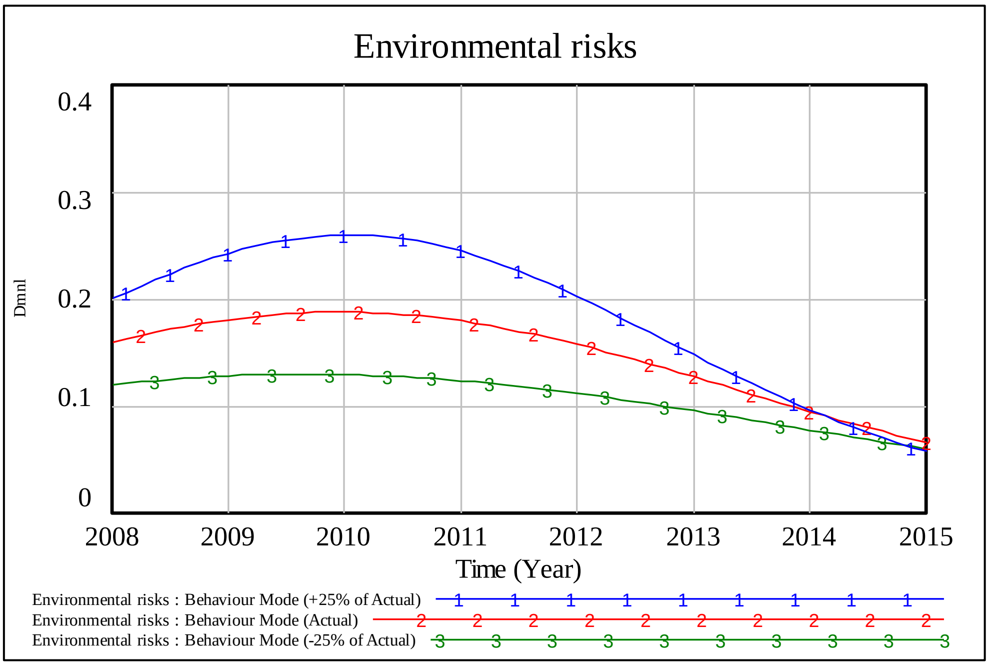


Figure 9.6: Behaviour Mode Sensitivity Graphs for Environmental Risks

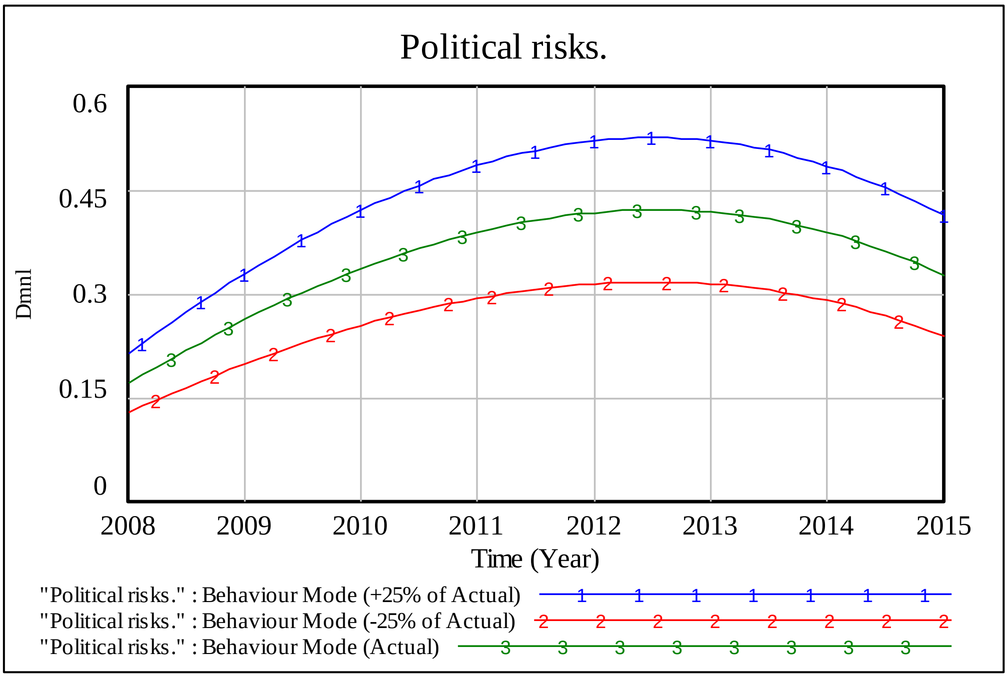


Figure 9.7: Behaviour Mode Sensitivity Graphs for Political Risks

It is noticed again that whereas the behaviour modes of these risks look different from one another and from the social risks and social grievances, the general behaviours have not changed. Even when each of these risks starts out with a larger or smaller amount of parameter values, the behaviours of the stocks of the models will not change greatly.

As expected, changing the values of parameters in the model produces certain differences in the behaviours observed. Also, the sensitivity tests indicate that some parameter changes result in "greater," or more significant, changes than others. For example, compare Figures 9.6 and 9.7. In Figure 9.6, the changes in "Environmental Issues from Works" and "Unfavourable Climatic Conditions" produce little difference in the behaviours, while in Figure 9.7, the curves show the same behaviours, but at different values of the stocks. This measure of more significant changes is studied through sensitivity analysis. In all cases, however, it is the structure of the system that primarily determines the behaviour mode. In general, but with exceptions, parameter values, when altered individually, only have a small influence on behaviour.

Now what should be expected if works on ETNP are not completed as per the revised completion dates in summer 2014? That means there is a need for simulation to continue for another few months or even years. If so then will the uncertainties and risks continue to grow larger with time or not within the extended time? The situations represented in Figures 8.4, 9.5, 9.6 and 9.7 are not the most likely outcomes. With a limited time available for works, one would expect the STEEP models to exhibit various shapes of growth over time. Monte Carlo simulation helps to generate most likely outcomes with dynamic confidence intervals for the trajectories of the variables in the STEEP models using the ranges of the probability distributions for the parameters represented in Table 9.3. The results of the Monte Carlo simulation are represented in Figures 9.8, 9.9, 9.10, 9.11, and 9.12. The Figures show the 50%, 75%, 95% and 100% levels for Social grievances, Technical risks, Economic risks, Environmental risks and Political risks in a sample of 500 simulations.

Figure 9.8 shows the sensitivity analysis of the social grievances. There are 0.06 (6%) of initial grievances level at the time of simulation, and the base case simulation (Actual run) shows the grievance level growing to around 19% after two years. The confidence bounds show the same general pattern as in the actual base run. There is a narrow band of uncertainty in the first quarter of year 2008 when the project commenced but the width of the interval grows in an equilibrium form over time. By the year 2010, the 95% confidence bounds suggest that the level of social grievances as a result of the construction activities range from a low of 18% to as high as 22%. The eventual equilibrium is found when the positive and negative loops come into balance.

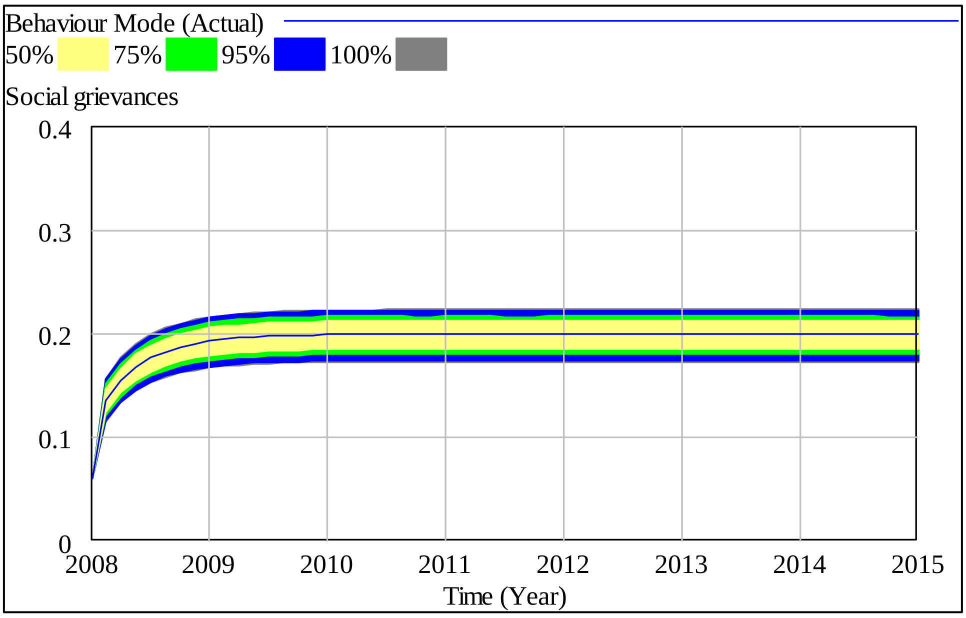


Figure 9.8: Dynamic Confidence Bounds Sensitivity Graph for Social Grievances

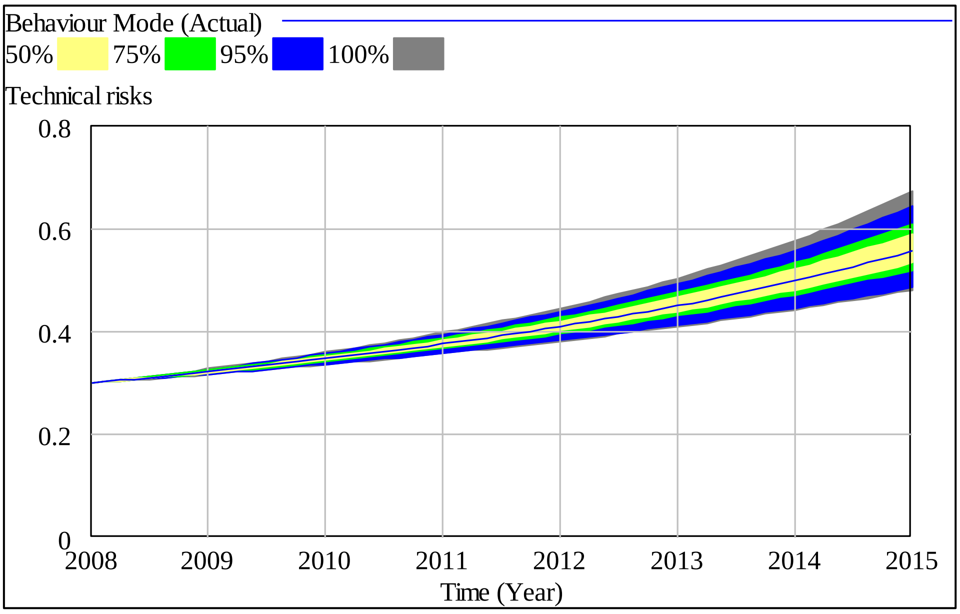


Figure 9.9: Dynamic Confidence Bounds Sensitivity Graph for Technical Risks

Similarly, in Figure 9.9, the analysis reveals that the width of the simulation intervals continue to grow larger over time. Narrow range of the technical risks in the early years of project development is typical to systems that are dominated by negative feedback loops. Differences in the input parameters are eventually overridden by the actions of the negative feedback loops and hence the technical uncertainties may shrink over time.

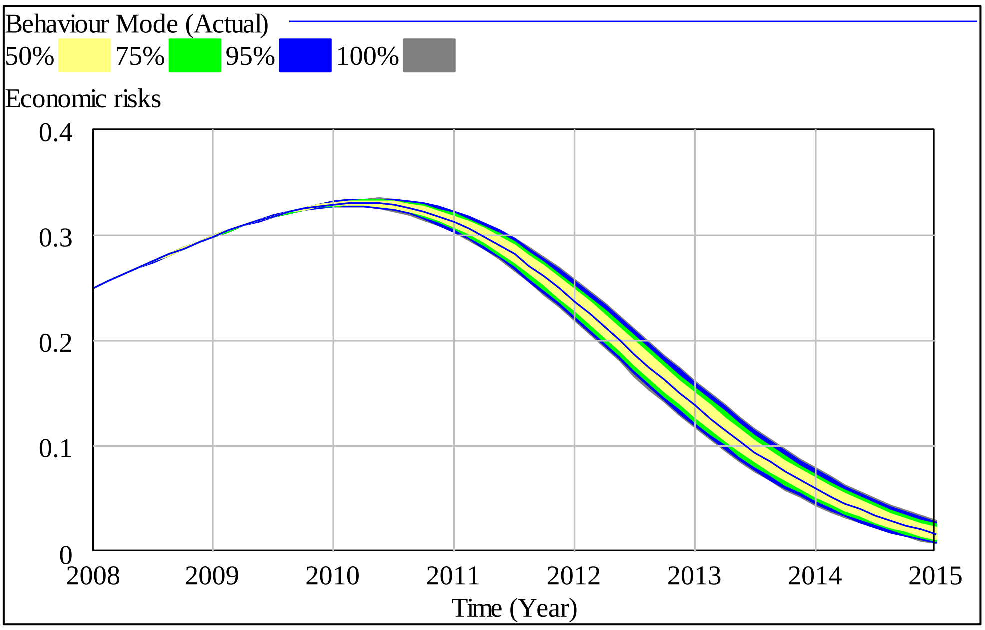


Figure 9.10: Dynamic Confidence Bounds Sensitivity Graph for Economic Risks

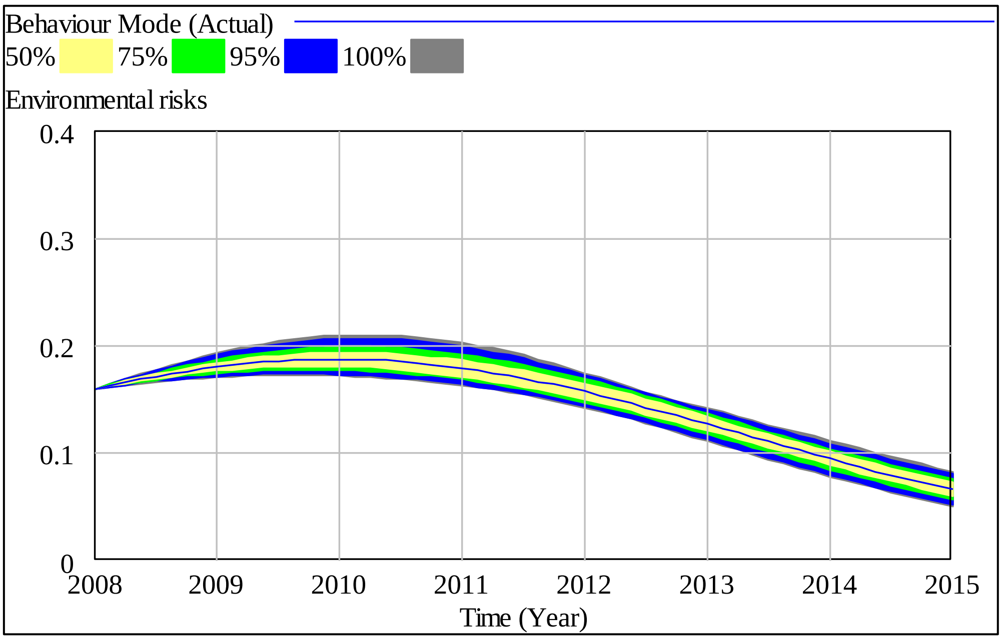


Figure 9.11: Dynamic Confidence Bounds Sensitivity Graph for Environmental Risks

In the case of Figure 9.10, the narrowing in the range of economic risks between year 2008 and year 2010 seems similar to that of the technical risks but much more dominated by negative feedback loops in the systems. By the first quarter in year 2010, the width of the interval started to grow larger. However, the graph declines steadily over time. A similar result is seen in Figure 9.11.

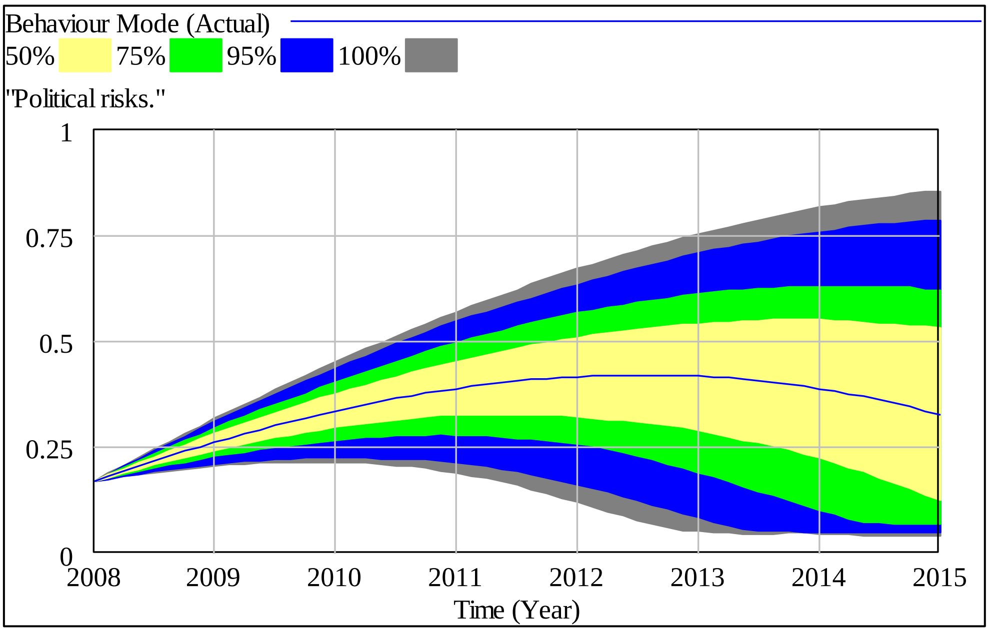


Figure 9.12: Dynamic Confidence Bounds Sensitivity Graph for Political Risks

Finally, Figure 9.12 shows a sensitivity analysis for the political risks model. The analysis reveals that the width of the simulation interval continues to grow larger over time. Until the 7th year (2015) of the simulation, there is a 50% chance that the level of political risks will be between 15% and 55%. By the same year, the 75% and the 95% confidence bounds suggest that the level of political risks could range from 10% to 65% and 5% to 80% respectively.

9.3.3.3: Other Tests

The remainder of the tests under the model behaviour test namely: Behaviour Anomaly; Family Member; Surprise Behaviour; Extreme Policy; Behavioural Boundary Adequacy and Statistical Character are all interrelated, so the MegaDS sub models were tested concurrently with their respective questions indicated in Table 9.1 in mind. The main goal for these tests is to determine if the model responds as expected under abnormal conditions and if the model responds (or does not respond) when system variables of each sub model are changed from their baseline values. Therefore, tests for effects from extreme policies were performed on each model. During these tests, the integration system variables were the sole focus, since this is the focus of the research. Comparative traces of baseline, minimum, and maximum values on each associated graph were also performed. Vensim software allows the modeller to simulate the same variable multiple times under differing conditions for each simulation run to allow comparison. Testing consisted of multiple simulation runs (and, as a result, multiple traces) of the same variable and graphed under different model conditions. Hence, each of the simulation runs and traces were represented by different behaviour based on the extreme points for the system variables being studied. In these cases, the variable scale was the same throughout each figure.

9.4: Data Validity

This section discusses data validity, even though it is often not considered to be part of model validation, because it is usually difficult, time consuming, and costly to obtain appropriate, accurate, and sufficient data, and is often the reason that attempts to validate a model fails. Data is needed for three purposes: for building the conceptual model, for validating the model, and for performing experiments with the validated model. In validating the STEEP models, two purposes are of concern. One is to build conceptual models that have sufficient data on the problem entity to develop the integrated models, to develop mathematical and logical relationships for use in the models such that they will adequately represent the problem entity for intended purpose, and the other is to test the model's underlying assumptions. In addition, behavioural data are needed on the problem entity to be used in the operational validity step of comparing the problem entity's behaviour with the model's behaviour.

With the system classification and explanation in Table 9.1, two tests (empirical and rational) can be said to be carried out with and without field data. Empirical tests are those tests that are based on the direct comparison between the model outcomes and field data. Empirical tests are conducted to examine the ability of a model to match the historical data (hind casting), the future data (forecasting), and other qualitative behaviours of the real system. In case no data is available, the hypothesized system and the model system are used to conduct a series of rational tests, such as: parameter-verification, structure-verification, and extreme policy tests listed in Table 9.1. These tests are referred to as rational tests, since they can be carried out, based on the availability of expert knowledge and through reasoning processes. Rational tests are increasingly important for the situation where the real data of the complex system are lacking and subject to considerable uncertainty.

Table 9.9: Data Validity on Edinburgh Tram Network Project

Original Project Information (OPI)						
Cost (£ Million)	Planned Project Budget (PPB)					545
	Revised Project Budget (RPB)					776
	Project Cost Variation (PCV)					231
Year of Completion	Original Planned Date (OPD)					2011 (3 Years)
	Expected New Date (END)					2014 (6 Years)
	Completion Date Variation (CDV)					3 Years
ANP/SD Simulation Project Information (SPI)					**Validated Project Information**	
Risks	Level of Risk Impact on Project Performance –LRIPP **(%)**				(OPI X SPI)	
	Cost (C) (SPI_C)	Time (T) (SPI_T)	Quality (Q) (SPI_Q)	Total Impact	Cost (£ million) {(SPI_C) x (PPB)}	Time (year) {(SPI_T) x (OPD)}
Social	12	6	1	19	65.4	0.18
Technical	1.24	0.43	0.15	1.82	6.758	0.013
Economic	22.36	30.74	8.88	61.98	121.862	0.922
Environmental	11.43	29.3	3.35	44.08	62.294	0.879
Political	2.56	5.14	1.95	9.65	13.952	0.154
Total Impact	**49.59**	**71.61**	**15.33**	**136.53**	**270.266**	**2.148**

Source: Field Work 2013

For practical reasons, the empirical tests are conducted to examine the ability of the STEEP models to match the historical data of the Edinburgh Tram Network Project (ETNP). The results of the real system compared to the simulated results of the level of risks impact on project cost and time are indicated on Table 9.9. As Table 9.9 indicates, the total level of risks impact of ETNP which led to cost overrun, time overruns and project quality deficiency is 136.53%. Out of this, the total level of impact of risks on cost, time and quality is 49.53%, 71.61% and 15.33% respectively. Before simulation was performed, the planned budget for the project was £545 million for a 3-year project completion times but was later revised to £776 million (a variation of £231 million) for a 6-year project completion time. After simulation, it is revealed that project information on cost is about £270.266 million of overrun within a 2.148- year of additional project completion time compared to that of the original project cost variation of £231 million for a 3-year completion time.

Similarly, the simulation results show that the project quality of ETNP has been impacted by 15.33%. However, there was no available historical data on the original level of project quality deficiency to be validated. As a result, the hypothesized system made up by expert's knowledge was used to compare the real system as the case of data validation with the model system and for performing experiments so that a better presentation of the real system and a higher degree of confidence can be obtained. Examples of expert knowledge calibration techniques used are meetings with academic staff, some members of E-COST and industrial stakeholders and the Analytical Network Process (ANP).

9.5: Policy Analysis, Design and Improvement

Once the model is fully tested and its properties understood, the final step is to test alternative new policies for system improvement. The system improvement tests ask whether the modelling process helps to change the system for better. To pass the test, the modelling process must identify policies that lead to improvement; those policies must be implemented for improved performance of the system. A policy is a decision rule, a general way of making decisions. In practice, assessing the impact of a model is extremely difficult. It is hard to assess the extent to which the modelling process will change people's mental models and beliefs. It is rare for clients to adopt the recommendations of any model promptly or without modification.

In this last step, alternative policies are designed and tested by simulation runs to minimize risks at the construction phase of transportation megaprojects. It must be noted that many other variables and conditions may change at the same time the new policies are implemented, confounding attempts to attribute any results to the policies. Performance improvement following a study does not mean the model-based policies were responsible; the system may have improved for reasons unrelated to the modelling process. Likewise, deteriorating performance after policy implementation does not mean the models failed since the outcome could have been even worse without the new policies.

To improve the system, the policy analysis and design are performed by altering one or more characteristics of the STEEP models and examining the resulting behaviours. Like sensitivity analysis, policy analysis can also be numerical or pattern oriented. Pattern-oriented policy analysis is naturally much more important, since the purpose of system dynamics studies is to improve undesirable dynamic behaviour patterns. Policy design is determining what changes in the model structure and parameters would lead to improved model behaviour. While choosing the policies, practicality and usefulness have been checked with the experts and industrial stakeholders working on mega transportation projects.

