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Megaproject Risk Analysis and Simulation: A Dynamic Systems Approach

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Chapter 1

1.1 Introduction

Major stakeholders on megaprojects have been facing risks associated with social, technical, economic, environmental, and political (STEEP) issues that may lead to significant cost and time overruns compared with initial budget and schedule estimates. Although much attention have been devoted to managing risks in megaproject delivery, results have always not been satisfactory in most cases across the world in the past. There have been increasing needs for advanced tools to support better risk assessment so as to inform decision making in megaproject management. Regarding the complexity of megaprojects, and the gigantic scope for risks and their interaction in megaproject construction and development, it has been widely accepted that quantitative approaches are necessary supplements in risk analysis process. However, there has been little attempt to apply sophisticated methods recommended by industry standards for risk analysis in megaproject practice. Through developing and using a dynamic systems approach over a 4-year period, the authors of the books have found a new tool that can significantly identify major project risk factors and provide predications on time and cost overruns with over 80 percent accuracy compared to real figures in one megaproject, i.e., the Edinburgh Tram Network (ETN) project, and they wish to summarise their research into megaproject risk analysis and simulation in this book to inform both academic researchers and megaproject stakeholders who have interest in qualitative and quantitative risk analysis and simulation for megaprojects across the world.

This book covers all aspects of a real case study oriented research into megaproject risk analysis and simulation through a dynamic systems approach. A case study on the ETN project is used as an example of megaproject to develop a general technical framework called SDANP for STEEP risks risk analysis and simulation on megaprojects. An analytic Network Process (ANP) (2015) is adopted for risk quantification modelling while a system dynamics (SD) (Brookes, 2015; Dimitriou, 2014; Flyvbjerg, 2014; Flyvbjerg et al., 2003a; Mentis, 2015; Priemus, 2014; Renuka et al., 2014; Spirkova, 2014; Van de Graaf and Sovacool, 2014) for risk simulation overtime. Both the ANP and SD provide practical guides for the application of the dynamic systems approach in megaproject research and practice.

By providing crucial background information for those who want to understand the dynamics of risks over time and their assessment during the decision-making processes on large transport infrastructure projects, this book can prove an important source of information for academics, researchers and students in the fields of transport, infrastructure, project management, management science, economic analysis (cost–benefit analysis), public policy, environmental policy and ethics. Practitioners, politicians and policymakers involved in large transport infrastructure projects can also find this book to be a useful reference of risk analysis and simulation for megaproject management.

1.2 Problem Statement

1.2.1 Megaproject risks

Flyvbjerg, et al. (2003b) found that 258 highway and rail projects ($90 billion worth) in 20 countries did not perform well on budgets as estimated; and about 90 percent of these projects suffered cost overruns, with the average rail project costing 45 percent more than what were projected, while it was over 20 percent in average for highway projects. Based on a continuous research, Flyvbjerg et al. (2003b) underscored that cost overrun has not decreased over 70 years in the 20th century and seems to be a global phenomenon, which can also be attested on many megaprojects. For example, the Pusan and Muckho harbour project suffered significant cost overruns in the mid-1970s and relied on an extra $75 million loan for it to complete (2003b), and the Big Dig project was estimated at a cost of $2.6 billion but was completed at a cost of $14.6 billion, additionally completion was delayed from 2002 to 2005 (2003b). These projects have made the learned society and the public acutely aware of the problems of project delay and cost overruns in megaproject development. In addition, these technical problems also indicate clearly that construction cost estimating on major infrastructure projects has not been improved in accuracy in the past more than half century, and the magnitude of underestimated project costs has been almost in the same order according to Flyvbjerg et al. (2002) and Salling and Leleur (2015). It has been identified by Flyvbjerg et al. (2002) that the main possible reason for cost and time overruns in many megaprojects across the world was to simplify the marginalisation of risks during feasibility studies by undependably assuming what the World Bank calls the “Everything Goes According to Plan” (EGAP) principle, and there have been increasing needs for new ideas and techniques (Davies et al., 2014; Flyvbjerg et al., 2002; Kwak et al., 2014) in order to tackle all risks associated with those significant problems for making the right decisions conditions (Mentis, 2015) on both business and project towards successful megaproject.

Evidence gleaned through research worldwide suggests that large and complex infrastructure projects such as airport, bridge, and highway 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 taking corrective actions to effectively control and manage the identified risks at the right time. Poole (Brookes, 2015; Dimitriou, 2014; Flyvbjerg, 2014; Flyvbjerg et al., 2003a; Mentis, 2015; Priemus, 2014; Renuka et al., 2014; Spirkova, 2014; Van de Graaf and Sovacool, 2014) asserts that the track record of megaprojects under his study was terrible during developmental phases and reflected many credibility problems especially on transportation megaprojects. Proost et al. (2014) and Salling and Leleur (2015) emphasised that costs for transportation megaprojects were often grossly underestimated while traffic is often overestimated, and the perceived failure of the project was subject to a public enquiry, which concluded that the planned budget and schedule were hardly realistic although some of the cost increases were justified spending indeed. In reality, significant wastes were caused by design delays, over-optimistic programming and uncertain authority at the construction and development stages of megaprojects.