With regard to the MegaDS models, it is argued here that four central characteristics make STEEP models well-suited for learning about and designing effective policies: 1) the feedback approach and emphasis on endogenous explanations of behaviour, 2) the disaggregation approach, 3) the simulation approach, and 4) the fact that the models are manageable enough such that their structures are clear and the links between structure and behaviour can be easily discovered through experimentation. Each of these four characteristics is explored in turn.

9.5.1: Feedback Approach

First, the STEEP models share feedback loop approaches to modelling endogenous sources of behaviour. The models illustrate how megaprojects under construction can be affected by risks and can endogenously create the conditions for time and cost overruns and quality deficiency once social, technical, economic, environmental and political uncertainties become high, causing excessive impact on project performance. By emphasizing feedback and an endogenous perspective, these system models will help policymakers understand how policy resistance can arise. The models challenge common beliefs about how systems work by revealing feedback loops that can exacerbate the situation, thereby facilitating learning for even the most overconfident users.

9.5.2: Disaggregation approach

Second, the MegaDS model takes a disaggregation approach to modelling. This implies that the STEEP system models are heterogeneous and do not track each individual model in the group, but instead are grouped in disaggregation. In keeping with the system dynamics modelling tradition, the building blocks of the model structure are stocks and flows rather than individual agents. However, these models are statistically estimated from data based on individual STEEP risk characteristics and level of impacts on a transportation megaproject. As such, a more efficient analysis, involving a better set of explanatory variables, can be carried out directly using disaggregated (i.e. individual risk level) data and model relationships. These reasons led to the development of the disaggregated models into five STEEP risk system models. The MegaDS model has five stocks each for the social, technical, economic and political sub models and four stocks for the environmental sub models (See Figure 9.13). All the models have common detailed implications of time and cost overruns and quality deficiency that arise from the interrelationship of variables within each sub system.

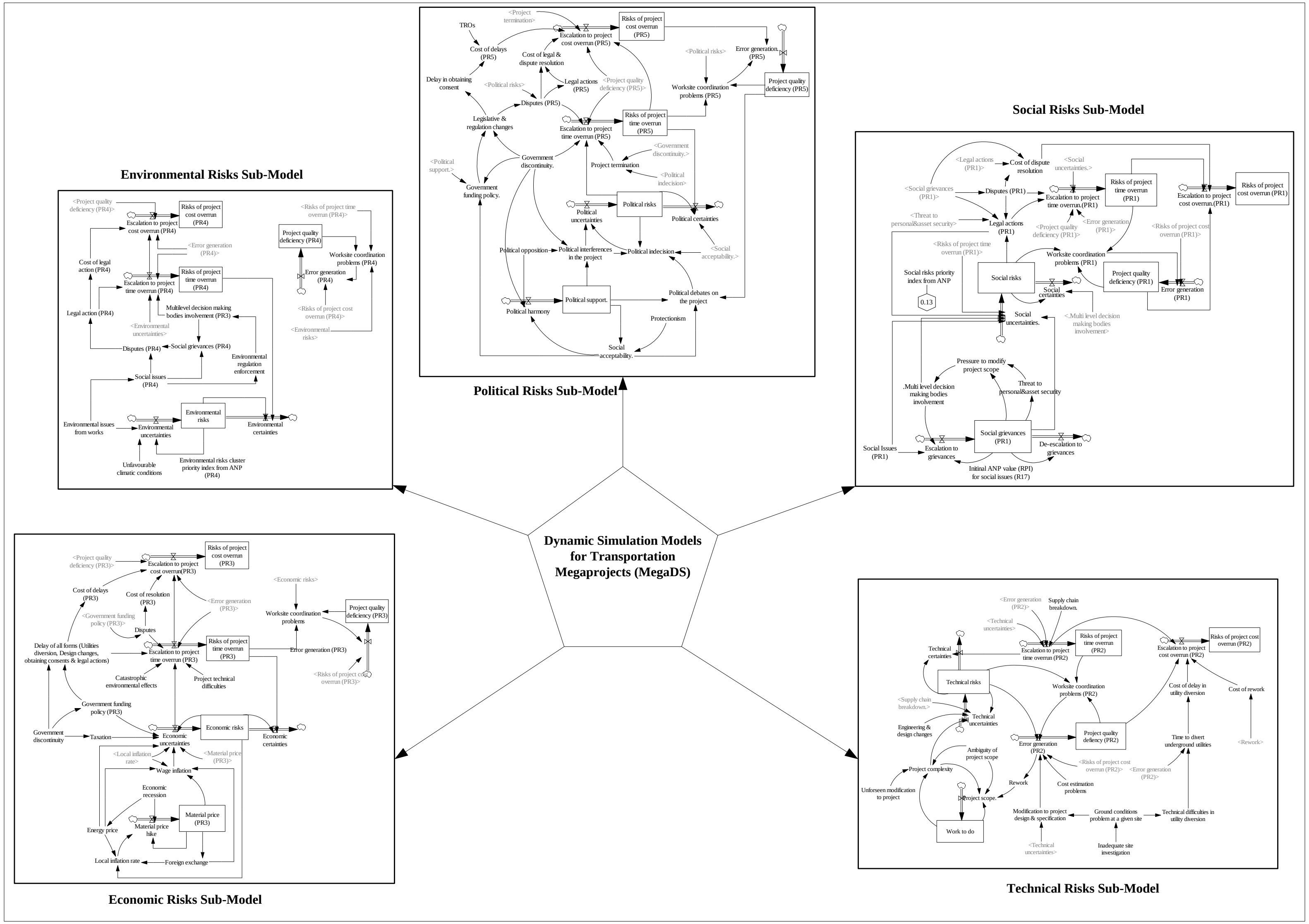


Figure 9.13: Disaggregation of the Dynamic Simulation Models for Transportation Megaprojects (See the attached sheet for clarity)

While there is much interest among modellers in an aggregated approach to the modelling of social problems, Rahmandad and Sterman (2008) argued that differential equation-based models – of which the models here are examples – are easier to understand and usually have similar policy implications when disaggregated. In addition, disaggregation reduces the models into manageable sizes, thereby decreasing the cost of developing and running complex models and allowing for easy but clear experimentation. Given limitations in individuals' cognitive capacity, disaggregation also allows users to focus on feedback ahead of agent level detail and therefore develop a more holistic and endogenous perspective to the problem.

Further, recent research has shown that individuals often fail to understand the dynamics of accumulation (Sterman, 2008), with huge implications for the policies that they will then support. By focusing on stocks and flows as the building blocks of model structure, the STEEP models can directly help policymakers build intuition regarding the dynamics of accumulation and thereby overcome one potential source of policy error.

9.5.3: Simulation Approach

Third, the reviewed models are running mathematical simulations that provide the opportunity to conduct experiments. While many lessons can be learned from a causal loop diagram, other more substantial insights require the development and testing of a simulation model. In both cases, simulation helps to illustrate why deliberate rational policies lead to policy resistance. In addition, the simulation models provide learning environments where modellers, policymakers, and other industrial stakeholders can design and test policies. Given the complexity of many policy environments, experimentation is essential for the design of effective policies. Simulations provide a helpful environment where policymakers can experiment and learn about the effects of different policies without any significant social and economic cost for policymakers.

Finally, simulations can help to build consensus surrounding difficult policy problems. By communicating the counter-intuitive nature of policy problems to policymakers, simulations can encourage dialogue and lead to the development of shared interpretations regarding the source of problem behaviour. Even when different goals and value systems persist, simulation can help to focus the discussion on specific variables and outcomes that are the sources of divergence.

9.5.4: Manageable Model Size

Finally, the STEEP models are “manageable.” Here, we define “manageable” to mean that the models consist of few significant stocks and feedback loops. There are two main benefits to these types of model sizes. First, they are small in size and allow for exhaustive experimentation through parameter changes. With these types of models, it is much easier to learn from sensitivity analysis (as shown in Figures 9.8, 9.9, 9.10, 9.11, and 9.12) and examine the interactions among different parameters. Thus, important leverage points in the system can more be easily identified.

Second, the manageable size ensures that the results of experiments can be fully and easily understood by policymakers. Short exposition makes a holistic view possible. Due to the small size, individuals can see the feedback structure as a whole and not be frustrated by the need to track many variables and links at once. In addition, short exposition facilitates presentation of lessons to others, and helps bring the dynamic lessons to the meetings of stakeholders. Our emphasis on small models reflects that of Repenning (2003), who argues that in an academic context as well, small models are necessary to build the intuition of readers who are not accustomed to a dynamic or holistic view of systems.

In conclusion, manageable but small system dynamics models offer numerous benefits to the policy making process during megaproject development. Table 9.10 summarizes the above discussion by depicting how each of the characteristics of the MegaDS models can help address the challenges inherent in policy making during megaproject development.

Table 9.10: The Significance of the Dynamics Simulation Models for Transportation Megaprojects in Addressing Policy Problems

Policy problems characteristics	**Model Characteristics**			
	Feedback Approach	**Disaggregated approach**	**Simulation Approach**	**Manageable Model Size**
The policy resistance environment	Feedback is the major source of policy resistance.	Accumulations (stocks) are essential to understanding policy resistance	Simulation can illustrate why some intuitive policies lead to policy resistance and allow for the design and testing of more robust policies	Small size allows for exhaustive experimentation and sensitivity analysis, wise interpretation of parameters and parameter changes.
Need to experiment and cost of experimenting	Feedback diagrams and mental simulation models must substitute actual policy trials.	Disaggregate approach decreases the cost of developing and running complex models, allowing for more experimentation.	Simulations allow for exhaustive experimentation and games for policymakers without incurring actual social and economic costs	Small size ensures that the results of experiments can be fully and easily understood by policymakers.
Need to persuade stakeholders	Feedback diagrams and qualitative analysis can contribute to policy discussions.	Disaggregate approach facilitates presentation of lessons to others. Highlights feedback and endogenous sources of problem behaviour.	Simulations can help build consensus around difficult policy problems that may otherwise have multiple interpretations.	Small size facilitates presentation of lessons to others. Short exposition and holistic view made possible.
Overconfident policymakers	Causal loop (feedback) diagrams reveal new insights and challenge policymakers to be wary of overconfidence	Failure to understand the dynamics of accumulation is a common source of policy error.	Simulations effectively communicate the counter intuitive nature of policy problems to policymakers who otherwise may remain not having been induced.	Small size ensures that model insights are fully understood, allowing policymakers to appreciate and address their own overconfidence.
Need to have an endogenous perspective	Feedback approach helps policymakers learn what an endogenous view is and why it is necessary to effective policymaking.	Disaggregate approach creates room and flexibility in individuals' cognitive capacity to concentrate on feedback and develop an endogenous perspective.	Simulations allow policymakers to explore how behaviours are created endogenously through a broad model boundary.	Small size allows individuals to see the feedback structure as a whole and not be frustrated by the need to track many variables and links at once.

Note: Project Policy refers to principles, rules, and guidelines formulated or adopted by an organization to reach its long-term goals and typically published in a booklet or other form that is widely accessible.

9.6: Policy Implementation

Having studied the influences of critical system variables on project performance for various simulation scenarios overtime, the megaproject managers can now implement appropriate policies that best suit the situation at hand to assess risks effectively. For best and worst case simulation scenarios that can inform project managers to design effective risk mitigation policies, the behaviour mode sensitivity graphs represented in Figures 9.3 to 9.7 for Edinburgh Tram Network Project are typical examples.

Other recommendations to contractors involved in megaproject construction for policy implementation are:

1. Megaproject contractors must obtain assurances from the relevant government departments in the host country, especially as regards the availability of consents and permits;

2. The Central Bank of the host government may be persuaded to guarantee the availability of hard currency for export in connection with the project; and/or

3. As a last resort, but an exercise which should be undertaken in any event, by a thorough review of the legal and regulatory regime in the country where the project is to be executed to ensure that all laws and regulations are strictly complied with and all the correct procedures are followed with a view to reducing the scope for challenges at a future date.

9.7: Summary

This penultimate chapter has addressed the validation of the model developed in this research. Unfortunately, there is no set of specific tests that can easily be applied to determine the “correctness” of the MegaDS models. Furthermore, no algorithm exists to determine what techniques or procedures to use because every new simulation project presents a new and unique challenge.

In this study, two major groups of tests (empirical and rational) were carried out and described with and without field data. The empirical tests were conducted to examine the ability of the STEEP models to match the historical data of the Edinburgh Tram Network Project (ETNP). The findings of these tests from the simulated results on the level of risks impact on project cost and time and quality compared to the real system suggest that the models reflect reasonable predictive fit and could therefore be generalised.

On the other hand, the hypothesized system and the model system are used to conduct a series of rational tests, such as: parameter-verification, structure-verification, extreme policy tests and sensitivity tests. Throughout this process, the concepts, methodology and the findings of the research have been found to be reasonably supported by the extensive use of the Vensim software tools in support of the study. It is therefore contended that the developed model has the potential for subsequent development and use by practitioners.

Finally, it can be said that validation is both an art and a science, requiring creativity and insight. But validation is difficult to comprehend and has diverse procedures, and is unavoidable as it is the evidence for the steadfastness and legitimacy of the model. This chapter has provided an insight on the widely approved schemes of model validation and techniques in practice. The validation schemes can be applicable to quantitative (mathematical/ computerised) as well as qualitative (conceptual) models. But reliability of the model can only be ascertained as the model passes more and more tests. Also, the decision of accepting a model as valid cannot be left to the modeller alone, and inclusion of the industrial practitioners involved in megaprojects development in the validation procedure should be obligatory. Researchers and practitioners may find this chapter quite useful as the procedures for validation discussed are quite generic, and hence may be applied to other dynamic models as well. The next chapter therefore concludes the research by providing a summary of the work done, drawing the main conclusions arising from the study and making recommendations for future research.

CHAPTER TEN: CONCLUSIONS AND RECOMMENDATIONS

10.1: Introduction

Against the background that owners and developers need to be proactive in employing effective measures for managing ever increasing challenges in megaproject during construction, this research has developed a model for assessing generic risks that impact on project performance leading to project cost and time overruns and quality deficiency. The eight chapters presented so far have elucidated the literary, conceptual, methodological and substantive approaches adopted in addressing the research agenda.

In this chapter, the research is brought to a close by summarising the issues addressed throughout the study. Readers are first reminded of the key research questions. Thereafter, a summary of how the key objectives were satisfied are presented, followed by the main conclusions of the research. Finally, the thesis is brought to a close with recommendations for future research.

10.2: Research Questions

In undertaking this research, four main questions were posed, namely:

1. What are the generic risk events inherent in transportation megaprojects during construction?
2. How can the qualitative risk effects on project performance be quantified, prioritized and analyzed in transportation megaprojects?
3. How can risk interrelationships in transportation megaprojects be modelled?
4. How can project managers (PMs) assess the dynamics of risk effects in transportation megaprojects over time?

To address the above research questions, the study performed a literature review, conducted a survey and interviews to investigate the generic risks that influence project performance. This was followed by risk prioritization and causal loop diagrams development to indicate the interdependencies and interactions of identified risk events.

Finally, simulations were conducted by integrating the Analytical Network Process (ANP) and the System Dynamics (SD) methodology to model the dynamics of risk impact on megaproject performance in the construction phase.

Table 10.1: Research Findings/Answers to the Research Questions

Research Questions	Findings/Answers	Reliability and Validity
1. What are the generic risk events inherent in transportation megaprojects during construction?	43 generic risk factors (See Table 5.6)	- Cross-checking the multiple sources of evidence. - Well defined risk factors. - Well documented data
2. How can the qualitative risk effects on project performance be quantified, prioritized and analysed in transportation megaprojects?	- Qualitative and quantitative Risk ranking methods - ANP Pairwise Comparison for all risks - Seven ANP Network Models	- Well defined questionnaire and risk effect rating scales. - Well documented data
3. How can risk interrelationships in transportation megaprojects be modelled?	- Five SD causal loop diagrams - Five SDANP integrated stock and flow diagrams	- Cross-checking the multiple sources of evidence. - Boundary adequacy test and model structure assessment. - Well documented data
4. How can project managers (PMs) assess the dynamics of risk effects in transportation megaprojects overtime?	- Fifteen integrated SDANP dynamic simulated diagrams	- Behaviour Reproduction Test - Monte-Carlo simulation. - Sensitivity Analysis. - Extreme Conditions tests, etc. - Cross-checking the multiple sources of evidence

Source: Fieldwork 2013

In all, 43 generic risk variables were drawn from 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 43 generic risks 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 transportation megaprojects. Table 10.1 illustrates the research questions, research answers/findings with related reliability, and validity processing to ensure research answers/findings is reliable and accurate to all of the research questions.

10.3: Review of Research Objectives

The main aim of this research, as noted earlier, was to apply and further develop the theory of risk informatics for megaprojects development for informed decision making under risk related scenarios. Subsequently a number of secondary objectives were developed in order to collectively satisfy this aim. Here, the research objectives are revisited to highlight the extent to which they were accomplished through the various phases of the research.

- ***Objective One:*** *To identify and describe the significant risks of partial or entire set of social, technical, economic, environmental and political (STEEP) problems for megaprojects development and construction.*

To address this objective, some important issues regarding significant STEEP risks which impact the performance of megaprojects in the construction phase were identified from the broader literature including recent contributions in construction management publications. The risk identification process began with the compilation of the risk events in transportation megaprojects. The identification process was dependent on the construction phase of the lifecycle of megaproject development, but began mostly with an examination of issues and concerns created in the early stages of the project development. These issues and concerns were derived from an examination of the project description, work breakdown structure, cost estimate, design and construction schedule, procurement plan, and the general risk checklists. Tables 2.4 and 2.6 (Chapter 2, p 29 and pp 44-48) and Table 4.4 (Chapter 4, pp 130-131) provide a summary of lists of risks identified in literature and case studies respectively.

The identified risks were examined and reduced to a level of detail that permits understanding of the impacts they have on project performance. This served as a practical way of addressing the large and diverse number of potential risks that often occur on megaproject construction projects. The selected risks are chosen as those events that are deemed to have adverse effect on megaproject development. After the risks are identified, they were described and classified into groups of like risks. Classification of the risks helps reduce redundancy and provides for easier management of the risks in later phases of the risk analysis process in the study. Classifying risks also provided for the creation of risk checklists and databases for future megaprojects and further scientific research. In the end, 43 risk variables were identified (See Table 5.6 of Chapter 5, pp 142-143) as the highest level of generic risks impacting on megaproject at the construction phase.

Based on these variables, a research instrument in the form of a self-administered postal questionnaire was developed. The questionnaire was piloted in Edinburgh (Scotland) by drawing on the expertise of experienced industrial and academic stakeholders involved in megaproject development. Suggestions made by the respondents were incorporated to improve the quality and suitability of the research instrument. The literature review was therefore helpful in underpinning the research agenda and provided reasonable justification for the need of the research.

- ***Objective Two:*** *To simulate and analyse the interactions among the risks*

In fulfilling this objective, a multi-criteria decision making tool, the Analytical Network Process (ANP) and the System Dynamics (SD) were employed to prioritise, simulate and analyse the interactions among all risks as designated in chapters six and seven respectively.

Recognising which risk will have the greatest effect on project performance is a difficult task. Additionally, managing risks which are currently presenting problems in a coordinated and joined up manner requires an informed policy response which proceeds in a transparent manner open to project management team scrutiny. Therefore, to address the second objective of this research, provision of a system(s) to meet such requirements is needed.

First, experts' decisions were solicited through a risk prioritization survey to select the potential "high risks" using a Likert scale type of 1 to 5 to score the level of STEEP risks impact on megaproject objectives (cost, time and quality) in the construction phase. The prioritization survey revealed some interesting results in the way respondents perceive the level of impacts that the 43 identified risk variables have on megaproject performances. It was noted that the results revealed could assist both project owners and developers to come to agreement on how to appropriately channel resources towards achieving project success in megaproject construction.

Thereafter, it was necessary to convert the 43 dependent risk variables to a single dependent variable. This was achieved using a weighted quantitative score (WQS) analysis as explained in section 3.4.4.1 of chapter three. The WQS analysis was useful in establishing which of the variables could be measuring the same underlying effect. Above all, the findings obtained emerged to be reasonably convincing and supported by the extant literature.

Second, risk prioritization was performed. Prioritization is one process that can allow megaproject owners and contractors to make decisions in a transparent and traceable manner within a risk assessment framework. This assessment method is a key to understanding the relative level of impact of risk associated with the project. The prioritisation risk assessment was carried out for 43 risks recorded during literature search and interviews conducted with stakeholders involved in the Edinburgh Tram Network Project. The Analytical Network Process (ANP) was chosen as against other alternative methods such as discriminant analysis and artificial neural network because of its explanatory characteristics, which is a most desired function of this research. The ANP technique included ANP network model construction; paired comparisons; criteria normalization through super matrix calculation; and risk priority index (RPI) calculation.

As a multi-criterion decision making (MCDM) tool, the Analytical Network Process (ANP) was used to aid the prioritisation of STEEP risk impacts on project performance and was successful. This risk assessment process developed by Professor Saaty (Saaty, 1991) allows for risk impact ranking and categorisation into very high, high, medium or moderate, low and very low impact categories. The categorisation provided a basis on which policy decision makers can focus their attention.

One key lesson is that risk issues will continue to emerge as the project proceeds and so experts involved in megaproject management will continue to identify new risks that are not currently listed in this research as their invasion may begin to exhibit new challenges suggesting an unforeseen potential. The ANP prioritization process therefore, allows for this in that it is easily updated as and when new risk information becomes available. However, this process stands and falls on the availability of relevant data on risks impact and experts willingness to engage the application of the ANP's risk prioritization process.

Lastly, the System Dynamics (SD) modelling approach was adopted to indicate and address interactions among all risks and their level of impact on the case study project during construction over time. The causal loop diagrams for the Edinburgh Tram Network Project system is presented in Figures 7.5, 7.9, 7.11, 7.14 and 7.17. These diagrams show all system entities (stocks, variables, parameters and flows), together with their respective interconnections and interactions, in a qualitative way. This diagram has been drawn using the Vensim software tool.

To conceptualize the real world system under investigation, SD was used to focus on the structure and behaviour of risks in Edinburgh Tram Network Project over time using multiple feedbacks (closed chains of cause and effect links, in which information about the results of actions is fed back to generate further action). Being an object-oriented simulation approach, SD was used to simulate the complex interrelated structure of social, technical, economic, environmental and political risk parameters resulting from the feedback processes.

The research process employed in the establishment of the SD based risk assessment model includes 1) problem analysis and identification, 2) conceptualization of system variable relationship using causal loop diagrams, 3) formulation of stock and flow model, and 4) model verification via Vensim software tools and case study. Finally, the levels and extents to which individual STEEP risks affect the objectives of the Case Study megaproject during construction were checked using one-way analysis of variance (ANOVA).

- ***Objective Three:*** *To assess major options against the risks*

One of the necessary conditions for the new risk assessment framework is that its application could be integrated with the traditional models, within the framework of the British Standard for risk management and other recognized risk management activities (See Figure 9.1) based on the Work Breakdown Structures (WBS).

In the case of using traditional methods, the decision-makers have to convene a panel/board discussion of the risks and their level of consequences by using individual participants' experience to identify or classify predictable risk events. Following current risk assessment practice, it is most likely that a risk assessment matrix (RAM) will be created. Although the RAM method is generally accepted by many decision-makers to assess the likelihood and the consequence of risks, its assessment method is, however, not based on either non-linear mathematical calculation or objective assumptions related to a real system. Also, it does not allow for comparisons amongst criteria. Therefore, the results produced by the matrix can be said to be subjective and do not provide detailed data required to assist decision makers to structure their decision- making processes effectively.

Since the risk factors are numerous and complicated, particularly in megaprojects development, human judgement is limited for assessing many of such complex risk factors at the same time. As a result, the Analytical Network Process (ANP) was chosen as a major risk prioritisation option against the RAM and other alternative methods such as discriminant analysis and artificial neural network because of its explanatory characteristics, which was a most desired function in this research.

Similarly, the system dynamics approach was also chosen over the conventional approach in aiding the risk assessment process. Unlike the conventional approach (PERT/CPM), where planners use human judgement to interpret their own mental models, the SD approach uses computer models to overcome limitations of the mental models (Sterman, 1992). Sterman established that the SD computer models are explicit and open to all to review; capable to compute the logical consequences of the modeller's assumptions; able to interrelate many factors simultaneously and finally, can be simulated under controlled conditions for analysts to conduct experiments outside the real system. As a proven tool and technique, the new methodology could be applied with success to various real megaproject cases to provide added value to risk management processes, in particular to risk identification, risk quantification and to response planning and control.

- ***Objective Four:*** *To develop a new megaproject dynamics methodology and tool for risk assessment in line with British and ISO standards on risk management.*

To explore the extent to which scientists can frame their ideas and research so that politicians, business-leaders and the general public can begin to understand the complex systems with which they interact and subsequently make transparent and scientifically based decisions about these systems, a new megaproject dynamics methodology and tool for risk assessment was developed in this research in line with the British and the ISO standards on risk management. The new risk assessment methodology provides a tool to understand, explain and address key challenges and problems that megaproject developers face during project execution and can provide a unique method of communicating project risk information rather than the usual language and concepts of the traditional risk management tools.

Within the new framework (See Figure 10.1), the ANP's RPIs can be used as credible exogenous risk values to be input into the SD final models during simulation to derive risk outputs and behaviour trends over time. As a new methodology, the new approach will provide a complete framework for understanding the criteria used for evaluating and assigning ratings to system elements, and the dynamic interrelationship among those elements. The simulation results from the new approach will serve as reliable outputs for the project management team to depend on when making decisions during risk assessment. This implies that the SDANP approach for risk assessment will go beyond the strict decision metaphor and can be applied to support effective thinking, group discussion and most importantly modelling of complex dynamic project systems.

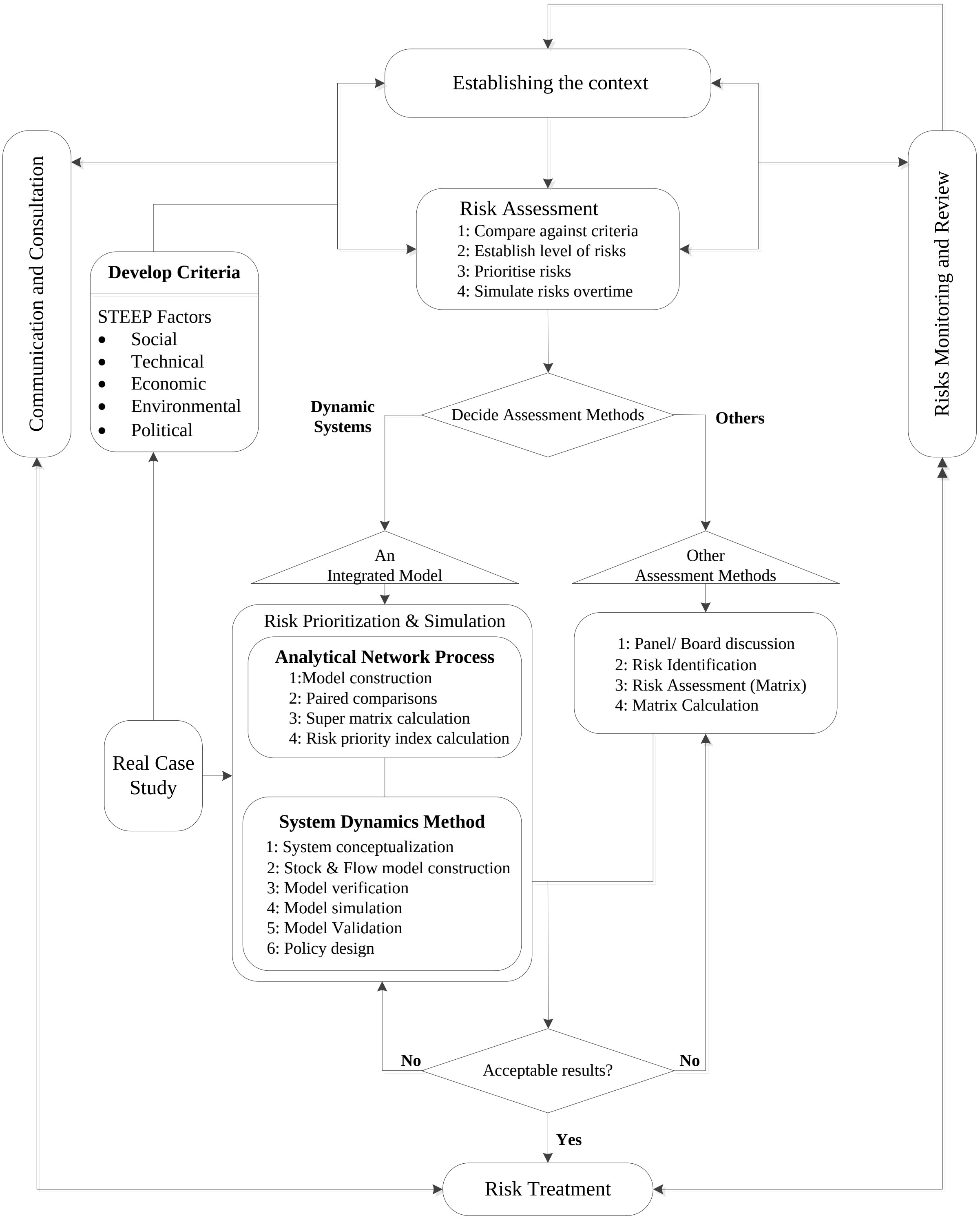


Figure 10.1: Proposed Framework for Dynamic Risks Assessment in Megaproject

The goal of the SDANP risk assessment approach is not to eliminate all risks from the project. Rather, it is to recognize the significant risk challenges and their complexities to the project over its life in the construction phase and to initiate appropriate management responses for their management.

The SDANP approach will cover a wide range of project management needs, by addressing the systemic issues that influence and dominate the outcome of megaprojects. It will ensure the proper management of risk and the highest value return from the project. It will also:

i. Provide a proactive new methodology for megaproject risk analysis and assessment

ii. Define the cluster of significant risks in megaprojects

iii. Provide an independent risk assessment tool for stakeholders.

iv. Aid policy-makers by allowing them to investigate different scenarios and policy options. Decisions about a system involve first considering, for certain relevant external conditions, a number of possible future scenarios, which should be based on an understanding of the broad structure of the system and how it operates. Then decisions have to be made in the light of these possible scenarios. The scenarios can be represented schematically as graphs of the changes in the operation, or output, over time, depending on inputs or external influences.

v. Provide better decision making support to cost and time management. That is to say decision-makers can use the new system modelling methodology and concepts more generally as a framework for describing and analysing the behaviour of a system in changing conditions.

The application of the new tool in the context of risk management will provide a dynamic analysis of risks. The limits of this dynamic modelling approach is essentially linked to the degree of complexity the expert seeks to handle, the time devoted to the development of the model, the definition of the variables, the simulation process and the interpretation of the results.

10.4: Conclusion

This study has successfully addressed an important research topic in the risk assessment literature — the patterns of risk during system development in the construction phase. The theoretical foundation of this study is risks in transportation megaproject construction. Based on findings from literature, a model known as the MegaDS model was developed to assess the level of identified risks and the interactions such risks cause to impact the performance of megaprojects during construction.

The MegaDS suggested that transportation megaproject system is composed of five subsystems namely, a social subsystem (actor and structure) and a technical subsystem (technology and task), an economic subsystem, an environmental subsystem and a political subsystem. From the simulation results, it can be emphasised that any organizational system can maximize performance only by ensuring these five subsystems are working in harmony. As a result, project managers involved in transportation megaproject construction must consider all of these factors equally important during the entire system development life cycle.

During the model validation process, it was revealed that there is no single model developed for managing risks within the domain of the construction industry. As companies face ever-increasing challenges, there is heightened awareness of generic risks preventing leading organizations from realizing the importance of well-defined model validation procedures. Regular and periodic review of models through a formal model validation process can help management and stakeholders gain confidence in these critically important business tools. Companies also need to validate their models to keep pace with changes in market dynamics; the model validated yesterday may not still be valid today given the changes and shifts in the marketplace. Put simply, model validation is the quintessential tool in an organization's model risk management process.

From the view point of industrial stakeholders and people living (social view) along the route of Edinburgh Tram Network Project (ETNP), risk management requires organizing and connecting heterogeneous actors within organizations that allow for project development and evolution. In other words, successful risk management is characterized by skilled actors within appropriate organizational contexts and institutional arrangements at all times. The more the actors, the greater the incurred risk of having an insufficient or inappropriate structure.

Considering technical risks in ETNP for example, task risks such as worksite coordination problems remain relatively consistent throughout the construction stages of the project life cycle but technology risks like correct size of tram car to fit tracks were not realized until the latter stages of development. Tasks are conducted on a regular basis with established procedures and generation of outputs, but technology is not realized until the testing and implementation stages. Thus, the pattern of realized risks follows a pattern similar to those of process importance and technology presence at the various stages of the life cycle. A successful project involves acquiring clear tasks and managing them to integrate, control and coordinate heterogeneous capabilities. Though the design of the technology may occur in earlier stages, the hands-on experiences occur in the latter stages.

In summary, the dynamic simulation patterns and results show that the economic risks tend to dominate and cause project cost and time overruns and quality deficiency as construction progresses followed by environmental risks and social risks, political risks, and technical risks. For project managers who control risks within the fixed problem and limited resources, there is a need to study how to manage the inter-relationships among these risks to ensure effective reactions to problems in the working environment. In controlling risks at multiple stages, the risk assessor and project management team need to focus on the mitigation techniques required by stages of the project life cycle to compose the portfolio of controls at the most appropriate time. Different risks will often require different forms of mitigation and control. Several of these have been described in the British Standards for risk management codes of practice (BS 31100:2011 Risk management- Code of practice; BS ISO 31000:2009 Risk management- Principles and guidelines and BS EN 31010:2010 Risk management-Risk assessment techniques), but resources for implementing control need to be allocated appropriately.

An organization may also find it useful to segregate risk policies according to the patterns identified in this research. Economic and environmental risks tend to be uniformly distributed throughout the project execution life cycle and may best be controlled through centralized practices, such as documented procedures established by a project office and skill databases maintained by human resources. Technical and political risks grow as the cycle progresses, indicating that they might best be controlled by the project teams rather than rely on uniform practices throughout an organization. Social risks represent a combination of challenges from the political risks and environmental issues created by the works (technical). Further, project managers of megaproject construction can't overlook the risks they create themselves which relate to poor project management practices.

Attention to good communication and structural practices by all levels of management will address the highest incidence of these risks in megaproject construction. Lastly, even if the risks are not realized until later stages, project managers should develop mitigation and control plans as early in the life cycle as possible in order to be best prepared. Even though this research has the merit of offering insights into a new way of assessing risks in the megaproject construction process, it considers only the dimensions of incidence and timing. We focused on STEEP risks impact on project time, cost and quality as a gap in literature by developing a new methodology for assessing the dynamics of impact of such risks on project performance in megaproject construction. Further, we rely on data from Edinburgh Tram Network Project to draw conclusions. Specific counts derived from the data may not reflect exact patterns in all socio-cultures and political environment. Future studies are encouraged to consider these limitations to generalize our findings and provide additional insights on understanding the impacts of these risk components during a megaproject development life cycle.

10.5: Long Term Impact of the New Methodology

It appears inescapable that megaproject consultants need an organized way to collect relevant risk information and make decisions on important factors that affect project performance throughout its lifecycle.

As a multi criterion methodology, the Analytical Network Process (ANP) can be applied by project consultants who facilitate risk identification workshops to conduct risk assessment based on the facilitator's skills and experience in risk elicitation to draw out judgments about uncertain events from the project team. The facilitator can conduct meetings with a smaller group of the most experienced project team members to elicit qualitative assessments of the major risks for the project. The likelihood and consequences of each risk event can be elicited from each team member. For simplicity, the facilitator has to use the discrete scale of 1 - 9 to represent the verbal judgment in pairwise comparisons to generate a ranked list of risk priority values of consequences or risk priority indexes (RPI).

As a proven Multi-Criterion Decision Making (MCDM) methodology, the ANP is capable to evaluate criteria and assign ratings to risks factors. It can further lead to the selection of most risky factors acceptable to decision makers during the establishment of the RPI for the entire project. However, there is one area that needs greater attention in its application during decision making. That is, how to use the RPI obtained from pair comparisons to perform risk assessment over time in order to anticipate and deal with the future more successfully through risk impact prediction and planning. To bridge this gap, system dynamics (SD) is proposed to integrate the RPI from the ANP paired comparisons into the system dynamics methodology in order to solve these important real world problems concerning nonlinear dynamics and feedback control of risks behaviour in megaprojects as complex systems.

System dynamics is one of the successful well formulated methodologies that provide a framework for building a highly interactive problem-solving environment in a system where decision makers are involved in reasoning about the relationships between the structure and the dynamics of a complex system. It provides a way to represent and model expectations of project management team over time for policy decision making. In its simplest form, SD focuses on information flow and return (feedback) through the system’s component. SD approach is capable of analysing relevant cause-effect relationships and the impacts of time delays and feedback loops in a complex system that exhibits unexpected behaviour. It provides this capability and supports conceptually linking the explanations for complex behaviour to the underlying structure. This allows decision makers or planners to use system dynamics simulation as a way to test a hypothesis about how a system will behave in particular circumstances. In other words, decision makers can use system dynamics to understand and explain system behaviour in terms of underlying system structure. In addition, the project management team can use system dynamics to show how changes in the structure of a system will lead to changes in its behaviour.

To reduce risks, companies can use the outputs of the new generic tool for risk management in five steps: risk management planning, risk identification, qualitative and quantitative risk analysis, risk response planning, risk monitoring and control.

Step 1: Risk management planning- Within the STEEP risk management planning, feedback loops concerning project risks can be used by planners to pro-actively test and improve the existing project plan such as forecasting and diagnosing the likely outcomes of the current plan.

Step 2: Risk identification-The SDANP models can support risk identification in a qualitative level through the causal loop diagrams. Given STEEP as specific risks, it is possible to identify which feedback loops favour or counter the occurrences of such risks so that the direct or indirect impacts of the project magnitude can be understood.

Step 3: Risk analysis-The causal loop models can further assist project managers in assessing all risks in both qualitative and quantitative manners. In the qualitative analysis, each feedback loop can be a dynamic force that pushes away from the risk occurrence. With regards to risk likelihood, magnitude and impacts, a simulation model can be used to identify and capture the full impacts of potential risks on the project. Further impacts of risks can be quantified and simulated to generate a wide range of estimates and scenarios to reflect the full impacts of the risks occurrences and impacts on megaprojects during construction.

Step 4: Risk response planning- The models can be effectively used to support risk response planning in megaproject development in three ways.

- Provide a feedback perspective for risk identification
- Provide a better understanding of the multiple- factor causes of risks and a trace through the chain to identify further causes and effects.
- Serve as powerful tools to support project managers to devise effective responses.

Step 5: Risk monitoring and control- The models provide effective tools for risk monitoring and control. Through the cause and effects diagrams, early signs of unperceived risk emergence can be identified to avoid aggravation. In addition, simulated models can provide an effective monitoring and control mechanism for risk diagnosis.

Based on the above reasons, it would therefore be more appropriate to assess risks in megaprojects during construction with the system dynamics methodology using Risk Priority Indexes (RPI) derived from the ANP as inputs for dynamic simulation. Then every project management team member at the decision level can benefit from the knowledge that went into making these decisions before arriving at the final level of risk implications on the megaproject objectives throughout the project schedule time.

- ***Implications of the SDANP models for Research, Practice, and Society.***

The developed SDANP system models in this thesis have a number of implications for research, practice, and/ or society.

Firstly, the study explored the complex intrinsic interrelationships among STEEP risks at the construction phase of megaproject development by capturing their causes and effects on project performance. This is with the sole aim of improving the understanding of the complex system of risk behaviours from systems thinking and analytical perspectives thereby extending the knowledge base for integrating the ANP and the SD to risk assessment in megaproject construction. For example, the causal diagrams can lead to theory building by the interested researchers. Additionally, the output of this research has the capability to spur research activities as enunciated under the recommendations for future research in Section 10.8.

Secondly, the research in this thesis has implications for practice and can be used to achieve results by following the under listed steps 1 to 15. The SDANP methodology builds on the existing modelling efforts, which are traditionally restricted to building physics and regression-based forecasting, in order to generate new insights into the future using a non-deterministic systems approach. This then adds to the pool of tools available in the field for practitioners. Since the SDANP modelling process is highly transparent as all the modelling steps, inputs such as variables, data and the algorithms developed can be scrutinised. Therefore, the new risk assessment tool has the capacity to immensely benefit from software developers by prototyping it into other suitable user friendly platforms.

1. Identify and categorise risks
2. List potential risks
3. Conduct prioritization survey
4. Perform weighted quantitative scores (WQS)
5. Develop ANP network model
6. Conduct comparison matrices using the WQS and normalize criteria
7. Calculate risk priority index (RPI) and list potential high risks.
8. Verify with experts and modify the model
9. Develop the initial SD model (Causer-loop diagram)
10. Repeat step (8)
11. Develop SDANP stock & flow model (Input RPI into SD model)
12. Test model for dimensional & structural consistencies
13. Perform risk scenario simulation to derive dynamic patterns
14. Validate results with the real system
15. Design policies for implementation to improve the system

Thirdly, the outcome of this research has implications for society and other stakeholders involved in megaproject development. This is by providing the policy makers with a decision making tool upon which different scenarios regarding STEEP risk assessment strategies can be tested before implementation.

10.6: Contribution to Knowledge

An original contribution to knowledge is an important concern in any doctoral research. The problem is that the concept of originality could be subject to individual judgment or preference (Fellows and Liu, 2008). Walker (1997) has documented various ways to demonstrate originality such as development of new methodologies, tools and/or techniques, new areas of research, new interpretation of existing material, new application of existing theories to new areas or a new blend of ideas.

Drawing on this background, this research has demonstrated the dynamic effects of social, technical, economic, environmental and political (STEEP) risks on the performance of megaproject construction using an integrated approach of Analytical Network Process (ANP) and the System Dynamics (SD) applications for risk assessment, and contributed to the body of knowledge regarding the interrelated system variables of risk effectiveness. The models produced by the new risk assessment tool successfully demonstrate the behaviour of project time and cost overruns and quality deficiency in a transportation megaproject under construction in Edinburgh, Scotland using the SDANP based risk assessment process. The model is able to predict the relative change in project performance. The new risk assessment model, also known as the MegaDS model, will support on-going research since updated model parameters can be easily incorporated. This work has also corroborated that the combined Analytical Network Process and System Dynamics is a suitable modelling paradigm for risks assessment processes in general in megaproject development and has shown that such modelling can be augmented with expert heuristics to support risk management. Other contributions to supports risk management are highlighted below:

- The research in this thesis indicates for the first time the application of a dynamic systems modelling to a transportation megaproject in order to model the risks of cost and time overruns and quality deficiencies during construction based on the complex STEEP interactions of the influencing variables

- It contributes to both project risk management (PRM) knowledge and ANP implementation in this field. From PRM perspective the ANP-based framework of the SDANP methodology is proposed for assessing the impact of different STEEP risk factors on megaproject construction. Since ANP is capable of dealing with all kinds of feedback and dependence when modelling a complex decision environment, this research contends that the study results are more accurate. ANP deals with uncertainty and complexity and provides insights that other, more traditional methods could miss. The proposed ANP approach would enable a decision maker to visualize the impact of various criteria in the final outcome. In such way that is very simple to communicate the results to all involved stakeholders, without time and place limitations and it is equally easy to have collaborative decision making processes by having more than one decision makers working on the same model. A secondary benefit of the research is that by using the proposed framework a valuable insight of the criteria that dominate the decision making process is given, providing value-added knowledge to front-ended stakeholders.

- The model, especially the developed SD conceptual model – system thinking aspect, is capable of improving the theoretical knowledge base regarding the complex intrinsic inter-relationships that exist among the STEEP risk influences of megaproject development.

- The SDANP system models within this thesis have the capabilities of being used to simulate and support behavioural understanding, prediction and evaluation of risks for project planning and project performance improvement across a range of alternative megaprojects. Some of the modelling constructs can be used for other project lifecycle models, such as an evolutionary risk-driven process.

- The SDANP system models have the capability to serve as decision making policy tools with the ability to direct policy decisions by testing the effect of different policy scenarios such system improvements and behavioural change likely to have on megaprojects during construction. The insights generated will allow policy makers to make informed decisions regarding any future policy formulations concerning the STEEP risks effect on megaproject performance.

Further to the above contribution to the body of knowledge, several facets of this research have been presented at conferences and others published in co-authorship in the lists of publications and presentations indicated on page xxiv of this report.

10.7: Limitations of the Findings

As with all survey based research there are bound to be limitations, which need to be acknowledged. Readers are therefore reminded of the potential effect of sampling, unsystematic (i.e. random) and measurement errors and their likely impact on the data collected, analysis undertaken and the conclusions drawn. These notwithstanding, the demographic profile of the respondents suggest that they have reasonable involvement and direct professional experience in megaproject construction which should accord some reasonable credibility to the quality of responses received.

It is also important to acknowledge the relatively small sample size used for the study (See Table 5.2 of Chapter 5, section 5.2.2). However, this should not nullify the conclusions drawn, given that the relevant preliminary tests associated with the adequacy of sample size (including the assumptions of central limit theorem) proved favourable for the analysis to proceed.

Also the margin of error associated with the study is 1.7 % (see chapter five). That is, the predictive power of the MegaDS model at 95% confidence level can be tolerated at an approximate confidence interval of • +/- 2%, which appears reasonably good for a stochastic study of this nature. Cross validation of the model suggested it has reasonable predictive power and could therefore be generalised at least in the risk assessment context for megaproject construction. While emphasising the significance of the model in reflecting the project lifecycle, it is important to remind readers that development of the substantive STEEP models focused on the "construction phase". This is largely due to resource constraints placed on the study. However, the successful completion of the model for the construction phase provides an important stepping stone for further research as indicated in section 9.9.

Furthermore, the researcher still lacked some real data to demonstrate the validity of the SDANP model developed by the proposed approach. Due to confidentiality and reserved matters, the public sector officials and contractors of ETNP were not allowed to disclose any data in terms of full project cost and level of quality deficiency. For example, the researcher could not obtain bidding proposals for various work packages with bidding costs for sub-contractors involved in the project and project cash flow during the construction stage. Most of data in terms of cost obtained by the researcher relied heavily on the current audit, media and government reports on the project and this data was limited. Also, with no data availability the researcher used hypothetical data to model the level of risk effects on the project quality. Without comparing simulation results on project quality deficiency against real data, there is inadequate evidence to support the position that the model can properly function to represent reality. As a result, the model validation for project quality deficiency modelling is very limited. Therefore, applying a case with sufficient real data in the future research to test the level of STEEP impact on project quality within the MegaDS model developed by the proposed SDANP approach is suggested.

10.8: Recommendations for Further Research

1. Although the researcher has established that the theoretical approach has proved to be valid in developing a risk assessment decision support model for transportation megaproject in the construction phase, this theory still requires further research to assure its realistic representation.

2. Since there was not enough real data in terms of qualitative risk effects, many parameter values in the MegaDS model heavily relied on interviewees with experts involved in megaproject development. To enhance the model validity, the model parameters needed to be calibrated (Lyneis, 2007) by tracing and comparing the simulation results with the real project data in the future, particularly with data concerning project quality at the construction phase which would normally be lacking in most megaprojects.

3. There is a need for future research to investigate into the dynamics of STEEP risks and impact on project performance in the total lifecycles of megaproject development and different types of megaprojects as compared to transportation megaprojects.

4. By this research, it is believed that the findings could be used by academic professionals and industrial stakeholders as a reflective document for initiating the establishment of an Association of a Dynamic Risk Assessment for Megaproject

Development **(ADRAMD),** and the competency profiles identified herein could be further developed to form baseline competencies in project managers’ performance, for gaining recognition and value in their performance and for benchmarking and best practices during risk management.

10.9: Summary

This chapter has provided a review of the original research objectives and the extent to which they were achieved. The main conclusions have been presented and the limitations of the research have been acknowledged. Recommendations for further research have been proposed.

In summary the research has developed a competency-based SDANP model representing a robust mechanism for assessing STEEP risks impact on the performance of transportation megaproject at the construction phase. The model, known as MegaDS, could be used by project managers to reveal the behaviour of risks and maximise project performance over time. It is contended that the MegaDS model has the potential for improving the performance of PMs anywhere in the world, when used as part of a wider sphere of risk management practices and procedures.

REFERENCES

Aaltonen, K., Kujala J. and Oijala, T. (2008) 'Stakeholder Salience in Global Projects', *International Journal of Project Management,* 26(5), 509–516.

Abdou, O.A. (1996) 'Managing Construction Risks', *Journal of Architectural Engineering*, 2 (1), 3–10.