The construction industry, like many other industries is a free-enterprise system, and has sizeable risks built into its structure and project based processes (Ball, 2014; Fulford and Standing, 2014; Guo et al., 2014). From the initiation to the closing stages, construction process especially that for megaproject development is complex and characterized by a number of uncertainties and inte(Brookes, 2015)ractions that can negatively influence the project delivery in many ways (Brookes, 2015; Dimitriou, 2014; Flyvbjerg, 2014; Flyvbjerg et al., 2003a; Mentis, 2015; Priemus, 2014; Renuka et al., 2014; Spirkova, 2014; Van de Graaf and Sovacool, 2014). For example, uncertainties about changes in weather conditions (Mentis, 2015), subcontractor delays (Diab and Nassar, 2012; Eizakshiri et al., 2015), community resistance (Jordhus-Lier, 2015), political interferences (Kennedy, 2015) and unpredictable site conditions (Adam et al., 2014; Boateng et al., 2012) can compromise the completion of megaproject development on time and on budget. Although economic and fiscal risks from natural disasters are quantifiable by using modern techniques, they remain difficult to incorporate into the megaproject decision-making process. As a result, many megaprojects fail to achieve their time, cost and quality goals (Brookes, 2015) due to a lack of accurate

assessment and timely control of risks associated with social, technical, economic, environmental, and political (STEEP) issues.

1.2.2 Megaproject risk assessment

Generally speaking, it has become a matured way to use statistical techniques for risk assessment and there have been many commercial software packages such as Palisade's @RISK to support professional risk analysis. Researchers such as Karimiazari et al. (2011) and Nieto-Morote and Ruz-Vila (2011) proposed the use of risk analysis techniques that are based on estimating probabilities and probability distributions for time and cost related risk assessment in projects. However, these techniques have limitations in terms of encouraging project participants to not only develop in-depth understanding of underlying risk elements and risk dynamics within interactive structures which constitute megaproject risk systems but also render explicit latent concepts and assumptions which are implicit to current risk assessment. Through learning from problems that led to significant cost and time overruns in megaproject delivery across the world, the authors of the book have a further review into the use of statistical techniques for risk assessment, and found some weaknesses. For example, these techniques do not allow for risks and uncertainties remedial measures in a complex project environment, and do not permit lessons and knowledge, which can be learned from previous projects with similar working environments, to be effectively captured and re-used for developing new projects, and as a result do not facilitate continuous learning and improvement at both enterprise and society level. All these weaknesses indicate a need for advanced risk assessment techniques to effectively tackle complex STEEP risks in mega construction and development projects.

With regards to the increasing complexity and dynamics of risks in megaproject construction and 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 Giezen (2012) and Kardes et al. (2013), a simple but an effective risk management approach can provide a framework for project managers to identify and response to potential risk factors quickly and to underpin effective and consistent communications throughout the construction supply chain; in addition, such a risk management framework can assist project members to implement early contingency plans to deal with problems resulting from the project environment. Mousavi et al. (2011) argued that the proliferation of techniques and software packages purporting to provide project risk management facilities unfortunately have failed to achieve anticipated and satisfactory results in practice, and it is therefore in need for using non-parametric jack-knife resampling technique to rank risks in megaprojects such as highway projects to meet the needs of project managers. For research into innovations in megaproject risk assessment, Mahato and Ogunlana (Mentis, 2015) applied the SD method for a case study on conflict dynamics in a dam construction project in Thailand, Chen and Khumpaisal (Brookes, 2015; Dimitriou, 2014; Flyvbjerg, 2014; Flyvbjerg et al., 2003a; Mentis, 2015; Priemus, 2014; Renuka et al., 2014; Spirkova, 2014; Van de Graaf and Sovacool, 2014) applied the ANP method for risks assessment in a large urban regeneration project in UK, and Chen, et al. (Brookes, 2015; Dimitriou, 2014; Flyvbjerg, 2014; Flyvbjerg et al., 2003a; Mentis, 2015; Priemus, 2014; Renuka et al., 2014; Spirkova, 2014; Van de Graaf and Sovacool, 2014) applied the ANP method for a total environmental risk assessment for three large international hub airports in China. These research initiatives have not only demonstrated the advantages of using ANP and SD in megaproject risk assessment, but also indicate the possibility and usefulness to form a new technical framework that integrates these powerful methods for megaproject risk assessment.

1.2.3 A new risk assessment framework

It has been found from research that many of the risk management approaches developed by contractors and consultants are not dynamically enough to analyse and assess risks (Too and Too, 2010), as a result, communicating construction project risks become poor, incomplete, and inconsistent throughout the entire supply chain network of megaprojects. As emphasised by Davies et al. (2014) that it is vital for a successful management team to make innovation happen in megaproject delivery, and an effective risk management approach can provide a framework to identify and assess potential risks so that response actions can be

taken to mitigate risks. This book is therefore presents a new dynamic systems approach to megaproject risk analysis and simulation. It covers the prioritization and assessment of complex STEEP risks in megaproject development at construction stage and tests a novel risk analysis model on the ETN project. The model incorporates not only tangibles such as work-to-do and project cost but also intangibles such as uncertainties, grievances, and inadequate project complexity analysis in the risk assessment process by using ANP to prioritise STEEP risks and using SD to simulate the dynamics of such risks over the time of project delivery. The model is the core of the new SDANP framework to increase both analytical and dynamic capabilities over traditional risk assessment methods, which focus on analytical parameters such as cost, duration, quality, and probabilities, etc. but show a lack of incorporating heuristics.