Ahmed, S., Azher, S., Castillo, M., & Kappagantula, P. (2002) Construction delays in Florida: an empirical study, *Final report submitted to the state of Florida, Department of Community Affairs*.

AIAA (1998) Guide for the Verification and Validation of Computational Fluid Dynamics Simulations [online], American Institute of Aeronautics and Astronautics, AIAA-G-077-1998, Reston, VA, available: www.aiaa.org/store, [accessed, 22 January 2014].

AI-Bahar, J. F. (1998) '*Risk management in construction projects: A systematic analytical approach for contractors',* PhD dissertation, Department of Civil Engineering, Berkeley: University of California.

AIRMIC, ALARM and IRM (2002), "Risk Management Standard" Available: http:// www.theirm.org/publications/documents/Risk_Management_Standard_030820.pdf (accessed 21 March 2012).

Aitken Edinburgh, (2009) '*Tram brinkmanship is not a new ploy'* [online], Aitken's Edinburgh (20 February 2009), available: http://aitkensedinburgh.blogspot.com, [accessed 25, October 2012].

Akintoye, A., Hardcastle C., Beck M., Chinyio E. and Asenoya D. (2003) 'Achieving Best Value in Private Finance Initiative Project Procurement', *Construction Management and Economics*, 21(5), 461-470.

Ali-Mohammed, B.A. (2010) *Risk and Stakeholder Management in Mega Projects beyond the Realms of Theory* [online], Ministry of Works and Housing, Kingdom of Bahrain, available: www.works.gov.bh/media/Researchs/pw04p06.pdf [accessed 25 October, 2012].

Alinaitwe, H. M., Mwakali, J. A. and Hansson, B. (2007) ‘Factors affecting the productivity of building craftsmen studies of Uganda’, *Journal of Civil Engineering and Management* 13(3), 169–176.

Al-Momani, A.H. (2000) ‘Construction delay: a quantitative analysis’, *International Journal of Project Management*, 18(1), 51-59.

Altshuler, A. and Luberoff, D. (2003) ‘*Mega-Projects: The Changing Politics of Urban Public Investment’*, Brookings Institution, Washington DC.

Anderson, G., and Roskrow, B. (1994) *The channel tunnel story*. London, UK: E & F N Spon.

Arber, S. (2011) ‘*Designing Samples. In: Gilbert N, ed. Researching Social Life’*, London: SAGE Publications.

Arrow, J. (2008) ‘Knowledge-Based Proactive Project Risk Management’, *AACE International transactions.*

Ashley, D. B. (1977) *‘Construction project risk-sharing’,* Technical Report No. 220, Department of Civil Engineering, Stanford University, Stanford, CA, 1977.

Association of Project Management, (2005) *PRAM: Project Risk Analysis and Management Guide.* Edition 2. Association of Project Managers: London.

Audit Scotland, (2004) ‘*Management of the Holyrood Building Project’*, prepared for the Auditor General for Scotland (June 2004), Audit Scotland.

Audit Scotland, (2007) ‘*Edinburgh transport projects review’* [online], Audit Scotland (June 2007), available: http://www.audit-scotland.gov.uk/docs/central/ Pdf, [accessed 14 November 2012].

Audit Scotland, (2011) ‘*Edinburgh trams interim report’* [online], Audit Scotland (February 2011), available: http://www.audit-scotland.gov.uk/docs/central/ Pdf, [accessed 14 November 2012].

Austin, S., Baldwin A., Li B. & Waskett, P. (2000) ‘Integrating Design in the Project Process’, *Proceedings of the ICE, Civil Engineering,* November*:* (138), 177-182.

Aven, T. (2008) ‘*Risk analysis: assessing uncertainties beyond expected values and probabilities’,* New Jersey: John Wiley & Sons Inc.

Ayyub, B.M. (2001) *Elicitation of Experts Opinions for Uncertainty and Risks*. CRC, Press.

Baccarini, D. (1996) 'The concept of project complexity – A review'. *International Journal of Project Management,* Vol. 14(4), 201–204.

Baccarini, D. and Archer, R. (2001) 'The risk ranking of projects: a methodology', *International Journal of Project Management; 19(3), 139–145.*

Baker, S., Ponniah, D. and Smith, S. (1999) 'Survey of Risk Management in Major UK Companies', *Journal of Professional Issues in Engineering Education and Practice; 125 (3), 94-102.*

Baldry, D. (1998) 'The evaluation of risk management in public sector capital projects', *International Journal of Project Management; 16(1), 35–41.*

Baloi, D. and Price, A.D.F. (2003) 'Modeling global risk factors affecting construction cost performance', *International Journal of Project Management, Vol. 21(4), 261–269.*

Barber, R.B. (2005) 'Understanding internally generated risks in projects', *International Journal of Project Management; Vol. 23(8), 584–590.*

Barr Construction, (2011) 'Edinburgh Tramway Depot', [online], available: http://www.barr-construction.co.uk [accessed 28, September 2013].

BBC News, (2007) 'Work begins on city tram project' [online], *BBC News* (9 July 2007), available: http://news.bbc.co.uk/1/hi/scotland/edinburgh_and_east/6282428.stm, [accessed 21 October 2013].

BBC News, (2008) Traders create tram action group [online], *BBC News* (29 April 2008), available: http://news.bbc.co.uk/1/hi/scotland/edinburgh_and_east/7373659.stm, [accessed 11 December 2011].

BBC News, (2008) Tram work to close Princes Street [online]; *BBC News* (24 April 2008), available: http://news.bbc.co.uk/1/hi/scotland/edinburgh_and_east/7364445.stm, [accessed 20 September 2013].

BBC News, (2009) Edinburgh tram lines throw cyclists off track [online], *BBC News* (7 December 2009), available: http://news.bbc.co.uk/1/hi/scotland/edinburgh_and_east/8400094.stm, [accessed17 February 2011].

BBC News, (2009) Funding concerns for tram project [online]; *BBC News* (24 April 2009), available: http://news.bbc.co.uk/1/hi/scotland/edinburgh_and_east/8016093.stm, [accessed 11 January 2012].

BBC News, (2011) Council to borrow £231m for Edinburgh trams project [online]; BBC News (19 August 2011), available: http://www.bbc.co.uk/news/uk-scotland-edinburgh-east-fife-14594872, [accessed 21 August 2011].

BBC News, (2011) Edinburgh tram line repair works get under way [online]; *BBC News* (17 September 2011), available: http://www.bbc.co.uk/news/uk-scotland-edinburgh-east-fife-14958817, [accessed 19 January 2012].

BBC News, (2011) Edinburgh trams: Council backs St Andrew Square option [online]; *BBC News* (2 September 2011), available: http://www.bbc.co.uk/news/uk-scotland-edinburgh-east-fife-14751711, [accessed 2 September 2011].

BBC News, (2011) Ministers withhold Edinburgh trams funding [online]; *BBC News* (30 August 2011), available: http://www.bbc.co.uk/news/uk-scotland-edinburgh-east-fife-14713476, [accesses 09 January 2012].

BBC News, (2011) UN to scrutinise Edinburgh tram complaint [online]; *BBC News* (13 December 2011), available: http://www.bbc.co.uk/news/uk-scotland-edinburgh-east-fife-16165656, [accessed 11 December 2012].

BBC News, (2012) Edinburgh tram project bosses payments revealed [online]; BBC News (20 June 2012), available: http://www.bbc.co.uk/news/uk-scotland-18518319, [accessed 8 October 2012].

BBC News, (2013) Edinburgh trams: Services will be running by next May [online]; *BBC News* (17 September 2013), available: http://www.bbc.co.uk/news/uk-scotland-edinburgh-east-fife-24124047, [accessed 16 September 2013].

BBC News, (2013) Edinburgh trams: Shandwick Place to reopen after works [online]; *BBC News* (18 October 2013), available: http://www.bbc.co.uk/news/uk-scotland-edinburgh-east-fife-24571752, [accessed 22 October 2013].

BCIS, (2012) '*BIS Construction Price and Cost Indices',* Available: http://www.bcis.co.uk: Building Cost Information Services, UK.

Boateng, P., Zhen C., Ogunlana S. and Ikediashi I. (2012) A system dynamics approach to risks description in megaprojects development, *International Journal of Organization, Technology and Management in Construction, DOI 10.5592/otmcj.2012.3.3.*

Bossel, H. (1992) *Modellbildung und Simulation, Vi.weg,* Braunschweig / Wiesbaden Communications.

Bourne, L. and Walker, D. (2006) ‘Visualizing stakeholder influence: two Australian examples’, *Project Manage J; 37(1):5–21.*

Boyce, J. K. (1990) ‘Birth of a Megaproject: Political Economy of Flood Control in Bangladesh’, *Environmental Management, vol. 14, pp. 419- 428.*

Brady, T. and Davies, A. (2004) ‘Building project capabilities: from exploratory to exploitative learning’, *Organization Studies,* 26 (9), 1601-1621.

British Standards Institute (2000) *BS6079-3:2000: Project Management Part 3: Guide to the Management of Business-related Project Risk*. London: BSI.

British Standards Institute (2002) *ISO/IEC Guide 73:2002: Risk Management Vocabulary and Guidelines for Use in Standards*. London: BSI.

Brockmann, C., and Girmscheid, G. (2007) ‘Complexity of megaprojects In: Proceedings of *CIB World Building Congress* (May 2007), “Construction for Development”, Cape Town, pp.219-230.

Bruijn, J. A., and Leijten, D. M. (2008) *Management characteristics of mega-projects*. In H. Priemus, B. Flyvbjer, & G. P. van Wee (Eds.), Decision-making on megaprojects: Cost–benefit analysis, planning and innovation (pp. 23–39). Cheltenham, UK/Northhampton, MA, USA: Edward Elgar Publishing Limited.

Bruzelius, N., Flyvbjerg, B., Rothengatter, W. (2002) ‘Big decision big risks, improving accountability in mega projects’; *Transport Policy,* 9(2), 143–154.

Bryman, A. (2001) *Social Research Methods,* 1st edition, New York: Oxford University Press.

Bryman, A. (2004) *Social Research Methods,* 2nd edition, Oxford: Oxford University Press.

Bryman, A. (2008) *Social Research Methods*, 4th edition, New York: Oxford University Press.

BSI, (2010) *BS EN 31010: 2010-Risk management, Risk assessment techniques*. London: British Standards Institute.

BSI, (2011) *BS 31100:2011-Risk management-Code of Practice and Guidance for the Implementation of BS ISO 31000*. London: British Standards Institute.

Capka, J. R. (2004) *'Megaprojects - They Are a Different Breed.' Public Roads 68(1): 2-9.*

Cardoso, J.M. (2005) 'Construction site environmental impact in civil engineering education', *European Journal of Engineering Education*, 30(1), 51-58.

CEC, (2006) *Trams facts 8, The City of Edinburgh Council, available:* http://www.edinburgh.gov.uk/info/20126/trams/177/the_tram_project, [accessed 20 November 2011].

CEC, (2011) *Edinburgh Tram Project, the City of Edinburgh Council report no. CEC/41/11-12/CE, available:* http://www.edinburgh.gov.uk/info/20126/trams/177/the_tram_project, [accessed 20 November 2011].

CEC, (2013) *The tram project, The City of Edinburgh Council, available:* http://www.edinburgh.gov.uk/info/20126/trams/177/the_tram_project, [accessed 9 April 2013].

Chan, W.M.C. and Kumaraswamy, M.M. (2002) 'Compressing construction durations: lessons learned from Hong Kong building projects', *International Journal of Project Management, 20, 23-35.*

Chapman, C. (1997) 'Project risk analysis and management: PRAM, the generic process', *International Journal of Project Management, 15(5):273–281.*

Chapman, C. (2006) 'Key points of contention in framing assumptions for risk and uncertainty management', *International Journal of Project Management, 24(4), 303-313.*

Chapman, C. and Ward, S. (2004) 'Why risk efficiency is a key aspect of best practice projects', *International Journal of Project Management, 22(8)619–32.*

Chapman, R.J. (2001) ‘The controlling influences on effective risk identification and assessment for construction design management’, *International Journal of Project Management, 19(3)147–160.*

Charmaz, K. (2006) *Constructing grounded theory: A practical guide through qualitative analysis,* London: Sage.

Chartered Institute of Building, (2010) A *Report Exploring Procurement in the Construction Industry* [online]; available: http://www.ciob.org/sites/ciob.org.uk/files/Procurement%20in%20the%20Construction%20Industry.pdf (accessed September 2013).

Chau, K. C. (1995) ‘The 3 Gorges Project of China - Resettlement Prospects and problems’, *Ambio*, 24(2) 98-102.

Chen, H., Hao, G., Poon, S.W. and Ng, F.F. (2004) ‘Cost Risk Management in West Rail Project of Hong Kong’, *2004 AACE International Transactions*.

Chen, Z. (2007a) *Buildings and Façade Systems Assessment: an evolution from exclusive ANP modelling to knowledge visualization,* The University of Reading, Reading, UK ISBN: 0-7049-9885-8.

Chen, Z. and Khumpaisal, S. (2008) ‘An Analytic Network Process for Risks Assessment in Sustainable Commercial Real Estate Development’, *Journal of Property Investment and Finance,* Special Issue: Sustainable Commercial Real Estate.

Chen, Z., Khumpaisal, S. (2009) “An analytic network process for risks assessment in commercial real estate development*”, Journal of Property Investment & Finance,* Vol. 27 Iss: 3, pp.238 – 258.

Chen, Z., Li, H. and Wong, C.T.C. (2000) ‘Environmental management of urban construction projects in China’, *Journal of Construction Engineering and Management, 126(4) 320-324.*

Chen, Z., Li, H. and Wong, C.T.C. (2005) ‘Environmental Planning: an analytic network process model for environmentally conscious construction planning’, *Journal of Construction Engineering and Management,* Vol.131 (1), 92-101.

Chen, Z., Li, H., Hong, R., Xu, Q. and Hong, J. (2011) ‘Total environmental risk assessment for international hub airport projects’, *International Journal of Project Management, 29(7) 856-866.*

Chidambaram, R. (2012) ‘Construction delays causing risks on time and cost: a critical review’, *Australasian Journal of Construction Economics and Building*, 12(1)37-57.

Choo, H.J., Hammond, J., Tommelein, D., Austin, S. and Ballard, G. (2004) ‘De-Plan: A Tool for Integrated Design Management’, *Automation in Construction*, 13(3), 313-326.

City of Edinburgh Council, (2004) *Edinburgh Tram Line One Act 2006* [online]; CEC (29 March 2006), available: http://www.legislation.gov.uk/asp/2006/7/contents, [accessed 13 March 2012].

City of Edinburgh Council, (2004) *Edinburgh Tram Line Two Act* 2006 [online]; CEC (29 March 2006), available: http://www.legislation.gov.uk/asp/2006/7/contents, [accessed 13 January 2012].

City of Edinburgh Council, (2013) Prior Approval 12/00915/PA at York Place [online]; Citydev-portal, Edinburgh, available: https://citydev-portal.edinburgh.gov.uk/idoxpa-web/applicationDetails.do, [accessed 19 September 2013].

City of Edinburgh Council, (2013) Tram wires power up [online]; CEC (19 November 2013), available: http://www.edinburgh.gov.uk/news/article/1387/ [accessed 21 November 2013].

Cleland, D. I., and King, W. R. (1983) *Systems analysis and project management* (3rd ed.). Singapore: McGraw-Hill.

Cole, R. J. (2000) ‘Building environmental assessment methods, assessing construction practices’, *Construction Management and Economics*, 18(8), 949-957.

Collis, J. and Hussey, R. (2009) *Business Research: A practical guide for undergraduate and postgraduate students, 3rd edition,* New York, Palgrave Macmillan.

Cooke, R.M. (1991) *Experts in Uncertainty: Opinion and Subjective Probability in Science*. New York: Oxford University Press.

Cooper D., Grey, S., Raymond, G. and Walker, P. (2005) *Project Risk Management Guidelines: Managing Risk in Large Projects and Complex Procurements*, England: John Wiley & Sons Ltd.

Coyle, R.G. (1996) *System Dynamics Modelling – A Practical Approach,* Chapman & Hall.

Coyle, R.G. (2000) 'Qualitative and Quantitative Modelling in System Dynamics: Some Research Questions', *System Dynamics Review, 16(3), 225-244.*

Creswell, J. W., & Clark, V. L. P. (2007) *Designing and conducting mixed methods research,* Thousand Oaks, CA: Sage.

Dainty, A. R. J. (2008) Methodological pluralism in construction management research, IN KNIGHT, A. & RUDDOCK, L. (Eds.), *Advanced Research Methods in the Built Environment,* 1-3, Wiley-Blackwell, Oxford, UK.

Dalton, A. (2010) 135 Changes, £16m bill: latest tram furore [online]; *The Scotsman* (12 April 2010), available: http://www.scotsman.com/news/scotland/top-stories/135-changes-163-16m-bill-latest-trams-furore-1-798991 [accessed 12 September 2011]

Davies, A. and Brady, T. (2000) 'Organisational capabilities and learning in complex product systems: towards repeatable solutions', *Research Policy*, 29(7-8), 931-53.

Davies, A., Gann, D., & Douglas, T. (2009) 'Innovation in megaprojects: systems integration at London heathrow Terminal 5', *California Management Review,* 51(2), 101-125.

Del-Caño, A. and De-La Cruz, M. P. (2002) 'Integrated Methodology For Project Risk Management', *Canadian Journal Of Civil Engineering,* 35(5) pp. 473 – 485.

Denscombe, M. (2003) *The Good Research Guide: For Small-Scale Social Research Projects*, 2nd edition, London: Open University Press.

Development Assistance Committee, (1993) *Development Co-operation*. 1993 Report: DAC/OECD, available: http://www.oecd.org/dac/ [accessed 10 October 2012].

Dul, J. & Hak, T. (2008) *Case study methodology in business research,* Oxford, Elsevier Ltd.

Durkin, J. (1994) *Expert System, Design and Development*, Prentice Hall: Englewood Cliffs, NJ.

Dvir, D. (2005) ‘Transferring projects to their final users: the effect of planning and preparations for commissioning on project success’, *International Journal for Project Management;* 23(4), 257–265.

Dvir, D., Lipovetsky S., Shenhar, A. and Tishler A. (1998) ‘In search of project classification: a non-universal approach to project success factors’, *Research Policy vol.27(9), 915–935.*

Dvir, D., Raz, T. & Shenhar, A.J. (2003) ‘An empirical analysis of the relationships between project planning and project success’, *International Journal for Project Management, 21(2), 89–95.*

EC, (2002) *London Underground Public-Private Partnerships,* (State aid No: N264/2002). European Commission.

EC, (2004b) “Directive 2004/18/EC of the European Parliament and of the Council of 31 March 2004 on the coordination of procedures for the award of public works contracts, public supply contracts and public service contracts.” *Official Journal of the European Union*, No. L 134, 30/04/2004, pp. 114-240.

ECC, (2007a) “Tackling the Unique Challenges of Mega Projects”, *Innovation and Organization, Panel discussion,* 39th ECC Conference, Sept. 2007.

Edinburgh Evening News, (2010) ‘Big freeze puts tram works on hold’ [Online] *Evening News* (9 January 2010), available: http://www.edinburghnews.scotsman.com/news/big-freeze-puts-tram-works-on-hold-1-1227728, [accessed 3 November 2011].

Edinburgh Evening News, (2011) Time's up: Today's the day the first tram should have been running in Edinburgh [Online]; *Evening News* (25 February 2011), available: http://edinburghnews.scotsman.com/12445/Time39s-up-Today39s-the-day.6724290.jp, [accessed 3 November 2011].

Edinburgh Evening News, (2013) Edinburgh trams on Princes Street by Christmas [online]; *Edinburgh Evening News* (17 September 2013), available: http://www.edinburghnews.scotsman.com/news/transport/edinburgh-trams-on-princes-street-by-christmas-1-3096728, [accessed 18 September 2013].

Edinburgh-history.co.uk (2012) History of Trams in Edinburgh [online]; archived from the original on 10 February 2012, available: http://www.edinburgh-history.co.uk [accessed 25 September 2013].

Edwards, P., Roberts I., Clarke, M., Di-Guiseppi, C., Pratap, S., Wentz, R. and Kwan, I. (2002) ‘Increasing response rates to postal questionnaires: systematic review’, *Br Med. J.*; 18(324), 1183-1191.

Eglin, R. (2003) Can Suppliers Bring Down Your Firm? *Sunday Times* (London), Nov. 23, appointments sec., p. 6.

Eisenhardt, K. M. and Graebner, M. E. (2007) ‘Theory building from cases: Opportunities and challenges’, *Academy of management journal, 50(1), 25-32.*

European Commission, (2008) *EVA-TREN: Improved decision-aid methods and tools to support evaluation of investment for transport and energy networks in Europe*, Final Report: Deliverable 6, Brussels.

Faridi, A.S. and El-Sayegh, S.M. (2006) ‘Significant factors causing delay in the UAE construction industry’, *Journal of Construction Management and Economics, 24 (11) 1167-1176.*

Feldmann, E. J. (1985) *Patterns of failure in government megaprojects: economics, politics and participation in industrial democracies*. In: Global dilemmas (Huntington, S. P. and Cooper, R. N., Eds), Univ. Press of America, Lanham, Md., pp. 138–158.

Fellows, R. (2010) ‘New research paradigms in the built environment’, *Construction Innovation: Information, Process, Management,* 10(1), 5-13.

Fellows, R., & Liu, A. (2008) *Research methods for construction, 3rd ed,* Chichester, Wiley-Blackwell.

Ferguson, B. (2010) ‘Soaring costs may force Edinburgh tram line to be cut short’ [online]; *The Scotsman* (19 June 2010), available: http://www.highbeam.com/publications/the-scotsman-p136910/jun-18-2010 [accessed 21 August 2011].

FHWA, (1982) *Social Impact Assessment: A Sourcebook for Highway Planners, Vol. III, Inventory of Highway Related Social Impacts,* Federal Highway Administration, U.S. Department of Transportation, Washington, DC.

Finnerty, J. D. (2007) *Project Finance: Asset-Based Financial Engineering,* 2nd edition, John Wiley & Sons.

Floricel, S. and Miller, R. (2001) 'Strategizing for anticipated risks and turbulence in large-scale engineering projects', *International Journal for Project Management; 19(8):445–455.*

Flyvbjerg, B, (2007b) 'Policy and Planning for Large-Infrastructure Projects: Problems, Causes, and Cures', *Environment and Planning B: Planning and Design,* 34(4), 578-597.

Flyvbjerg, B. (2006) 'From Nobel Prize to Project Management: Getting Risks Right', Project *Management Journal,* 37(3), 5-15.

Flyvbjerg, B. (2007c) 'Cost overruns and demand shortfalls in urban rail and other infrastructure', *Transportation Planning Technology, Vol. 30(1), 9-30.*

Flyvbjerg, B. **(**2009) 'Survival of the unfit test: why the worst infrastructure gets built- and what we can do about It.*', Oxford Review of Economic Policy*, 25(3), 344-367.

Flyvbjerg, B., Bruzelius, N. & Rothengatter, W. (2003a) *Megaprojects and risk : an anatomy of ambition,* Cambridge, Cambridge University Press.

Flyvbjerg, B., Bruzelius, N. and Rothengatter, W. (2003) *Megaprojects and risk.* Cambridge University Press, Cambridge.

Flyvbjerg, B., Holm M., K. S., and Buhl, S. L. **(**2000) 'How common and how large are cost overruns in transport infrastructure projects?' *Transport Reviews,* 23(1), 71-88.

Flyvbjerg, B., Holm, M. K. S. and Buhl, S. L. (2002) 'Cost underestimation in public works projects: error or lie?' *Journal of the American Planning Association,* 68(3), 279-295.

Forrester, J.W. (1961), *Industrial Dynamics,* MIT Press: Cambridge, MA.

Forrester, J.W. (1971) *Principles of Systems,* Productivity Press: Cambridge.

Forrester, J.W. and Senge, P. (1980) 'Tests for building confidence in System Dynamics Models', *TIMS Studies in the Management Sciences*, Vol 14, pp209-228.

Frame, J.D. (2003) '*Managing risk in organizations: A guide for managers',* Washington: Jossey-Bass, 69, 70, 79-81 pp., ISBN 0-7879-6518-9.

Fraser, R. M. (1990) ‘Compensation for extra preliminary and general (P & G) costs arising from delays, variations and disruptions: The palmiet pumped storage scheme’, *Tunnelling and Underground Space Technology, 5(3), 205-216.*

Frick, K. T. (2008) *The cost of the technological sublime: Daring ingenuity and the new San Francisco–Oakland Bay Bridge*. In H. Priemus, B. Flyvbjerg, & B. v. Wee (Eds.), Decision-making on mega-projects: Cost–benefit analysis, planning and innovation (pp. 239–262). Cheltenham, UK: Edward Elgar Publishing.

Frimpong, Y., Oluwoye, J. and Crawford, L. (2003) “Causes of delay and cost overruns in construction of groundwater projects in a developing countries: Ghana as a case study”. *International Journal of Project Management,* 21(5), 321-326.

Fugar, F. D. K. and Agyakwah-Baah, A. B. (2010) “Delays in building construction projects in Ghana”, *Australasian Journal of Construction Economics and Building, 10 (1/2)* 103-116.

Funderburg, R. G., Nixon, H., Boarnet, M. and Ferguson, G. (2010) “New highways and land use change: results from a quasi-experimental research design”, *Transportation Research Part A: Policy and Practice* 44(2), 76-98.

Galloway, P.E. (2009) ‘Design-Build/EPC Contractor’s Heightened Risk: Changes in a Changing World’. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction* 1(1), 7-15.

Gandy, M. (2002) ‘*Concrete and clay: Reworking Nature in New York City’*, Cambridge, Mass: MIT Press.

Gannon, M. J. (2007) ‘*The Use of Business Cases in Project Decision-making’*, PhD dissertation, The University of Leeds.

Garry, G. (2005) *‘Risk Factors Leading to Cost Overrun in Highway Projects’*, Queensland University of Technology, Australia.

Garzia, R.F. and Garzia, M.R. (1990) *‘Network Modelling, Simulation, and Analysis’*, Marcel Dekker, NY.

Gerring, J. (2007) ‘*Case study research: Principles and practices’,* Cambridge, Cambridge University Press.

Geurs, K. T., Boon, W., & Van Wee, B. (2009) 'Social impacts of transport: literature review and the state of the practice of transport appraisal in the Netherlands and the United Kingdom', *Transport reviews,* 29(1), 69-90.

Ghosh, S., and Jintanapakanont, J. (2004) "Identifying and assessing the critical risk factors in an underground rail project in Thailand: A factor analysis approach." *Int. J. Proj. Manage., 22(8), 633–643.*

Gilbert, R. (2008) 'Bilfinger Berger Canada files suit against Metro Vancouver over Capilano-Seymour project', *Journal of Commerce* [online]; August 4, 2008, available: http://www.journalofcommerce.com/article/id29663 [accessed 10 January 2013].

Glaeser, E.L. and Ward, B.A. (2006) "The causes and consequences of land use regulation: evidence from Greater Boston", *Journal of Urban Economics,* 65(3), 265-278.

Godfrey, P.S. (1996), *Control of risk: A guide to the systematic management of risk for construction,* London, Construction Industry Research and Information Association, Special Publication 125.

Goemans, T. and Visser, T. (1987) *The Delta Project. The Netherlands Experience with a Megaproject for Flood Protection,* Technology in Society, 9 (1), pp. 97-11

Gould, F. E. (2002) *'Managing the construction process: Estimating, scheduling, and project control',* Upper Saddle River, NJ: Prentice Hall.

Greenberger, M., Crenson, M. A. and Crissey, B. L. (1976) *'Models in the Policy Process',* Russell Sage Foundation, New York.

Griffith, A. (1994) '*Environmental Management in Construction',* London: The MacMillan Press.

Grimsey, D. & Lewis, M. K. (2002) 'Evaluating the Risks of Public Private Partnerships for Infrastructure Projects', *International Journals of Project Management,* 20, 107-188.

Grimsey, D. & Lewis, M. K. (2005) 'Are Public-Private Partnerships Value for Money: Evaluating Alternative Approaches and Comparing Academic and Practitioner Views', *Accounting Forum*, 29(4), 345-378.

Gunton, T. (2003) ‘Megaprojects and regional development: pathologies in project planning’, *Regional Studies*, vol. 37, (5) 505-519.

Hall, P. (1980) *Great planning disasters*, Univ. of Calif. Press, Berkeley, California.

Harris, E.C. (2013) ‘Supply Chain Analysis into the UK Construction Sector [online]; available: www.bis.gov.uk [accessed 29 November 2013]

Harvie, C. (2009) ‘A year with Salmond, Scottish Affairs, No 65, autumn 2008 [online], available:http://www.Scotishaffairs.org/onlinepub/sa/harviesa65autumn08.html, [accessed 29 November 2013].

Haynes, W. (2002) ‘Transportation at the millennium: in search of a megaproject lens’, *Review of Policy Research*, 19 (2), 62–64.

Henderson, D. (2009) ‘Edinburgh trams saga is far from over’ [online]; *The Herald*, (11 December 2009), available: http://www.heraldscotland.com/blogs/scotland-now/edinburgh-trams-saga-is-far-from-over-1.991682 [accessed 10 March 2011].

Henderson, D. (2010a) ‘Tram scheme row ramps up a gear’ [online]; *The Herald* (4 April 2010), available: http://www.heraldscotland.com/news/transport-environment/trams, [accessed 27 September 2012].

Henderson, D. (2010b) ‘Trams running two years late and £100m over budget’ [online]; *The Herald* (12 April 2010), available: http://www.heraldscotland.com/news/ [accessed 27 September 2012].

Hendrickson, C. (1998) ‘*Project Management for Construction: Fundamental Concepts for Owners, Engineers, Architects and Builders’*. Carnegie Mellon University: Pittsburgh.

Hertogh, M., Baker, S., Staal-Ong, P. L. and Westerveld, E. (2008) *Managing Large Infrastructure Projects. Research on Best Practices and Lessons Learnt in Large Infrastructure Projects in Europe.* Baarn: AT Osborne.

Hertogh, M., Baker, S., Staal-Ong, P. L., & Westerveld, E. (2008) *Managing large infrastructure projects: Research on best practice lessons learnt in large infrastructure projects in Europe*. Bennebroek: AT Osbourne.

Hilber, C.A. and Robert-Nicoud, F. (2013) ‘On the origins of land use regulations: theory and evidence from US metro areas’, *Journal of Urban Economics* 75(1), 29-43.

Hillson, D. (2002) ‘Extending the risk process to manage opportunities’, *International Journal of Project Management* 20(3), 235–240.

HM Treasury, (2004) *Management of Risk Principles and Concepts*. London: UK HM Treasury.

Hodge, G. A. (2004) The Risky Business of Public-Private Partnerships. *Australian Journal of Public Administration* 63[4], 37-49.

HS2 Ltd, (2009) ‘High Speed Rail London to the West Midlands and Beyond: HS2 Cost and Risk Model’, Available: http://www.railwaysarchive.co.uk/documents/HS2_HS2CostAndRiskModel2010.pdf [accessed 29 September 2012].

http://www.edinburghnews.scotsman.com/news/, [accessed 21 September 2013].

Husnan, S. S. M. (2000) ‘Studi Kelayakan Proyek’, Yogyakarta.

Ingold, T. (2000) *‘Ancestry Generation Substance, Memory, Land, in the Perception of the Environment’* Ed. London: Routledge.

International Organization for Standardization, Retrieved 29 March 2009, from www.iso.org

ISO, (2009) *BS/ISO31000:2009 - Risk Management Principles and Guidelines*, International Organization for Standardization.

ISO/DIS 31000 (2008), “Risk management Principles and guidelines on Implementation.”

Jafaari, A. (2004) *‘Modelling of large projects In: Morris PWG, Pinto JK, editors. The Wiley guide to managing projects’*, Hoboken, NJ: John Wiley & Sons Inc.; p. 288–320.

Jennings, W., and Martin, L. (2011) ‘Governing Mega-Events: Tools of Security Risk Management for the London 2012 Olympic Games and FIFA 2006 World Cup in Germany’, *Government and Opposition* 46(2): 192-222.

Johnson, S. (2008) ‘Edinburgh tram network falls victim to credit crunch’ [online]. *The Daily Telegraph* (19 November 2008), available: http://www.telegraph.co.uk/news/uknews/scotland/3485321/Edinburgh-tram-network-falls-victim-to-credit-crunch.html [accessed 11 January 2012].

Jones, T. and Brinkert, R. (2008) '*Conflict Coaching, Conflict Management Strategies and Skills for the Individual'*, London: Sage publications.

Jyh-Bin Y. (2010) 'Causes of Delay in the Planning and Design Phases for Construction Projects', *Journal of Architectural Engineering*, pp.80-83.

Kaliba, C., Muya, M. and Mumba, K. (2009) 'Cost escalation and schedule delays in road construction projects in Zambia', *International Journal of Project Management*, 27(5), 522-531.

Kane, M. (2001*) 'Inventory Controls Re-examined: Attacks Reveal Vulnerability of Just-in-Time',* Cleveland Plain Dealer, Oct. 29, sec. C, p.4.

Kang, S. W. (2010) 'Causes, effects and methods of minimizing Delays in construction projects', [online] available: http://www.efka.utm.my/thesis/IMAGES/3PSM/2010/JSB-3/kangsikweiaa060080d10ttt.pdf [accessed 11 January 2012].

Kapila, P., and Hendrickson, C. (2001) 'Exchange rate risk management in international construction ventures', *J. Manage., Eng.*, 17(4), 186–191.

Keraminiyage, K.P., Amaratunga, R.D.G. and Haigh, R.P. (2005) *'A capability maturity approach for construction projects improvement: use of case studies approach',* 5th Postgraduate research conference, University of Salford, April 13th-15th, pp. 465-475

Kettis, M. (2004) '*The Challenge of Political Risk Exploring the Political Risk Management of Swedish Multinational Corporations',* Department of Political Science, Stockholm University, Stockholm Studies in Politics.

Kikwasi, G.J. (2012) 'Causes and effects of delays and disruptions in construction projects in Tanzania'. *Australasian Journal of Construction Economics and Building*, Conference Series, pp. 52-59.

Klein, J. H, Cork, R.B. (1998) 'An approach to technical risk assessment', *Int. J Proj Manage;* 16(6):345–351.

Kolltveit, B. J., & Grønhaug, K. (2004) 'The importance of the early phase: The case of construction and building projects', *International Journal of Project Management,* Vol. 22(7), 545–551.

Kumaraswamy, M. M. & Morris, D. A. (2002) ‘Build-Operate-Transfer-Type Procurement in Asia Megaprojects’, *Journal of Construction Engineering and Management,* 128(2), 93-102.

Kytle, B., and Ruggie G.J. (2005) ‘Corporate Social Responsibility as Risk Management, A Model for Multinationals’. *Corporate Social Responsibility Initiative Working Paper* No. 10, Cambridge, MA: John F. Kennedy School of Government, Harvard University.

Law, A.M. (2003) ‘Model Verification and Validation’, *Proceedings of the 2003 Winter Simulation Conference,* (eds), pp. 66-70.

Leask, D. (2010) Tram chiefs admit: we have no idea what final bill will be [online], *The Herald* (19 June 2010), available: http://journalisted.com/david-leask?allarticles=yes, [accessed 12 June 2011].

Lebo, J. & Schelling, D. (2001) ‘Design and Appraisal of Rural Transport Infrastructure’, *World Bank Technical Paper 496,* Washington D.C.: World Bank.

Lee, L. (2008) ‘Cost Overrun and Cause in Korean Social Overhead Capital Projects: Roads, Rails, Airports, and Ports’, *Journal of Urban Planning and Development* 134(2): 59-62.

Lerche, I. and Glaesser, W. (2006) *Environmental Risk Assessment: Quantitative Measures, Anthropogenic Influences*, Human Impact Springer Berlin Heidelberg Ltd.: US.

Leung, H.M., Chuah, K.B. and Tummala, V.M.R. (1998) ‘A based System for Identifying Potential Project Risks’ Omega: *International Journal of Management Science*, 26 (5), 623-638.

Leveson, N. (2000), “Intent Specifications: An Approach to Building Human-Centered Specifications,” IEEE Transactions on Software Engineering, 26 (1), January, pp 15–35. Available: http://sunnyday.mit.edu/papers/intent-tse.pdf.

Levitt, R.E., Logcher, R.D., and Quaddumi, N.H. (1998) ‘Impact of Owner-Engineer Risk Sharing on Design Conservatism’, *ASCE Journal of Professional Issues in Engineering*, Vol. 110, 1984, pp. 157-167.

Ling, Y. Y. and Lim, H. K. (2007) “Foreign firms financial and economic risk in China”, *Eng., Constr., Archit. Manage.*, 14(4), 346–362.

Long, N.D., Ogunlana, S., Quang, T. and Lam, K.C. (2004) ‘Large construction projects in developing countries: a case study from Vietnam’, *International Journal of Project Management,* 22(7), 553-561.

Loosemore, M., Raftery, M., Reilly, C. and Higgon, D. (2006) *‘Risk Management in Projects*, 2nd edition’. Taylor and Francis, Abingdon.

Lor, P. (2011) ‘Preparing for research: meta-theoretical considerations [online], available: http://pjlor.files.wordpress.com/2010/06/chapter-4-draft-2011-04-152.pdf. [accessed November 2013]

Love, G. and Back, G. (2000) ‘Model Verification and Validation for Rapidly Developed Simulation Models: Balancing Cost and Theory’, *Proceedings of the 18th International Conference of the System Dynamics Society,* Bergen, Norway, August 6-10.

Love, P. E. D., Mandal, P., Smith, J., & Li, H. (2002) ‘Modelling the dynamics of design error induced rework in construction’, *Construction Management and Economics,* 18(5), 567-574.

Love, P.E.D., Holt G.D, Shen L.Y., Lib H., Irani Z. (2002) ‘Using systems dynamics to better understand change and rework in construction project management systems’, *International Journal of Project Management,* 20 (6) 425-436.

Lu, Y. (2004) *Risk Management for Large-scale Infrastructure Projects in China* Beijing: Department of Construction Management, Tsinghua University.

Luke (14:28) *The Holy Bible, New King James Version (NKJV, 1982).* Thomas Nelson, Inc.

Mackie, P., Nellthorp, J., & Laird, J. (2003) *‘Toolkit for the Economic Evaluation of World Bank Transport Projects’*, Institute for Transport Studies, University of Leeds.

Major Projects Association (2008) *The Investor, the Board and major Projects Report of seminar 144* held on 12th November 2008 at the Council Chamber, Savoy Place, London.

March, M.C. (1992) ‘Construction and environment, a management matrix’, *Chartered Builder*, 4, pp.11-12.

Marcinek, K., Foltyn-Zarychta, M., Pera, K., Saługa, P. and Tworek, P. (2010) Ryzyko w finansowej ocenie projektów inwestycyjnych, Wybrane zagadnienia, Katowice Uniwersytet Ekonomiczny w Katowicach. ISBN 9788372466341.

Marshall, C. (2010) Trams shocker: Residents face window washing ban over electrocution fears [online], *The Scotsman* (4 March 2010), available: http://www.edinburghnews.scotsman.com/news/trams-shocker-residents-face-window-washing-ban-over-electrocution-fears-1-1232079, [accessed 20 November 2011].

Marshall, C. (2010), Shambolic' tram project is up to two years behind [online], *The Scotsman* (25 January 2010), available: http://www.scotsman.com/news/scotland/top-stories/shambolic-tram-project-is-up-to-two-years-behind-1-1228943, [accessed 20 March 2012].

Marshall, C. (2011) Trams spend so far hits £440m [online]. *The Scotsman* (13 May 2011), available: http://www.scotsman.com/news/tram-spend-so-far-hits-163-440m-1-1630547, [accessed 19 April 2011].

Mawby, D. Stupples, D. (2002) ‘Systems Thinking for Managing Projects’, *Engineering Management Conference 2002.* IEMC '02 (pp. 344–349).

McHarg, I., (1971) ‘*Design with Nature, Doubleday and Company’*, Inc., Garden City, New York, NY.

McIntosh, L. (2009) Tram works turn Edinburgh into war zone [online], The *Times* (27 July 2009), available: http://www.thetimes.co.uk/tto/news [accessed 09 January 2011].

McKellar, R., (2010) ‘*A Short Guide to Political Risk’*. Farnham: Gower Publishing Limited.

McTague, B., and Jergeas, G. (2002) ‘Productivity improvement on Alberta major construction projects, Phase I-Back to Basics’, *Construction Productivity Improvement Report, Project Evaluation Tool*, May 2002, Alberta Economic Development Board.

MEGAPROJECT COST ACTION TU1003, (2012) *Megaproject Portfolio of case studies,* (1/08/2012).

Merrow, E. W. (1988) *Understanding the outcomes of megaprojects*, Santa Monica, CA.

Merrow, E. W. (2011) *Industrial megaprojects: Concepts, strategies and practices for success*. Chichester: John Wiley.

Merrow, E. W., McDonnell, L.M. and Arguden, R.Y. (1988) *'Understanding the outcome of mega-projects: A quantitative analyse of very large civilian projects'*. Santa Monica: The Rand Corporation.

Mihm, J.; Loch, C., and Huchzermeier, A. (2003) 'Problem-solving oscillations in complex engineering projects', *Management Science,* Vol. 49(6), 733–750.

Miller, D. (2013) Slow tram test flanked by 21 contractors [online], *Edinburgh Evening News* (9 October 2013), available: http://www.edinburghnews.scotsman.com/news/transport/, [accessed 15 October 2013[.

Miller, R. and Lessard, D. (2001) '*The strategic management of large engineering projects: shaping institutions, risks and governance'*, Cambridge, MA: MIT Press; 2001.

Miller, R. and Lessard, D. (2001) 'Understanding and managing risks in large engineering projects', *Int J Project Manage*; 19(8):437–443.

Millet, C. (2009) Carillion hits delay on £500m Edinburgh Tram works. Contracts Journal, 8 May, 2009.

Moenaert, R.K., Meyer, A.D., Souder, W.E., Deschoolmeester, D. (1995) 'R-and-D marketing communication during the fuzzy front-end', *IEEE Transactions on Engineering Management* 42(3): 243-258.

Mohammad, A., Mustafa, Z. M. and Jamal, F. A. (1991) 'Project Risk Analytic Assessment Using the Hierarchy Process', *Transactions on Engineering Management,* 38 (1).

Mohd, R.B.M. (2010) 'The Factors and Effect of Delay in Government construction Project (Case Study In Kuantan), *International Journal of Project Management*, pp. 32-45.

Molenaar, K. R. (2005) 'Programmatic cost risk analysis for highway megaprojects', *Journal of Construction Engineering & Management*, 131(3), 343-353.

Moore, D. (1998) ‘Many World Bank Projects Haunted by Grand Delusions’, *Forum for Applied Research and Public Policy,* vol. 13(1), 26-31.

Moore, D. R. and Abadi, M. (2005) ‘Virtual Team Working and Associated Technologies within the UK Construction Industry’, *Architectural Engineering and Design Management,* 1(1), 21-32.

Mortanges, C. and Allers, V. (1996) ‘Political risk assessment: theory and the experience of Dutch corporations’, *International Business Review,* 5(3): 303-318.

Mullay, S. (1996) ‘*The Edinburgh Encyclopaedia’*, Mainstream Publishing. pp. 348–351, ISBN 1851587624.

Mumford, (2011) Edinburgh Trams delivered almost two hours late. The deadline news (17 October 2011), available: http://www.deadlinenews.co.uk/2011/10/17/edinburgh-trams-delivered-almost-two-hours-late/, [accessed 23 June 2012].

Murphy, S. and Salzman, J. (2008) *More Big Dig charges brought,* Boston Globe.

Murray, L. (2007) ‘*The Will to Improve Governmentality: Development and the Practice of Politics’,* Durham, and London: Duke University Press.

NAO (2005) *Department for Transport: Progress on the Channel Tunnel*. (Report by the comptroller and auditor general HC 77 Session 2005-2006).

NAO, (2004a) *London Undergound: Are the Public Private Partnerships Work Successfully? (Rep. No. HC 644, Session 2003-04).* London: National Audit Office.

NAO, (2004b) *Refinancing Public Private Partnership for National Air Traffic Services (Rep. No. HC 157, Session 2003-04).* London: National Audit Office.

Naseena J. and Bhatt, M.S. (2006) ‘Modelling and Simulating the Dynamics in Project Monitoring and Earned Value analysis’, *Journal of Advances in Management Research,* 3(1), 26-43.

National Audit Office, (2007) *Estimating and monitoring the costs of building roads in England,* Department for Transport Audit report.

NCHRP, (2001) National Cooperative Highway Research Program, Contractor’s Final Report, NCHRP Web Document 31 (Project B25-19).

New Scientist (1990), “High-speed protest (Newspaper article)”. New Scientist, no. 1719, June 2, 1990.

Ng, H.S., Pena-Mora, F. and Tamaki, T. (2007) ‘Dynamic Conflict Management in Large-Scale Design and Construction Projects’. *Journal of Management in Engineering,* Vol. 23(2), 252-266.

Ng, S.T., Mak, M.M., Skitmore, R.M. and Vamam, M. (2001) “The predictive ability of Bromilow’s time-cost model”, *Construction Management and Economics,* 19 (2), 165-173.

Nguyen, L. D. & Ogunlana, S. O. (2005) ‘Modelling the Dynamics of an Infrastructure Project’, *Computer-aided Civil and Infrastructure Engineering,* 20(4), 265-279.

Norrman, A. and Jansson, U. (2004) ‘Ericsson’s Proactive Supply Chain Risk Management Approach after a Serious Sub-Supplier Accident’, *International Journal of Physical Distribution & Logistics Management* 34(5), 434–456.

Office of Government Commerce, (2001) *Getting value for money from procurement: how auditors can help*. Office of Government Commerce: Norwich, UK. Eds., p. 78.

Ofori, G. (1992) ‘The Environment: The Fourth Construction Project Objective?’ *Construction Management and Economics,* 10(5), 369-395.

Ogunlana, S., Lim, J., Saeed, K. (1998) ‘DESMAN: a dynamic model for managing civil engineering projects’, *Computers and Structures,* 67(5), 401 - 419.

Ogunlana, S.O., Sukhera and Li, H., (2003) ‘System Dynamics Approach to Exploring Performance Enhancement in a Construction Organization’, *J. Constr. Engrg and Mgmt,* 129(5), 528-536.

Olander, S, and Landin, A. (2005) ‘Evaluation of stakeholder influence in the implementation of construction projects’, *International Journal of Project Management*; 23(4):321–328.

Olsson, R. (2007) ‘In search of opportunity management: is the risk management process enough’, *International Journal of Project Management*; 25(8)745–752.

Opler, T. C., Saron M., Titman S. (1997) ‘Designing Capital Structure to Create Shareholder Value’, *Journal of Applied Corporate Finance,* 10 (1), 4-19.

Owen, (2004) *“Mega Project Excellence: Preparing for Alberta’s Legacy; An Action Plan*”, Alberta Economic Council, December 10, 2004.

PAC, (2002b) *The Channel Tunnel Rail Link (Rep. No. HC 630, Session 2002).* London: Public Account Committee.

PAC, (2003) *The Public Private Partnership for National Air Traffic Services Ltd, Report of Public Account Committee, House of Common (Rep. No. HC 80, Session 2002-03).* London: Public Account Committee.

PAC, (2005b) *PFI: The STEPS Deal, Report of Public Account Committee, House of Commons (Rep. No. HC 553, Session 2004-05).* London: The Stationery Office.

PAC, (2006a) *The BBC's White City 2 Development, Report of Public Accounts Committee,* House of Commons London: London: The Stationery Office.

PAC, (2006b) *The refinancing of the Northfolk and Norwich PFI Hospital, Report of Public Accounts Committee, House of Commons (Rep. No. HC 964*). London: The Stationery Office.

Park, M. & Pena-Mora, F. (2004) ‘Dynamic Change Management for Construction: Introducing the Change Cycle into Model-based Project Management, *System Dynamics Review,* 20, 170, Productivity Press, Portland, Oregon, 413p.

Park, M., Nepal, M.P, and Dulaimi, M.F. (2004) ‘Dynamic modelling for construction innovation’, *Journal of Management in Engineer*, 20(4), 170-177.

Pearce, D. (1998) ‘Cost-Benefit Analysis and Environmental Policy’, *Oxford Review of Economic Policy*, 14(4), 84-100.

Pena-Mora, F. and Park, M. (2001) ‘Dynamic Planning for Fast-Tracking Building Construction Project’, J*ournal of Construction Engineering and Management*, 127 (6), 445-456.

Perminova O, Gustanfsson M, Wikstrom K. (2008) ‘Defining uncertainty in projects: a new perspective’. *International Journal of Project Management*; 26:73–79.

Perminova, O.; Gustafsson, M. and Wikström, K. (2008) ‘Defining uncertainty in projects: a new perspective; *International Journal* of *Project Management’*, 26 (1), 73-79.

Pich, M.T., Loch, C.H., and De Meyer, A. (2002) ‘On uncertainty, ambiguity, and complexity in project management’, *Management Science* 48(8): 1008–1023.

Pickard, A. J. (2007) '*Research methods in information'*, London: Facet Publishing.

Pickavance, K. (2005) '*Delay and disruption in construction contracts'*, 3rd edition, Informa- Legal Publishing, UK.

Pollack, J. (2007) 'The changing paradigms of projects management', *International Journal of Project Management,* 25(3), 266-274.

Poole, R. W. and Peter, S. (2011) Transportation Mega-Projects and Risk Reason, Foundation Policy Brief 97.

Priemus, H., Flyvbjerg B. and Bert van W. (Eds). (2008) '*Decision-Making On Mega-Projects: Cost–benefit Analysis, Planning, and Innovation',* Cheltenham: Edward Elgar.

Priemus, H., Flyvbjerg, B. and Wee, B. v. (2008) '*Decision Making on Mega- Projects: Cost-Benefit Analysis, Planning and Innovation'*, 1 ed Cheltenham: Edward Elgar Publishing Limited, pp. 120-327.

Project Management Institute, (2000) '*A Guide to the Project Management Body of knowledge (PMBOK)*'. 2000 Edition, Pennsylvania.

Project Management Institute, (2004) '*A guide to the project management body of knowledge (PMBOK)'.* Third Edition, Upper Darby, PA.

Project Management Institute, (2009) *'Practice Standard for Project Risk Management'.* Inc., Newtown Square, pp.72-76.

Proverbs, D. & Gameson, R. (2008) '*Case study research',* Advanced research methods in the built environment, Chichester,Wiley-Blackwell.

Pryke, S. and Smyth, H. (2006) *'The Management of Complex Projects'.* Oxford: Blackwell.

Rahmandad, H. and Sterman, J.D. (2008) 'Heterogeneity and network structure in the dynamics of diffusion: Comparing agent-based and differential equation models', *Management Science* 54(5): 998-1014.

Rail Staff, (2013) Edinburgh wires go up [online], *Rail Staff* (21 June 2013), available: http://www.railstaff.co.uk/2013/06/21/edinburgh-wires-go-up/, [accessed 12 July 2013].

Railway-technology, (2013) Major Tram track route completed [online], *Railway-technology* (11 March 2013) available: http://www.railway-technology.com/news/newsmajor-edinburgh-tram-track-route-completed [accessed 15 March 2013].

Randers, J. (1980) '*Elements of the System Dynamics Method'*, Cambridge, MA: The MIT Press.

Ranganath, B. J. and Rodrigues, L.L.R. (2008), *'System dynamics: Theory and case studies'*, I.K. International Publishing House Pvt. Limited, New Delhi.

Raz, T, Michael, E. (2001) 'Use and benefits of tools for project risk management', *International Journal of Project Management;* 19(1), 9–17.

Reilly, J. & Brown, J. (2004) 'Management and Control of Cost and Risk for Tunneling and Infrastructure Projects In Proc.', *International Tunnelling Association Conference,* Singapore.

Reilly, J. (2005) 'Cost Estimating and Risk-Management for Underground Projects', *In Proc. International Tunnelling Association Conference,* Istanbul.

Reinersten, D. and Reinersten, D. (2000) 'Watch your step! Here comes the megaproject trap', *Electronic Design,* vol. 48, p. 58.

Repenning, N.P. (2003) 'Selling System Dynamics to (Other) Social Scientists', *System Dynamics Review* 19(4): 303-327.

Rezgui, Y. & Miles, J. (2010) 'Exploring the Potential of SME Alliances in the Construction Sector', *Journal of Construction Engineering & Management,* 136(5), 558-567.

Richardson, G.P. and Pugh III, A.L. (1981) *Introduction to System Dynamics Modeling With Dynamo,* the MIT Press, Cambridge.

Roberts E.B. (1964) *The Dynamics of Research and Development,* Harper & Row: New York.

Rodrigues, A. & Bowers, J. (1996) 'The Role of System Dynamics in Project Management', *International Journal of Project Management,* 14(4), 213-220.

Rooke, J. A. and Kagioglou, M. (2007) 'Criteria for evaluating research: the unique adequacy requirement of methods', *Construction management and economics*, 25(9), 979 – 987.

Ross K, Cartwright P, Novakovic O, (2006) '*NF1: A guide to modern methods of construction',* NHBC Foundation report. Garston, Watford, IHS BRE Press.

Rowson, J. (2008) Final contracts awarded for Edinburgh Tram [online], New Civil Engineer (16 May 2008), available: http://www.nce.co.uk/final-contracts-awarded-for-edinburgh-tram/1346152.article, [accessed May 2013].

Royer, P.S. (2000) 'Risk Management: The Undiscovered Dimension of Project Management', *Project Management Journal*, 31(1), 6-13.

Ruuska, I., Artto, K., Aaltonen, K. and Lehtonen, P. (2009) 'Dimensions of distance in a project network: Exploring Olkiluoto 3 nuclear power plant project', *International Journal of Project Management*, 27(2), 142-153.

Saaty, T. L. (2005) '*Theory and Applications of the Analytic Network Process'*, Pittsburgh, PA: RWS Publications, 4922 Ellsworth Avenue, Pittsburgh, PA 15213.

Saaty, T. L. and Vargas, L. (2005a) "The possibility of group welfare functions," *The International Journal of Information Technology and Decision Making*, 4(2), 167-176

Saaty, T. L., & Vargas, L. G. (2006) '*Decision Making with the Analytic Network Process Economic, Political, Social and Technological Applications with Benefits, Opportunities, Cost and Risk'.* United States of America: Springer.

Saaty, T.L. (1996) *'Decision Making with Dependence and Feedback: the Analytic Network Process'.* RWS Publications, Pittsburgh, USA ISBN: 0-9620317-9-8.

Saaty, T.L. and Vargas, L.G. (1991) '*Prediction, Projection and Forecasting',* Boston: Kluwer Academic.

Saaty, T.L. and Vargas, L.G. (2000) '*Models, Methods, Concepts and Applications of the Analytic Hierarchy Process',* Boston: Kluwer Academic Publishers.

Safer Ali et al (2012) 'Time waste and delay in construction projects', *NICMAR-journal of construction management,* 27(4), 64-75.

Sands, B. R., (1992) '*InterCity Express: A technical and commercial assessment',* Univ. Calif. Transp. Center, Berkeley, California High Speed Rail Service Working Paper, no. 101.

Sargent, R.G. (2003) ‘Verification and Validation of Simulation Models’; *Proceedings of the 2003 Winter Simulation Conference*, S. Chick, P. J. Sanchez, D. Ferrin, and D. J. Morrice, (eds.), pp. 37-48.

Saunders, M., Lewis, P. & Thornhill, A. (2009) ‘*Research methods for business students’* (5th edition); Harlow, Pearson Education.

Schaufelberger, J. E. (2005) ‘Risk Management on Build-Operate-Transfer Projects’, *Broadening Perspectives Construction Congress’* April 5–7 2005, San Diego, California.

Scholten, B. (2006) *“The Netherlands Ex Post vs. Ex Ante, Overlooked issues, ECOTRANS experience”*, EVA-TREN 1st Experts’ Workshop on transport and energy appraisal in Europe: Theoretical basis in perspective, Lausanne, November 7, 2006.

Schultze, G. and Miller, C. (2004) ‘The search for meaning and career development’, *Career Development International*, 9 (2), 142-152.

Senge, P. (1990) ‘*The Fifth Discipline: The Art and Practice of the Learning Organization’*, New York. Doubleday.

Seung H. H., Yun S., Kim H., Kwak, Y .H., Park, H. K., and Lee H. S., (2009) ‘Analyzing Schedule Delay of Mega Project: Lessons Learned From Korea Train Express’, *IEEE, Transactions on Engineering Management*, 56(2).

Severin, C. (2011) ‘Edinburgh tram project may yield less network for more money [online], the guardian (23 June 2011), available: http://www.theguardian.com/uk/, [accessed 15 November 2011].

Sewell, W.R.D. (1987) The Politics of Hydro-Megaprojects: Damming with Faint Praise in Austrialia, New Zealand, and British Columbia, *Natural Resources Journal*, 27(3),PP.497-532.

Sexton, M. & Barrett, P. (2003) ‘Appropriate innovation in small construction firms’, *Construction Management and Economics,* 21(6), 623-633.

Seymour, D. and Rooke, J. (1995) ‘The culture of the industry and the culture of research’, *Construction management and economics*, 13(6), 511 – 523.

Shaikh A.W., Muree M. R. (2010) *'Identification of critical delay factors in construction'*, Institute of Mathematics and computer science, University of Sindh, Jamshoro, pp. 11-14.

Shaoul, J. (2005) *'A Critical Financial Analysis of the Private Finance Initiative: Selecting A Financing Method or Allocating Economic Wealth',* Critical Perspectives on Accounting, 16, 441-471.

Shen L.Y. (1997) 'Project risk management in Hong Kong', *International Journal of Project Management*, 15 (2), 101–105.

Shen, L. Y. and Tam, W. Y. V. (2002) 'Implementing of environmental management in the Hong Kong construction industry', *International Journal of Project Management*; 20 (7), 535-543.

Shenhar, A. J. (2001) 'One size does not fit all projects: Exploring classical contingency domains, *Management Science*, Vol. 47(3), 394–414.

Shin, H., Watanabe, H., and Kunishima, M. (1989) 'A new methodology for evaluating a new construction technology from the viewpoint of constructability', *Proceedings of the 47th Doboku Gakkai Rombun-Hokokushu*, Japan Society of Civil Engineers April 1989, JSCE, Japan, p4.

Singh, R. (2009) **'***Delays and Cost Overruns in Infrastructure Projects: An Enquiry into Extents, Causes and Remedies',* Department of Economics, Delhi School of Economics, Centre for Development Economics, Working Paper No. 181.

Sinha, K. C., & Labi, S. (2011) *'Transportation decision making: Principles of project evaluation and programming'* Wiley. com.

Smith, D. (2006) Leveraging Government- the Role of Public-Private Partnerships, *In: the 7th Annual Public Private Partnerships European Summit*.

Smyth H.J. and Morris, P.W.G. (2007) 'An Epistemological Evaluation of Research into Projects and Their Management: Methodological Issues, *International Journal of Project Management*, 25(4), 423-436.

Soderholm A., (2008) 'Project management of unexpected events', *International Journal of Project Management*; 26(1):80–86.

Sommer, S. C., and Loch, C. H. (2004) ‘Selectionism and learning in projects with complexity and unforeseeable uncertainty’, *Management Science,* Vol. 50 (10), 1334–1347.

Stacy M. C. and Miles L. (2007) ‘Justifying Knowledge, Justifying Method, Taking Action: Epistemologies, Methodologies, and Methods in Qualitative Research, *Qual. Health Res.* Vol. 17(5), 1316-1328.

Sterman, J. D. (1992) *‘System Dynamics Modelling for Project Management’,* Cambridge: MIT.

Sterman, J.D. (2000) *‘Business Dynamics: Systems Thinking and Modelling for a Complex World’,* Irwin McGraw-Hill, pp845-861.

Sterman, J.D. (2008) *‘Risk Communication on Climate: Mental Models and Mass Balance’,* Organization Science, 10, 322 (24 October): 532-533.

Sterman, J.D. (2010) *‘Business Dynamics: Systems Thinking and Modelling for a Complex World’,* Irwin McGraw-Hill, p846.

Stough, R.R. and Haynes, K.E. (1997) *Megaproject Impact Assessment, In: Regional science perspectives for the future* (Chatterji, M., Ed) Macmillan [u.a], Basingstoke, pp. 384-395.

STV News Trams (2010) Firm faces axe as it reveals Edinburgh work may take until 2014 [online], *STV News* (10 March 2010), available: http://news.stv.tv/east-central/162746-trams-contractor-could-be-axed-over-further-30-month-delay/, [accessed 09 May 2011].

Sushil, (1993) ‘*System Dynamics: A Practical approach for managerial problems’,* Wiley Eastern Limited, New Delhi.

Sycamore, Douglas and Collofello, James S. (1999) ‘Using System Dynamics Modelling to Manage Projects’, *Twenty-Third Annual International Computer Software and Applications Conference*, p. 213.

Tah, J. H. M., and Carr, V. (2000) ‘A proposal for construction project risk assessment using fuzzy logic’, *Construction management and economics* 18(4): 491–500.

Tatum, C. B. (1987) ‘Process of innovation in construction firm’, *Journal of Construction Engineering and Management*, 113(4), 648-663.

Tesfamariam, D., and Lindberg, B. (2005) 'Aggregate analysis of manufacturing systems using system dynamics and ANP', *Computers & Industrial Engineering,* vol. 49, pp. 98–117.

The Scotsman (2009) Traders unhappy as Shandwick Place to close for 18 months [online], The Scotsman (22 December 2009), available: http://www.scotsman.com/news/scotland/top-stories/traders-unhappy-as-shandwick-place-to-close-for-18-months-1-1226555, [accessed12 April 2012].

The Scotsman (2010) "*Big freeze puts tram works on hold"* [online], *The Scotsman* (9 January 2010), available: http://www.edinburghnews.scotsman.com/news/big-freeze-puts-tram-works-on-hold-1-1227728, [accessed 11 August 2012].

The Scotsman (2011) Tram repair crews out to fix 'botched' road works [online]. *The Scotsman* (9 March 2011), available: http://www.scotsman.com/news/tram-repair-crews-out-to-fix-botched-roadworks-1-1531045, [accessed 12 March 2012].

The Scotsman (2013) Tram wires on buildings keep the clutter down [online]. *The Scotsman* (10 August 2013), available: http://www.edinburghnews.scotsman.com/news/, [accessed 21 September 2013].

The Scotsman, (2007) City chiefs give go-ahead to £498m tram line [online], *The Scotsman* (25 October 2007), available: http://archive.is/kPRw, [accessed 21 June 2012].

The Scotsman, (2007) *City* leaders back the final case for trams [online], *The Scotsman* (22 December 2007), available: http://www.scotsman.com/news/, [accessed 21 November 2011].

The Scotsman, (2010) Trams set to stop at York Place [online], *The Scotsman* (23 June 2010), available: http://www.edinburghnews.scotsman.com/news/transport/, [accessed 10 June 2013].

The Scotsman, (2013) Contractors admit concrete blunder [online], *The Scotsman* (9 August 2013), available: http://www.scotsman.com/news/transport/, [accessed 2 October 2013].

The Scotsman, (2013) Section of track to be ripped up [online]. The Scotsman (31 May 2013), available: http://www.scotsman.com/news/transport/, [accessed 2 October 2013].

The Work Bank, (1999) *Asian Toll Road Development Program: Review of Recent Toll Road Experience in Selected Countries and Preliminary Tool Kit for toll Road Development.* Final Report, May 1999.

Tommy, Y. Lo et al (2006) 'Construction Delays in Hong Kong Civil Engineering Projects', *Journal of Construction Engineering and Management*, 132(6), 636-649.

Towell, R. Denis (1993) 'System Dynamics-Background, Methodology and Applications', *Computing and Control Engineering Journal*, 4(5), 201-208.

Transport Initiatives Edinburgh, (2007) Edinburgh tram network, final business case, Version 2, 7 December 2007.

Turner, M., Haughwout, A. and van der Klaauw, W. (2011) Land use regulation and welfare, Federal Reserve Board of New York, Available: http://www.newyorkfed.org/research/ economists/ haughwout/land_use_reg.pdf, [accessed 17 December 2011].

Turner, P. (2002) Is the PSC an Objective Assessment? *Public Private Finance*, 67, 14.

Uher, T.E. and Toakley, A.R. (1999) 'Risk management in the conceptual phase of a project' *Int J Proj Manage*, 17 **(**3), 161–169.

Vaaland, T. I., & Håkansson, H. (2003) 'Exploring interorganizational conflict in complex projects', Industrial Marketing Management, 32(2), 127–138.

Van Marrewijk, A., Clegg, S. R., Pitsis, T. S., and Veenswijk, M. (2008) 'Managing public–private megaprojects: Paradoxes, complexity and project design', *International Journal of Project Management*, Vol. 26 (6), 591–600.

Walker, D. H. T. (1997) Choosing an appropriate research methodology. *Construction Management and Economics*, 15(2), 149-159.

Walliman, N. (2006) *Social Research Methods*, 1st. Edition, London: SAGE Publications.

Wang, S. Q., Tiong, R. L. K., Ting, S. K., and Ashley, D. (2000) 'Evaluation and management of foreign exchange and revenue risks in China's BOT projects; *Construction Management and Economics.*, 18 (2), 197–207.

Ward, S, Chapman, C. (2003) ‘Transforming project risk management into project uncertainty management’, *International Journal of Project Management*; 2197–105.

Ward, S.C. (1999) ‘Assessing and managing important risks, *International Journal of Project Management*; 17(6):331–336.

Watson, K. (2005) *Cost-Benefit Manual.* Canada: Rideau Strategy Consultants Ltd.

Wilkinson, D. & Birmingham, P. (2003) *‘Using Research Instrument: A Guide for Research’,* Routhledge-Famer, Taylor-Francis Group, New-York.

Williams, T., Samset, K., Sunnevåg, K.J. Eds. (2009) *Making Essential Choices with Scant Information: Front-End Decision Making in Major projects*. Palgrave Macmillan, Basingstoke.

Williams, T. (2008) *Project Modelling.* In Turner JR (Ed) Gower Handbook of Project Management, 4th Edition, pp. 587-599. Aldershot: Gower.

Williams, T. M.., Ackermann, F., and Eden, C. (2003) ‘Structuring a delay and disruption claim: An application of cause-mapping and system dynamics’, *European Journal of Operational Research*, 148(1), 192-204.

Williams, T. (2002) *Modelling Complex Projects,* Blackwell, London.

Williams, T. (2000) ‘Safety regulation changes during projects: the use of system dynamics to quantify the effects of change’, *International Journal of Project Management*, Vol. 18(1), pp. 23-31.

Williams, T. M (1994) ‘Using a risk register to integrate risk management in project definition’, *International Journal of Project Management*; 12(11):17–22.

Winch, G.M. (2000) ‘*Managing project stakeholders’*; In: Morris PWG, Pinto JK, editors. The Wiley guide to managing projects, Hoboken, NJ: John Wiley & Sons Inc.; p. 321–39.

Windsor, J. E. and McVey J. A. (2005) ‘Annihilation of Both Place and Sense of Place: The Experience of the Cheslatta T'En Canadian First Nation within the Context of Large-Scale Environmental Projects’, *Geographic Journal*, vol. 171, pp. 146-165.

Wolstenhome, A. (2009) 'Never Waste a Good Crisis A Review of Progress since Rethinking Construction and Thoughts for Our Future Constructing Excellence [online], available: www.constructingexcellence.org.uk, [accessed 22 June 2013].

World Bank, (2009) '*Publishing Information on Public Construction Projects'*, mimeo: World Bank.

World Commission on Dams, (2000) '*Dams and Development: A New Framework for Decision-Making',* Earthscan Publications Ltd. London and Sterling, United Kingdom.

Wright, R. (2010) Extra cost of Edinburgh tram line fuels dispute [online]. *Financial Times* (16 February 2010), available: http://www.ft.com/, [accessed 10 January 2012].

Xenidis, Y. and Angelides, D. (2005) '*The financial risks in build operate- transfer projects', Construction Management and Economic,* 23(4), 431–441.

Yasemin, N. (2013) 'Quantification of Delay Factors Using the Relative Importance Index Method for Construction Projects in Turkey', *Journal Of Management In Engineering*, 29(2), 133-139.

Ye, S. & Tiong, L. K. (2000) 'NPV- at –Risk: Method in Infrastructure Project Investment Evaluation', *Journal of Construction Engineering and Management,* 126, 227-223.

Yeganli, N., Ali Chekah, A., and Yakchali, S.H. (2011) 'Organizational Behaviour Factors In Responding To Project Risks Using System Dynamics Approach', *2nd International Conference on Construction and Project Management*, IPEDR vol.15, IACSIT Press, Singapore.

Yin, R. K. (2003a) *Applications of case study research, 2nd edition,* London: SAGE Publications.

Yin, R. K. (2003b) *Case study research: Design and methods, 3rd edition,* London: SAGE Publications.

Yin, R. K. (2009) *Case study research: Design and methods, 4th edition,* Thousand Oak, CA: Stage.

Young, M. D. (1992) '*Sustainable Investment and Resource Use: Equity, Environmental Integrity, and Economic Efficiency Park Ride'*, N.J: Parthenon Pub. Group Inc.

Zou, P., Zhang, G. and Wang, J. (2007) 'Understanding the key risks in construction projects in China', *International Journal of Project Management* 25(7), 601–614.

APPENDICES

Appendix A: Research Instruments for Data Collection

1. Cover letter for the Questionnaires Survey

Dear Sir/Madam,

1 March 2013

To Whom It May Concern

Dear Sir/Madam,

Invitation to Questionnaire Survey

We would very much appreciate it if you could take time to contribute to an on-going doctoral research into a Dynamic System Approach to Risk Assessment in Megaprojects in the School of Built Environment (SBE) at Heriot-watt University in Edinburgh.

The research aims to use Analytical Network Process (ANP) and System Dynamics (SD) methods to prioritize and simulate risks against cost and time overruns and quality deficiency in megaproject development for the first time. Data to be collected from this questionnaire survey will be used to develop an integrated (SDANP) models to cover social, technical, economic, environmental and political (STEEP) risks related to megaproject development at construction stage in order to inform better decision making on risk management.

The questionnaire consists of the following three parts:

- Section A: About the Respondent ,
- Section B: Project characteristics,
- Section C: Project performance, and
- Section D: STEEP risks in mega construction projects.

We would like to thank you very much for your valued and kind help and contribution, and look forward to hearing from you soon. Many thanks.

Yours sincerely,

Prince Boateng
PhD Candidate
School of Built Environment,
Heriot Watt University,
Riccarton, Edinburgh,
EH14 4AS
Tel: +44 (0) 131 451 4664(O)
Mobile: +44 (0) 754 1930 957
Email: pb128@hw.ac.uk

Dr. George Zhen Chen
Lecturer in Facility Management
School of Built Environment,
Heriot Watt University,
Riccarton, Edinburgh,
EH14 4AS
Tel: + +44 (0)131 451 4635 (O)
Email: Zhen.Chen@hw.ac.uk

2. Questionnaires to Participants involved in Edinburgh Tram Network Construction

Section A: General information (Optional)

Name of Respondent: ______________________________

Educational Level of Respondent:

Address of Respondent: ______________________________
____

Telephone: ____________________ Email: ____________________

Section B: Project characteristics (most recently completed sections of the project)

Please provide a description of the most recently completed/ongoing project section on which you were personally involved, by providing appropriate answers to the questions below.

1. Type of work (please tick all applicable options)

- Infrastructure works
  - Ground works ☐
  - Earthworks ☐
  - Foundation works ☐
  - Concrete works ☐
  - Laying of trucks ☐
  - Steel and welding works ☐
  - False works ☐
  - Demolishing works ☐
- Utility diversion works ☐
- Others (please specify) ____________________
  ____

	Very simple			Very Complex	
2. How would you rate the complexity of this project?	1	2	3	4	5

3. What is the contract price? ____________________
4. What is the proposed project duration? ____________________

5. Which of these areas is the project located? (please check applicable)

Edinburgh Airport ☐
Picardy place ☐
Edinburgh Park station ☐
Ocean Terminal ☐
Shandwick place ☐
Edi. Int. Gateway ☐
Foot of the walk ☐
St. Andrews square ☐

Edinburgh Park & Ride ☐
Port of Leith ☐
Haymarket ☐
Gogarburn ☐
Balfour street ☐
Saughton ☐
Gyle centre ☐
Other, (Please state) ____________________

Murray field station ☐
Ingliston Park & Ride ☐
MacDonald road ☐
Bank head ☐
Newhaven ☐
Princes street ☐
Balgreen ☐

6. How long have you worked on this project? (please tick)

☐ 1 years ☐ 2 years ☐ 3years ☐ 4 years and above ☐ Other (please state) ________

7. Please indicate the procurement approach employed for this project. (Please tick)

Traditional lump sum competitive tendering	☐
Design & Build	☐
Partnering	☐
Management contracting	☐
Construction Management	☐
Other approach (Please specify) ____________________	

8. What is the designation of your company on this project? (Please tick)

Main contractor	☐	Subcontractor	☐	Project Manager	☐
Consultant	☐	Supplier	☐	Other (Please specify) ________	

9. For each of the following participants, indicate how much influence they have on the project lifecycle. (Please rank from 1 to 5)

	No influence				Highly influential
	1	2	3	4	5
	Project lifecycle Phases				
	Concept	Planning	Execution	Transfer	Operation
Client	☐	☐	☐	☐	☐
Architect	☐	☐	☐	☐	☐
Project Manager	☐	☐	☐	☐	☐
Civil Engineer	☐	☐	☐	☐	☐
Main Contractor	☐	☐	☐	☐	☐
Local business owners	☐	☐	☐	☐	☐
Regulatory bodies	☐	☐	☐	☐	☐
Other (please specify) ________	☐	☐	☐	☐	☐

10. Was your company involved in the design phase of this project? Yes ☐ No ☐

11.Please rank the following objectives from 1 to 5 in order of priority on this project

	Very low			Very High	
Cost	1	2	3	4	5
Time	1	2	3	4	5
Quality	1	2	3	4	5
Other (Please specify) ____________________	1	2	3	4	5

Section C: Project performance outcomes for the project described above.

Please indicate by providing appropriate answers below for the project performance.

Cost

1. What is/was the final cost of this project? ______________________

2. Which of these risk factors account for differences between project final cost and contract price on this project? (Please rank from 1 to 5 in order of priority)

	Very low			Very High	
Social risk	1	2	3	4	5
Technical risk	1	2	3	4	5
Economical risk	1	2	3	4	5
Environmental risk	1	2	3	4	5
Political risk	1	2	3	4	5
Other (Please specify) ____________	1	2	3	4	5

Time

3. How long did it take to complete this project? ______________________

4. Which of these risk factors account for differences between actual and proposed duration for this project? (Please rank from 1 to 5 in order of priority)

	Very low			Very High	
Social risk	1	2	3	4	5
Technical risk	1	2	3	4	5
Economical risk	1	2	3	4	5
Environmental risk	1	2	3	4	5
Political risk	1	2	3	4	5
Other (Please specify) __________	1	2	3	4	5

Quality

5. At the time of handing over completed sections of the project, to what extend was the project free from defects as a result of STEEP risks impact on the project during construction?

☐ The project was free from defects
☐ There were few defects but the project handed over on time
☐ There were few defects that delayed handover slightly - by how many week? ______
☐ There were major defects which delayed hand over substantially - by how many week? ______
☐ Don’t know

Productivity

6. Please rate the overall level of productivity during project delivery under the listed risks below

	Very low				Very high
Social risk	1	2	3	4	5
Technical risk	1	2	3	4	5
Economical risk	1	2	3	4	5
Environmental risk	1	2	3	4	5
Political risk	1	2	3	4	5
Other (Please specify) ______________	1	2	3	4	5

Section D: STEEP risks in Megaproject development and construction

From your experience on this project, please indicate by ranking the extent to which the following risk factors impact on the project objectives (Please rank from 1 to 5)

	Level of impact on project objectives														
7. *Social risk factors*	*cost*					*Time*					*Quality*				
Social grievances	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Multi-player/level decision making bodies	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Disputes	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Legal action by project external stakeholders	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Legal actions by Client	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Stakeholders’ pressure	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Treats to person/asset security	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Social issues	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5

	Level of impact on project objectives														
8. *Technical risk factors*	*cost*					*Time*					*Quality*				
Ambiguity of project scope	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Ground conditions on given project sites	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
inadequate project complexity analysis	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Unforeseen modification to project	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Incorrect project cost estimate	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Incorrect project time estimate	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Failure to meet specified standards	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Technical difficulties in utilities diversions	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Project time overruns	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Project delays of all forms	1	2	3	3	5	1	2	3	4	5	1	2	3	4	5

	Level of impact on project objectives														
9. *Economic risk factors*	*cost*					*Time*					*Quality*				
Change in government funding policy	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Taxation changes	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Change in government	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Changes in V.A.T	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Wage inflation	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Local inflation change	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Foreign exchange	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Material price changes	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Global economic recession	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Global energy price changes	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Catastrophic environmental effects	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Project technical difficulties	1	2	3	3	5	1	2	3	4	5	1	2	3	4	5
Project delays of all forms	1	2	3	3	5	1	2	3	4	5	1	2	3	4	5

	Level of impact on project objectives														
10. *Environmental risk factors*			*cost*					*Time*					*Quality*		
a. Unfavourable climatic conditions															
Earthquake	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Hurricane	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Heat waves	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Thunder and Lightning	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Drought	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Heavy rainfall	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Snowfall	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Flood	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Wind storm	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Dust storm	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
High and low humidity conditions	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Temperature	1	2	3	3	5	1	2	3	4	5	1	2	3	4	5
b. Environmental issues from works															
Pollution (air, water, soil, noise, dust, waste generation etc...)	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Traffic	1	2	3	3	5	1	2	3	4	5	1	2	3	4	5

	Level of imp Level of impact on project objectives act on project objectives														
11. *Political risk factors*			*cost*					*Time*					*Quality*		
Change in government funding policy	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Political opposition	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Government discontinuity	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Lack of political support	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Political indecision	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Project termination	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Delay in obtaining consent	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Legislative/regulatory changes	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Delay in obtaining temporary Traffic Regulation Orders (TROs)	1	2	3	3	5	1	2	3	4	5	1	2	3	4	5

Learning /Innovation					
12.Please rate the following:	Very low				Very high
a. The level of organisational learning that took place on this project relative to previous projects you undertook under similar weather conditions	1	2	3	4	5
b. The level of innovation on this project relative to similar projects you undertook under similar weather conditions	1	2	3	4	5

Satisfaction

13. In your opinion, how satisfied are the project stakeholders with:	Very dissatisfied				Very satisfied
a. Service	1	2	3	4	5
b. Project cost	1	2	3	4	5
c. Project duration	1	2	3	4	5
d. Project quality	1	2	3	4	5
14. In your opinion, how satisfied are the employees and operatives with:					
a. Site conditions and welfare facilities	1	2	3	4	5
b. Wages	1	2	3	4	5
c. Level of health and safety on/off sites	1	2	3	4	5
15. How satisfied is your company with the level of profitability of this project?	1	2	3	4	5
16. How satisfied was management with the level of collaboration and harmony between project participants?	1	2	3	4	5

THANK YOU

3. Prior Notification to Potential Respondents

HERIOT
WATT
UNIVERSITY

Bilfinger Construction UK Limited
9 Lochside Avenue
Edinburgh, EH12 9DJ
United Kingdom

21 March 2013

To Whom It May Concern

Dear Sir/Madam,

Request to conduct research survey

I'm writing to you to introduce Mr. Prince Boateng, PhD Candidate of the School of the Built Environment at Heriot-Watt University, Edinburgh. In order to collect data for his research, Prince is conducting a questionnaire survey and interviews with professionals who are involved in mega construction projects.

For the Edinburgh Tram Network (ETN) project, the questionnaire survey and a series of semi-structured interviews are being conducted to professionals, including Project Managers, Engineers, Consultants, and other senior staff working on the project.

Data collected from questionnaire survey and interviews will be used to develop a System Dynamics model to cover STEEP (social, technical, economic, environmental and political) risks against megaproject development at the construction stage. The System Dynamics model aims to aid better decision making and management activities via descriptive simulation and prediction on project risks in megaproject development.

It would be very much grateful if you could kindly help Prince in carrying out this survey and interview. All information and data collected will be treated as strictly confidential and used for the research only.

If there is any concern on this academic research excesise, please do not hesitate to contact me.

Thank you very much.

Yours sincerely,

Dr George Z. Chen
Lecturer in Facility Management
School of Built Environment, Heriot Watt University
Riccarton, Edinburgh, EH14 4AS
Tel: + +44 (0)131 451 4635 (O)
Email: zhen.chen@hw.ac.uk

School of the Built Environment
Edwin Chadwick Building Gait 4 Heriot-Watt University Edinburgh EH14 4AS United Kingdom
Telephone +44 (0)131 449 5111 Fax +44 (0)131 451 3161 www.sbe.hw.ac.uk

Edinburgh Campus • *Scottish Borders Campus* • *Orkney Campus* • *Dubai Campus*
Heriot-Watt University is a Charity registered in Scotland, SC000278

Appendix B: Structured Interview Questionnaire and Participants

1. Structured Interview Questionnaire

A Dynamic System Approach to Risk Assessment in Megaprojects

Profile/Demography of Interviewee

Type of Organisation: ___________________Date: _______________ Time: _______________

Type of Megaproject: ____

Size of Megaproject: ________________________ Designation: ____________________

1. Role/Responsibility of Interviewee:

a. What was your role on the Project?

b. How long were you involved in megaproject construction?

2. Project Goal/Scope:

b. What were the main goals and objectives?

c. How did the project scope change over time?

3. Generic Risk Events:

a. What were the generic risk events inherit in the project?

b. How did the generic risk events affect the project schedule overtime?

c. How did the generic risk events affect the project cost?

7. Funding:

a. Was the project funding source a dedicated fund source?

b. How were additional funds obtained as project costs increased?

c. Was the funding source stable over time?

8. How can the qualitative risk effects on project performance be quantified and analyzed to reduce under performances in megaproject construction?

5. How effective were the risks assessment practices used in managing /modeling risk interrelationships in megaprojects during construction?

2. Structured Interview Participants

	Company	Type of Organisation
1	Atkins	Consultant
2	Atkins PLC	Consultant
3	Bilfinger Berger /Siemens Consortium	Contractor
4	City of Edinburgh Council	Owner
5	Crummock (Scotland) Ltd	Contractor
6	Farrans Construction	Contractor
7	Halcrow Group	Contractor
8	Jacobs Consultancy	Consultant
9	McNicholas Construction Co. Ltd	Contractor
10	Scottish Water	Consultant
11	Turner& Townsend	Consultant

Appendix C: Respondent's Mean Scores of Importance

1. Respondent's Mean Scores of Importance for Project Objectives (P_o) Considerations: Cost, Time and Quality Risks

Number of respondents	Years of experience (Y) in %			Input (*i*) for Cost (*c*), Time (*t*) & Quality (*q*)			Experimental Input (E*i*) E*i* = Y**i*		
N	*Yr. Range*	*Year (Yr)*	*Y (%)*	i_c	i_t	i_q	$Y\ i_c$	$Y\ i_t$	$Y\ i_q$
1	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
2	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
3	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
4	< 5	5	0.3715	4	4	5	1.4859	1.4859	1.8574
5	11-20	16	1.1887	4	4	5	4.7548	4.7548	5.9435
6	0	0	0.0000	0	0	0	0.0000	0.0000	0.0000
7	21+	21	1.5602	4	4	4	6.2407	6.2407	6.2407
8	5-10	8	0.5944	0	0	0	0.0000	0.0000	0.0000
9	5-10	8	0.5944	3	5	3	1.7831	2.9718	1.7831
10	5-10	8	0.5944	3	3	3	1.7831	1.7831	1.7831
11	11-20	16	1.1887	5	4	5	5.9435	4.7548	5.9435
12	5-10	8	0.5944	0	0	0	0.0000	0.0000	0.0000
13	5-10	8	0.5944	5	2	3	2.9718	1.1887	1.7831
14	5-10	8	0.5944	4	1	5	2.3774	0.5944	2.9718
15	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
16	11-20	16	1.1887	5	3	5	5.9435	3.5661	5.9435
17	0	0	0.0000	0	0	0	0.0000	0.0000	0.0000
18	21+	21	1.5602	0	0	0	0.0000	0.0000	0.0000
19	21+	21	1.5602	4	5	4	6.2407	7.8009	6.2407
20	11-20	16	1.1887	5	4	3	5.9435	4.7548	3.5661
21	11-20	16	1.1887	3	4	5	3.5661	4.7548	5.9435
22	5-10	8	0.5944	5	3	5	2.9718	1.7831	2.9718
23	< 5	5	0.3715	4	5	5	1.4859	1.8574	1.8574
24	5-10	8	0.5944	4	5	5	2.3774	2.9718	2.9718
25	5-10	8	0.5944	4	4	4	2.3774	2.3774	2.3774
26	5-10	8	0.5944	4	4	4	2.3774	2.3774	2.3774
27	5-10	8	0.5944	4	4	4	2.3774	2.3774	2.3774
28	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
29	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
30	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
31	5-10	8	0.5944	5	5	5	2.9718	2.9718	2.9718
32	5-10	8	0.5944	5	5	5	2.9718	2.9718	2.9718
33	5-10	8	0.5944	5	5	5	2.9718	2.9718	2.9718
34	5-10	8	0.5944	5	5	5	2.9718	2.9718	2.9718
35	5-10	8	0.5944	5	5	5	2.9718	2.9718	2.9718
36	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
37	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
38	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
39	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
40	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
41	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
42	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
43	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
44	21+	21	1.5602	0	0	0	0.0000	0.0000	0.0000

45	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
46	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
47	< 5	5	0.3715	4	5	4	1.4859	1.8574	1.4859
48	< 5	5	0.3715	4	5	4	1.4859	1.8574	1.4859
49	< 5	5	0.3715	4	5	4	1.4859	1.8574	1.4859
50	< 5	5	0.3715	4	5	4	1.4859	1.8574	1.4859
51	< 5	5	0.3715	4	5	4	1.4859	1.8574	1.4859
52	< 5	5	0.3715	4	5	4	1.4859	1.8574	1.4859
53	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
54	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
55	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
56	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
57	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
58	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
59	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
60	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
61	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
62	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
63	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
64	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
65	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
66	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
67	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
68	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
69	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
70	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
71	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
72	5-10	8	0.5944	5	5	5	2.9718	2.9718	2.9718
73	5-10	8	0.5944	5	5	5	2.9718	2.9718	2.9718
74	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
75	21+	21	1.5602	4	4	3	6.2407	6.2407	4.6805
76	21+	21	1.5602	4	4	5	6.2407	6.2407	7.8009
77	21+	21	1.5602	4	4	5	6.2407	6.2407	7.8009
78	11-20	16	1.1887	4	4	4	4.7548	4.7548	4.7548
79	11-20	16	1.1887	4	4	4	4.7548	4.7548	4.7548
80	21+	21	1.5602	3	5	3	4.6805	7.8009	4.6805
81	11-20	16	1.1887	3	3	3	3.5661	3.5661	3.5661
82	21+	21	1.5602	5	4	5	7.8009	6.2407	7.8009
83	21+	21	1.5602	4	4	5	6.2407	6.2407	7.8009
84	11-20	16	1.1887	5	2	3	5.9435	2.3774	3.5661
85	11-20	16	1.1887	4	1	5	4.7548	1.1887	5.9435
86	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
87	21+	21	1.5602	5	3	5	7.8009	4.6805	7.8009
88	11-20	16	1.1887	4	3	5	4.7548	3.5661	5.9435
89	11-20	16	1.1887	4	3	5	4.7548	3.5661	5.9435
90	11-20	16	1.1887	4	5	4	4.7548	5.9435	4.7548
Total		**1346**	100.0000				**444.58**	**432.32**	**450.8**
Mean Value **(MVp$_o$)** = $|\sum \mathbf{E}\boldsymbol{i}_{X1\text{-}3}| / \mathbf{N}_{total}$							**4.9**	**4.8**	**5.0**

Ei *= Experimental Input,* ***X*** *= Value for individual experimental inputs for cost, time and quality*
i *= Respondents inputs,* $X_1 = i_c$ *= Respondents inputs for project cost,* $X_2 = i_t$ *= Respondents inputs for project time and* $X_3 = i_q$ *= Respondents inputs for project quality,* N_{total} *= Total number of respondents*

2. Respondent’s Mean Scores of Importance for Potential Risks (P_{R1}): Social Risks

Number of respondents	Years of experience (Y) in %			Input (*i*) for G_1 under Cost (*c*), Time (*t*) & Quality (*q*)			Experimental Input (E*i*) E*i* = Y**i*		
N	*Yr. Range*	*Year (Yr)*	*Y (%)*	i_c	i_t	i_q	$Y\ i_c$	$Y\ i_t$	$Y\ i_q$
1	11-20	16	1.1887	4	5	2	4.7548	5.9435	2.3774
2	11-20	16	1.1887	4	5	2	4.7548	5.9435	2.3774
3	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
4	< 5	5	0.3715	3	1	3	1.1144	0.3715	1.1144
5	11-20	16	1.1887	4	3	4	4.7548	3.5661	4.7548
6	0	0	0.0000	0	0	0	0.0000	0.0000	0.0000
7	21+	21	1.5602	3	3	3	4.6805	4.6805	4.6805
8	5-10	8	0.5944	0	0	0	0.0000	0.0000	0.0000
9	5-10	8	0.5944	2	4	3	1.1887	2.3774	1.7831
10	5-10	8	0.5944	2	3	3	1.1887	1.7831	1.7831
11	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
12	5-10	8	0.5944	0	0	0	0.0000	0.0000	0.0000
13	5-10	8	0.5944	0	0	0	0.0000	0.0000	0.0000
14	5-10	8	0.5944	0	0	0	0.0000	0.0000	0.0000
15	21+	21	1.5602	5	5	2	7.8009	7.8009	3.1204
16	11-20	16	1.1887	5	5	3	5.9435	5.9435	3.5661
17	0	0	0.0000	0	0	0	0.0000	0.0000	0.0000
18	21+	21	1.5602	0	0	0	0.0000	0.0000	0.0000
19	21+	21	1.5602	0	0	0	0.0000	0.0000	0.0000
20	11-20	16	1.1887	4	5	4	4.7548	5.9435	4.7548
21	11-20	16	1.1887	0	0	0	0.0000	0.0000	0.0000
22	5-10	8	0.5944	4	5	5	2.3774	2.9718	2.9718
23	< 5	5	0.3715	0	0	0	0.0000	0.0000	0.0000
24	5-10	8	0.5944	5	3	1	2.9718	1.7831	0.5944
25	5-10	8	0.5944	5	3	1	2.9718	1.7831	0.5944
26	5-10	8	0.5944	5	3	1	2.9718	1.7831	0.5944
27	5-10	8	0.5944	5	3	1	2.9718	1.7831	0.5944
28	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
29	21+	21	1.5602	2	2	2	3.1204	3.1204	3.1204
30	21+	21	1.5602	4	4	4	6.2407	6.2407	6.2407
31	5-10	8	0.5944	5	4	1	2.9718	2.3774	0.5944
32	5-10	8	0.5944	5	4	1	2.9718	2.3774	0.5944
33	5-10	8	0.5944	5	4	1	2.9718	2.3774	0.5944
34	5-10	8	0.5944	5	4	1	2.9718	2.3774	0.5944
35	5-10	8	0.5944	5	4	1	2.9718	2.3774	0.5944
36	11-20	16	1.1887	2	4	1	2.3774	4.7548	1.1887
37	21+	21	1.5602	4	4	1	6.2407	6.2407	1.5602
38	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
39	21+	21	1.5602	0	0	0	0.0000	0.0000	0.0000
40	11-20	16	1.1887	0	0	0	0.0000	0.0000	0.0000
41	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
42	21+	21	1.5602	0	0	0	0.0000	0.0000	0.0000
43	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
44	21+	21	1.5602	0	0	0	0.0000	0.0000	0.0000
45	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
46	11-20	16	1.1887	0	0	0	0.0000	0.0000	0.0000
47	< 5	5	0.3715	5	2	2	1.8574	0.7429	0.7429
48	< 5	5	0.3715	5	2	2	1.8574	0.7429	0.7429

49	< 5	5	0.3715	3	2	2	1.1144	0.7429	0.7429
50	< 5	5	0.3715	5	2	2	1.8574	0.7429	0.7429
51	< 5	5	0.3715	5	2	2	1.8574	0.7429	0.7429
52	< 5	5	0.3715	3	2	2	1.1144	0.7429	0.7429
53	11-20	16	1.1887	0	0	0	0.0000	0.0000	0.0000
54	11-20	16	1.1887	0	0	0	0.0000	0.0000	0.0000
55	21+	21	1.5602	5	4	3	7.8009	6.2407	4.6805
56	11-20	16	1.1887	5	4	3	5.9435	4.7548	3.5661
57	21+	21	1.5602	5	5	3	7.8009	7.8009	4.6805
58	21+	21	1.5602	5	4	3	7.8009	6.2407	4.6805
59	21+	21	1.5602	5	4	1	7.8009	6.2407	1.5602
60	21+	21	1.5602	5	4	3	7.8009	6.2407	4.6805
61	21+	21	1.5602	5	4	1	7.8009	6.2407	1.5602
62	21+	21	1.5602	5	4	3	7.8009	6.2407	4.6805
63	21+	21	1.5602	5	5	2	7.8009	7.8009	3.1204
64	21+	21	1.5602	5	5	2	7.8009	7.8009	3.1204
65	21+	21	1.5602	5	5	1	7.8009	7.8009	1.5602
66	21+	21	1.5602	5	5	2	7.8009	7.8009	3.1204
67	21+	21	1.5602	5	4	1	7.8009	6.2407	1.5602
68	21+	21	1.5602	5	4	5	7.8009	6.2407	7.8009
69	21+	21	1.5602	5	5	4	7.8009	7.8009	6.2407
70	11-20	16	1.1887	5	4	4	5.9435	4.7548	4.7548
71	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
72	5-10	8	0.5944	4	5	4	2.3774	2.9718	2.3774
73	5-10	8	0.5944	5	5	3	2.9718	2.9718	1.7831
74	11-20	16	1.1887	2	2	1	2.3774	2.3774	1.1887
75	21+	21	1.5602	5	2	2	7.8009	3.1204	3.1204
76	21+	21	1.5602	5	2	2	7.8009	3.1204	3.1204
77	21+	21	1.5602	2	2	2	3.1204	3.1204	3.1204
78	11-20	16	1.1887	1	1	1	1.1887	1.1887	1.1887
79	11-20	16	1.1887	3	4	3	3.5661	4.7548	3.5661
80	21+	21	1.5602	5	3	1	7.8009	4.6805	1.5602
81	11-20	16	1.1887	5	3	1	5.9435	3.5661	1.1887
82	21+	21	1.5602	5	3	1	7.8009	4.6805	1.5602
83	21+	21	1.5602	5	4	1	7.8009	6.2407	1.5602
84	11-20	16	1.1887	5	4	3	5.9435	4.7548	3.5661
85	11-20	16	1.1887	5	3	2	5.9435	3.5661	2.3774
86	11-20	16	1.1887	5	3	3	5.9435	3.5661	3.5661
87	21+	21	1.5602	5	3	2	7.8009	4.6805	3.1204
88	11-20	16	1.1887	5	4	2	5.9435	4.7548	2.3774
89	11-20	16	1.1887	5	3	3	5.9435	3.5661	3.5661
90	11-20	16	1.1887	5	3	2	5.9435	3.5661	2.3774
Total		1346	100.00				375.93	321.77	215.97
Mean Value (MV_{PR1})	**=**		**$\lvert\sum Ei_{X1-3}\rvert / N_{total}$**				**4.2**	**3.6**	**2.4**

Ei *= Experimental Input,* ***X*** *= Value for individual experimental inputs for cost, time and quality*

i *= Respondents inputs,* $X_1 = i_c$ *= Respondents inputs for project cost,* $X_2 = i_t$ *= Respondents inputs for project time and* $X_3 = i_q$ *= Respondents inputs for project quality,* N_{total} *= Total number of respondents*

3. Respondent’s Mean Scores of Importance for Potential Risks (P_{R2}): Technical Risks

Number of respondents	Years of experience (Y) in %			Input (*i*) for G_2 under Cost (*c*), Time (*t*) & Quality (*q*)			Experimental Input (E*i*) E*i* = Y**i*		
N	*Yr. Range*	*Year (Yr)*	*Y (%)*	i_c	i_t	i_q	$Y\ i_c$	$Y\ i_t$	$Y\ i_q$
1	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
2	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
3	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
4	< 5	5	0.3715	3	4	3	1.1144	1.4859	1.1144
5	11-20	16	1.1887	3	3	3	3.5661	3.5661	3.5661
6	0	0	0.0000	0	0	0	0.0000	0.0000	0.0000
7	21+	21	1.5602	3	3	3	4.6805	4.6805	4.6805
8	5-10	8	0.5944	0	0	0	0.0000	0.0000	0.0000
9	5-10	8	0.5944	3	3	3	1.7831	1.7831	1.7831
10	5-10	8	0.5944	3	2	2	1.7831	1.1887	1.1887
11	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
12	5-10	8	0.5944	5	5	5	2.9718	2.9718	2.9718
13	5-10	8	0.5944	5	5	5	2.9718	2.9718	2.9718
14	5-10	8	0.5944	5	5	5	2.9718	2.9718	2.9718
15	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
16	11-20	16	1.1887	5	5	4	5.9435	5.9435	4.7548
17	0	0	0.0000	0	0	0	0.0000	0.0000	0.0000
18	21+	21	1.5602	0	0	0	0.0000	0.0000	0.0000
19	21+	21	1.5602	0	0	0	0.0000	0.0000	0.0000
20	11-20	16	1.1887	4	4	4	4.7548	4.7548	4.7548
21	11-20	16	1.1887	3	2	5	3.5661	2.3774	5.9435
22	5-10	8	0.5944	4	4	4	2.3774	2.3774	2.3774
23	< 5	5	0.3715	5	5	4	1.8574	1.8574	1.4859
24	5-10	8	0.5944	5	5	5	2.9718	2.9718	2.9718
25	5-10	8	0.5944	4	4	4	2.3774	2.3774	2.3774
26	5-10	8	0.5944	4	4	4	2.3774	2.3774	2.3774
27	5-10	8	0.5944	4	4	4	2.3774	2.3774	2.3774
28	11-20	16	1.1887	4	4	5	4.7548	4.7548	5.9435
29	21+	21	1.5602	1	2	1	1.5602	3.1204	1.5602
30	21+	21	1.5602	4	4	4	6.2407	6.2407	6.2407
31	5-10	8	0.5944	5	5	5	2.9718	2.9718	2.9718
32	5-10	8	0.5944	5	5	5	2.9718	2.9718	2.9718
33	5-10	8	0.5944	5	5	5	2.9718	2.9718	2.9718
34	5-10	8	0.5944	5	5	5	2.9718	2.9718	2.9718
35	5-10	8	0.5944	5	5	5	2.9718	2.9718	2.9718
36	11-20	16	1.1887	4	4	2	4.7548	4.7548	2.3774
37	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
38	21+	21	1.5602	5	5	4	7.8009	7.8009	6.2407
39	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
40	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
41	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
42	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
43	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
44	21+	21	1.5602	0	0	0	0.0000	0.0000	0.0000
45	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
46	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
47	< 5	5	0.3715	2	3	2	0.7429	1.1144	0.7429
48	< 5	5	0.3715	2	3	2	0.7429	1.1144	0.7429

49	< 5	5	0.3715	2	3	2	0.7429	1.1144	0.7429
50	< 5	5	0.3715	2	3	2	0.7429	1.1144	0.7429
51	< 5	5	0.3715	2	3	2	0.7429	1.1144	0.7429
52	< 5	5	0.3715	2	3	2	0.7429	1.1144	0.7429
53	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
54	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
55	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
56	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
57	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
58	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
59	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
60	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
61	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
62	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
63	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
64	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
65	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
66	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
67	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
68	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
69	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
70	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
71	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
72	5-10	8	0.5944	5	5	5	2.9718	2.9718	2.9718
73	5-10	8	0.5944	5	5	5	2.9718	2.9718	2.9718
74	11-20	16	1.1887	3	4	3	3.5661	4.7548	3.5661
75	21+	21	1.5602	3	3	3	4.6805	4.6805	4.6805
76	21+	21	1.5602	3	3	3	4.6805	4.6805	4.6805
77	21+	21	1.5602	3	3	3	4.6805	4.6805	4.6805
78	11-20	16	1.1887	3	3	3	3.5661	3.5661	3.5661
79	11-20	16	1.1887	3	3	3	3.5661	3.5661	3.5661
80	21+	21	1.5602	3	2	2	4.6805	3.1204	3.1204
81	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
82	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
83	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
84	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
85	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
86	11-20	16	1.1887	5	5	4	5.9435	5.9435	4.7548
87	21+	21	1.5602	5	5	4	7.8009	7.8009	6.2407
88	11-20	16	1.1887	5	5	4	5.9435	5.9435	4.7548
89	11-20	16	1.1887	5	5	4	5.9435	5.9435	4.7548
90	11-20	16	1.1887	5	5	4	5.9435	5.9435	4.7548
Total		1346	100.00				422.59	424.59	412.18
Mean Value (MV_{PR2})	**=**		$|\sum \mathbf{E}\boldsymbol{i}_{X1\text{-}3}| / \mathbf{N}_{\mathbf{total}}$				**4.7**	**4.7**	**4.6**

Ei = *Experimental Input*, ***X*** = *Value for individual experimental inputs for cost, time and quality*

i = *Respondents inputs*, $X_1 = i_c$ = *Respondents inputs for project cost*, $X_2 = i_t$ = *Respondents inputs for project time and* $X_3 = i_q$ = *Respondents inputs for project quality*, N_{total} = *Total number of respondents*

4. Respondent's Mean Scores of Importance for Potential Risks (P_{R3}): Economic Risks

Number of respondents	Years of experience (Y) in %			Input (i) for G_3 under Cost (c), Time (t) & Quality (q)			Experimental Input (Ei) Ei = Y*i		
N	*Yr. Range*	*Year (Yr)*	*Y (%)*	i_c	i_t	i_q	$Y\ i_c$	$Y\ i_t$	$Y\ i_q$
1	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
2	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
3	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
4	< 5	5	0.3715	4	4	1	1.4859	1.4859	0.3715
5	11-20	16	1.1887	4	3	3	4.7548	3.5661	3.5661
6	0	0	0.0000	0	3	3	0.0000	0.0000	0.0000
7	21+	21	1.5602	3	3	3	4.6805	4.6805	4.6805
8	5-10	8	0.5944	0	3	3	0.0000	1.7831	1.7831
9	5-10	8	0.5944	4	3	3	2.3774	1.7831	1.7831
10	5-10	8	0.5944	2	3	2	1.1887	1.7831	1.1887
11	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
12	5-10	8	0.5944	5	5	5	2.9718	2.9718	2.9718
13	5-10	8	0.5944	5	5	5	2.9718	2.9718	2.9718
14	5-10	8	0.5944	5	5	5	2.9718	2.9718	2.9718
15	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
16	11-20	16	1.1887	5	5	4	5.9435	5.9435	4.7548
17	0	0	0.0000	0	0	0	0.0000	0.0000	0.0000
18	21+	21	1.5602	0	0	0	0.0000	0.0000	0.0000
19	21+	21	1.5602	0	0	0	0.0000	0.0000	0.0000
20	11-20	16	1.1887	5	4	3	5.9435	4.7548	3.5661
21	11-20	16	1.1887	3	3	5	3.5661	3.5661	5.9435
22	5-10	8	0.5944	5	5	3	2.9718	2.9718	1.7831
23	< 5	5	0.3715	5	5	4	1.8574	1.8574	1.4859
24	5-10	8	0.5944	5	5	3	2.9718	2.9718	1.7831
25	5-10	8	0.5944	4	4	4	2.3774	2.3774	2.3774
26	5-10	8	0.5944	4	4	4	2.3774	2.3774	2.3774
27	5-10	8	0.5944	4	4	4	2.3774	2.3774	2.3774
28	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
29	21+	21	1.5602	3	3	3	4.6805	4.6805	4.6805
30	21+	21	1.5602	4	4	4	6.2407	6.2407	6.2407
31	5-10	8	0.5944	5	5	5	2.9718	2.9718	2.9718
32	5-10	8	0.5944	5	5	5	2.9718	2.9718	2.9718
33	5-10	8	0.5944	5	5	5	2.9718	2.9718	2.9718
34	5-10	8	0.5944	5	5	5	2.9718	2.9718	2.9718
35	5-10	8	0.5944	5	5	5	2.9718	2.9718	2.9718
36	11-20	16	1.1887	2	2	2	2.3774	2.3774	2.3774
37	21+	21	1.5602	5	2	2	7.8009	3.1204	3.1204
38	21+	21	1.5602	5	5	2	7.8009	7.8009	3.1204
39	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
40	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
41	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
42	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
43	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
44	21+	21	1.5602	0	0	0	0.0000	0.0000	0.0000
45	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
46	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
47	< 5	5	0.3715	2	3	2	0.7429	1.1144	0.7429
48	< 5	5	0.3715	2	3	2	0.7429	1.1144	0.7429

49	< 5	5	0.3715	2	3	2	0.7429	1.1144	0.7429
50	< 5	5	0.3715	2	3	2	0.7429	1.1144	0.7429
51	< 5	5	0.3715	2	3	2	0.7429	1.1144	0.7429
52	< 5	5	0.3715	2	3	2	0.7429	1.1144	0.7429
53	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
54	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
55	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
56	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
57	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
58	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
59	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
60	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
61	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
62	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
63	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
64	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
65	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
66	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
67	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
68	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
69	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
70	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
71	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
72	5-10	8	0.5944	5	5	5	2.9718	2.9718	2.9718
73	5-10	8	0.5944	5	5	5	2.9718	2.9718	2.9718
74	11-20	16	1.1887	4	4	1	4.7548	4.7548	1.1887
75	21+	21	1.5602	3	3	3	4.6805	4.6805	4.6805
76	21+	21	1.5602	3	3	3	4.6805	4.6805	4.6805
77	21+	21	1.5602	3	3	3	4.6805	4.6805	4.6805
78	11-20	16	1.1887	3	3	3	3.5661	3.5661	3.5661
79	11-20	16	1.1887	4	3	3	4.7548	3.5661	3.5661
80	21+	21	1.5602	2	3	2	3.1204	4.6805	3.1204
81	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
82	21+	21	1.5602	3	3	3	4.6805	4.6805	4.6805
83	21+	21	1.5602	3	3	3	4.6805	4.6805	4.6805
84	11-20	16	1.1887	3	3	3	3.5661	3.5661	3.5661
85	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
86	11-20	16	1.1887	5	5	4	5.9435	5.9435	4.7548
87	21+	21	1.5602	5	5	4	7.8009	7.8009	6.2407
88	11-20	16	1.1887	5	5	4	5.9435	5.9435	4.7548
89	11-20	16	1.1887	5	5	4	5.9435	5.9435	4.7548
90	11-20	16	1.1887	5	5	4	5.9435	5.9435	4.7548
Total		1346	100				420.06	417.38	394.58
Mean Value (MV_{PR3})		=	$\lvert\sum \mathbf{E}\boldsymbol{i}_{X1\text{-}3}\rvert / \mathbf{N}_{\mathbf{total}}$				**4.7**	**4.6**	**4.4**

Ei *= Experimental Input,* ***X*** *= Value for individual experimental inputs for cost, time and quality*

i *= Respondents inputs,* $\boldsymbol{X_1} = \boldsymbol{i_c}$ *= Respondents inputs for project cost,* $\boldsymbol{X_2} = \boldsymbol{i_t}$ *= Respondents inputs for project time and* $\boldsymbol{X_3} = \boldsymbol{i_q}$ *= Respondents inputs for project quality,* $\boldsymbol{N_{total}}$ *= Total number of respondents*

5. Respondent’s Mean Scores of Importance for Potential Risks (P_{R4}): Environmental Risks

Number of respondents	Years of experience (Y) in %			Input (*i*) for G_4 under Cost (*c*), Time (*t*) & Quality (*q*)			Experimental Input (E*i*) E*i* = Y**i*		
N	*Yr. Range*	*Year (Yr)*	*Y (%)*	i_c	i_t	i_q	$Y\ i_c$	$Y\ i_t$	$Y\ i_q$
1	11-20	16	1.1887	3	3	4	3.5661	3.5661	4.7548
2	11-20	16	1.1887	3	3	4	3.5661	3.5661	4.7548
3	11-20	16	1.1887	4	4	4	4.7548	4.7548	4.7548
4	< 5	5	0.3715	4	4	4	1.4859	1.4859	1.4859
5	11-20	16	1.1887	4	4	4	4.7548	4.7548	4.7548
6	0	0	0.0000	0	0	0	0.0000	0.0000	0.0000
7	21+	21	1.5602	2	2	2	3.1204	3.1204	3.1204
8	5-10	8	0.5944	0	0	0	0.0000	0.0000	0.0000
9	5-10	8	0.5944	3	3	3	1.7831	1.7831	1.7831
10	5-10	8	0.5944	2	3	3	1.1887	1.7831	1.7831
11	11-20	16	1.1887	1	1	1	1.1887	1.1887	1.1887
12	5-10	8	0.5944	1	1	1	0.5944	0.5944	0.5944
13	5-10	8	0.5944	1	1	1	0.5944	0.5944	0.5944
14	5-10	8	0.5944	1	1	1	0.5944	0.5944	0.5944
15	21+	21	1.5602	3	3	3	4.6805	4.6805	4.6805
16	11-20	16	1.1887	5	5	4	5.9435	5.9435	4.7548
17	0	0	0.0000	0	0	0	0.0000	0.0000	0.0000
18	21+	21	1.5602	0	0	0	0.0000	0.0000	0.0000
19	21+	21	1.5602	0	0	0	0.0000	0.0000	0.0000
20	11-20	16	1.1887	4	3	3	4.7548	3.5661	3.5661
21	11-20	16	1.1887	4	3	3	4.7548	3.5661	3.5661
22	5-10	8	0.5944	5	5	5	2.9718	2.9718	2.9718
23	< 5	5	0.3715	5	5	5	1.8574	1.8574	1.8574
24	5-10	8	0.5944	4	4	3	2.3774	2.3774	1.7831
25	5-10	8	0.5944	4	4	4	2.3774	2.3774	2.3774
26	5-10	8	0.5944	4	4	4	2.3774	2.3774	2.3774
27	5-10	8	0.5944	4	4	4	2.3774	2.3774	2.3774
28	11-20	16	1.1887	4	4	3	4.7548	4.7548	3.5661
29	21+	21	1.5602	3	2	2	4.6805	3.1204	3.1204
30	21+	21	1.5602	4	4	4	6.2407	6.2407	6.2407
31	5-10	8	0.5944	5	5	4	2.9718	2.9718	2.3774
32	5-10	8	0.5944	5	5	4	2.9718	2.9718	2.3774
33	5-10	8	0.5944	5	5	4	2.9718	2.9718	2.3774
34	5-10	8	0.5944	5	5	4	2.9718	2.9718	2.3774
35	5-10	8	0.5944	5	5	4	2.9718	2.9718	2.3774
36	11-20	16	1.1887	2	3	2	2.3774	3.5661	2.3774
37	21+	21	1.5602	5	5	3	7.8009	7.8009	4.6805
38	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
39	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
40	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
41	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
42	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
43	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
44	21+	21	1.5602	0	0	0	0.0000	0.0000	0.0000
45	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
46	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
47	< 5	5	0.3715	1	1	2	0.3715	0.3715	0.7429
48	< 5	5	0.3715	1	1	2	0.3715	0.3715	0.7429

49	< 5	5	0.3715	1	1	2	0.3715	0.3715	0.7429
50	< 5	5	0.3715	1	1	2	0.3715	0.3715	0.7429
51	< 5	5	0.3715	1	1	2	0.3715	0.3715	0.7429
52	< 5	5	0.3715	1	1	2	0.3715	0.3715	0.7429
53	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
54	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
55	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
56	11-20.	16	1.1887	5	5	5	5.9435	5.9435	5.9435
57	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
58	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
59	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
60	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
61	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
62	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
63	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
64	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
65	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
66	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
67	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
68	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
69	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
70	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
71	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
72	5-10	8	0.5944	3	3	3	1.7831	1.7831	1.7831
73	5-10	8	0.5944	4	4	4	2.3774	2.3774	2.3774
74	11-20	16	1.1887	1	1	1	1.1887	1.1887	1.1887
75	21+	21	1.5602	3	3	3	4.6805	4.6805	4.6805
76	21+	21	1.5602	3	3	3	4.6805	4.6805	4.6805
77	21+	21	1.5602	3	3	3	4.6805	4.6805	4.6805
78	11-20	16	1.1887	2	2	2	2.3774	2.3774	2.3774
79	11-20	16	1.1887	3	3	3	3.5661	3.5661	3.5661
80	21+	21	1.5602	2	3	3	3.1204	4.6805	4.6805
81	11-20	16	1.1887	1	1	1	1.1887	1.1887	1.1887
82	21+	21	1.5602	2	2	2	3.1204	3.1204	3.1204
83	21+	21	1.5602	2	2	2	3.1204	3.1204	3.1204
84	11-20	16	1.1887	2	2	2	2.3774	2.3774	2.3774
85	11-20	16	1.1887	3	3	3	3.5661	3.5661	3.5661
86	11-20	16	1.1887	3	3	3	3.5661	3.5661	3.5661
87	21+	21	1.5602	5	5	4	7.8009	7.8009	6.2407
88	11-20	16	1.1887	5	5	4	5.9435	5.9435	4.7548
89	11-20	16	1.1887	5	5	4	5.9435	5.9435	4.7548
90	11-20	16	1.1887	5	5	4	5.9435	5.9435	4.7548
Total		1346	100.00				371.40	370.80	360.03
Mean Value (MV_{PR4})		**=**	$\lvert\sum Ei_{X1\text{-}3}\rvert / N_{total}$				**4.1**	**4.1**	**4.0**

Ei *= Experimental Input,* ***X*** *= Value for individual experimental inputs for cost, time and quality*
i *= Respondents inputs,* $X_1 = i_c =$ *Respondents inputs for project cost,* $X_2 = i_t =$ *Respondents inputs for project time and* $X_3 = i_q$ *= Respondents inputs for project quality,* N_{total} *= Total number of respondents*

6. Respondent’s Mean Scores of Importance for Potential Risks (P_{R5}): Political Risks

Number of respondents	Years of experience (Y) in %			Input (*i*) for G_5 under Cost (*c*), Time (*t*) & Quality (*q*)			Experimental Input (E*i*) E*i* = Y**i*		
N	*Yr. Range*	*Year (Yr)*	*Y (%)*	i_c	i_t	i_q	$Y\ i_c$	$Y\ i_t$	$Y\ i_q$
1	11-20	16	1.1887	3	4	2	3.5661	4.7548	2.3774
2	11-20	16	1.1887	3	3	2	3.5661	3.5661	2.3774
3	11-20	16	1.1887	3	5	2	3.5661	5.9435	2.3774
4	< 5	5	0.3715	3	1	1	1.1144	0.3715	0.3715
5	11-20	16	1.1887	3	2	2	3.5661	2.3774	2.3774
6	0	0	0.0000	0	0	0	0.0000	0.0000	0.0000
7	21+	21	1.5602	2	2	2	3.1204	3.1204	3.1204
8	5-10	8	0.5944	0	0	0	0.0000	0.0000	0.0000
9	5-10	8	0.5944	4	4	3	2.3774	2.3774	1.7831
10	5-10	8	0.5944	3	4	3	1.7831	2.3774	1.7831
11	11-20	16	1.1887	4	2	4	4.7548	2.3774	4.7548
12	5-10	8	0.5944	4	2	4	2.3774	1.1887	2.3774
13	5-10	8	0.5944	4	2	4	2.3774	1.1887	2.3774
14	5-10	8	0.5944	4	2	4	2.3774	1.1887	2.3774
15	21+	21	1.5602	5	5	2	7.8009	7.8009	3.1204
16	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
17	0	0	0.0000	0	0	0	0.0000	0.0000	0.0000
18	21+	21	1.5602	0	0	0	0.0000	0.0000	0.0000
19	21+	21	1.5602	0	0	0	0.0000	0.0000	0.0000
20	11-20	16	1.1887	4	4	3	4.7548	4.7548	3.5661
21	11-20	16	1.1887	1	1	1	1.1887	1.1887	1.1887
22	5-10	8	0.5944	5	5	5	2.9718	2.9718	2.9718
23	< 5	5	0.3715	5	5	3	1.8574	1.8574	1.1144
24	5-10	8	0.5944	5	5	3	2.9718	2.9718	1.7831
25	5-10	8	0.5944	4	4	4	2.3774	2.3774	2.3774
26	5-10	8	0.5944	4	4	4	2.3774	2.3774	2.3774
27	5-10	8	0.5944	4	4	4	2.3774	2.3774	2.3774
28	11-20	16	1.1887	4	4	3	4.7548	4.7548	3.5661
29	21+	21	1.5602	1	1	1	1.5602	1.5602	1.5602
30	21+	21	1.5602	4	4	4	6.2407	6.2407	6.2407
31	5-10	8	0.5944	2	3	3	1.1887	1.7831	1.7831
32	5-10	8	0.5944	2	3	2	1.1887	1.7831	1.1887
33	5-10	8	0.5944	2	3	2	1.1887	1.7831	1.1887
34	5-10	8	0.5944	2	3	3	1.1887	1.7831	1.7831
35	5-10	8	0.5944	2	3	3	1.1887	1.7831	1.7831
36	11-20	16	1.1887	2	2	2	2.3774	2.3774	2.3774
37	21+	21	1.5602	5	5	3	7.8009	7.8009	4.6805
38	21+	21	1.5602	5	5	2	7.8009	7.8009	3.1204
39	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
40	11-20	16	1.1887	5	2	2	5.9435	2.3774	2.3774
41	11-20	16	1.1887	5	2	2	5.9435	2.3774	2.3774
42	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
43	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
44	21+	21	1.5602	0	0	0	0.0000	0.0000	0.0000
45	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
46	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
47	< 5	5	0.3715	5	4	1	1.8574	1.4859	0.3715
48	< 5	5	0.3715	5	4	1	1.8574	1.4859	0.3715

49	< 5	5	0.3715	5	3	1	1.8574	1.1144	0.3715
50	< 5	5	0.3715	5	3	1	1.8574	1.1144	0.3715
51	< 5	5	0.3715	5	4	1	1.8574	1.4859	0.3715
52	< 5	5	0.3715	5	4	1	1.8574	1.4859	0.3715
53	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
54	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
55	21+	21	1.5602	5	3	5	7.8009	4.6805	7.8009
56	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
57	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
58	21+	21	1.5602	5	3	5	7.8009	4.6805	7.8009
59	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
60	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
61	21+	21	1.5602	5	3	2	7.8009	4.6805	3.1204
62	21+	21	1.5602	5	5	2	7.8009	7.8009	3.1204
63	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
64	21+	21	1.5602	5	3	5	7.8009	4.6805	7.8009
65	21+	21	1.5602	5	5	2	7.8009	7.8009	3.1204
66	21+	21	1.5602	5	3	2	7.8009	4.6805	3.1204
67	21+	21	1.5602	5	5	2	7.8009	7.8009	3.1204
68	21+	21	1.5602	5	3	2	7.8009	4.6805	3.1204
69	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
70	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
71	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
72	5-10	8	0.5944	3	3	2	1.7831	1.7831	1.1887
73	5-10	8	0.5944	5	5	2	2.9718	2.9718	1.1887
74	11-20	16	1.1887	1	1	1	1.1887	1.1887	1.1887
75	21+	21	1.5602	3	2	2	4.6805	3.1204	3.1204
76	21+	21	1.5602	3	2	2	4.6805	3.1204	3.1204
77	21+	21	1.5602	3	2	2	4.6805	3.1204	3.1204
78	11-20	16	1.1887	3	1	1	3.5661	1.1887	1.1887
79	11-20	16	1.1887	4	4	3	4.7548	4.7548	3.5661
80	21+	21	1.5602	3	4	3	4.6805	6.2407	4.6805
81	11-20	16	1.1887	4	2	4	4.7548	2.3774	4.7548
82	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
83	21+	21	1.5602	5	5	5	7.8009	7.8009	7.8009
84	11-20	16	1.1887	5	5	2	5.9435	5.9435	2.3774
85	11-20	16	1.1887	5	4	2	5.9435	4.7548	2.3774
86	11-20	16	1.1887	5	4	5	5.9435	4.7548	5.9435
87	21+	21	1.5602	5	5	2	7.8009	7.8009	3.1204
88	11-20	16	1.1887	5	4	2	5.9435	4.7548	2.3774
89	11-20	16	1.1887	5	4	5	5.9435	4.7548	5.9435
90	11-20	16	1.1887	5	5	5	5.9435	5.9435	5.9435
Total		1346	100.0000				401.56	359.36	310.33
Mean Value (MV_{PR5})		=	$\|\sum Ei_{X1-3}\|/N_{total}$				**4.5**	**4.0**	**3.4**

Ei *= Experimental Input,* ***X*** *= Value for individual experimental inputs for cost, time and quality*

i *= Respondents inputs,* $X_1 = i_c =$ *Respondents inputs for project cost,* $X_2 = i_t =$ *Respondents inputs for project time and* $X_3 = i_q$ *= Respondents inputs for project quality,* N_{total} *= Total number of respondents*