Against the backdrop of risks in megaproject development and need for innovations in megaproject risk management, the authors, in the process of developing a new megaproject risk assessment framework, first employed a combination of quasi-ethnography, interviews and the literature to identify different STEEP risk factors that impacted on the performance of the ETN project at construction phase. The identified risk factors were then prioritised by using ANP to establish a set of the most salient STEEP variables on the project. These risk factors include material and energy price increases as a result of the 2008 recession, and inflation and changes as a result of government funding policies. The selected risk factors based on ANP ranking were then modelled within SD computing environment in order to appraise their measured impacts on the cost, time and quality performance of the project. The use of this approach is to gain a fuller understanding of the interrelationships between the multiple variables in the system, and to demonstrate the potential benefits of the SDANP methodology. The book therefore is to explore and model, by using such a new SDANP framework, problems caused by STEEP risks to construction cost, time and performance and to provide insights and toolkits that can lead to organizational learning and risk control in megaproject development. As effective knowledge gain and reuse have been adopted in the new risk assessment framework, it is expected that the new methodology could be used to improve the accuracy of risks estimation and prediction, and thereby effectively reduce the problem of cost and time overruns as well as quality deficiencies during megaproject delivery.

1.3 Purpose and scope

The purpose of this book is to provide the learned society with a technical summary of a dedicated 4-year research into megaproject risk analysis and simulation, and to make a good contribution to the body of knowledge in risk management on megaprojects. The research has been conducted under the Megaproject Management research theme at Heriot-Watt University from 2010 to 2014, and through collaborative research extensively with partners among 21 European countries at COST Action TU1003 (The effective design and delivery of megaprojects in the European Union) from 2011 to 2015. This book focuses on technical descriptions about a newly developed dynamic systems approach to megaproject risk analysis and simulation with regard to its methodology and application in a real case study on the ETN project. This book therefore provides useful information and toolkits for both academic researchers and megaproject stakeholders with the latest information on quantitative and qualitative risks study for further research and development.

This book provides a dynamic risk assessment framework that incorporates ANP into SD models to form a new SDANP methodology which is a comprehensive and analytical approach to prioritise and simulate risks in megaprojects over the time of project delivery. The SDANP methodology described in this book has been developed through the 4-year research by achieving the following research objectives for risks analysis and simulation at the construction and development stages of megaproject:

- describe a set of significant risks across all STEEP issues related to megaprojects,
- develop a technical framework that utilises ANP for STEEP risks prioritization,
- simulate all identified STEEP risk factors based on their interactions over project period within a SD environment, and

- integrate ANP and SD models to form a new SDANP methodology as a dynamic systems approach to risk analysis and simulation.

Just as solving any engineering and/or managerial problem requires the definition of system boundaries, writing a book like this 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. Therefore, the risks considered in this research include an entire set of risks associated with STEEP issues which result in cost and schedule overruns in megaproject delivery. Following data obtained from literature, field study, and questionnaire survey, an incorporated case study on the ETN project was used to develop and validate the proposed risk assessment models for illustrative decision making process on risk management on megaprojects.

Most of the techniques upon which this research is based were derived from the theories of ANP and SD. For the development of the new SDANP methodology, 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, individual STEEP risk system model fulfilled the following two main conditions when they were developed:

- have a large number of risk components that cannot be influenced by the internal environment of the project, and
- exhibit social, technical, economic, environmental and political complexity.

STEEP complexity in megaprojects is not a discrete characteristic but can be defined along a continuum which ranges from very simple elements within a risk cluster to extremely complex interactions across risk clusters. As complexity is relative and a function of current intellectual manageability, which is evolving as new tools and techniques are developed (Remington and Pollack, 2007; Smyth, 2014), it is a big challenge at present to quantitatively measure the degree of complexities and their interactions within individual STEEP sub-systems as well the entire STEEP system which all megaprojects face. The goal of the SDANP risk assessment approach is not to eliminate all risks from the project but to identify significant risk challenges and their complex interactions to the project over its construction and development phases, and to initiate appropriate management responses for risk control by recognise the consequences of complex risk interactions. From this point of view, this book provides examples illustrating the set of complex STEEP sub-systems and their integration on megaprojects.

The strategic use of the new approach being provided in this book is to inform the learned society by enhancing the understanding of strengths, weaknesses, opportunities and threats among existing project risk management tools given by the series of international standards on risk management, including

- ISO 31000:2009 Risk management – Principles and guidelines, and
- ISO/IEC 31010:2009 Risk management – Risk assessment techniques;

In addition to their implications for risk assessment for megaprojects at construction and development stages. This book also highlights the importance of the new approach to remove a number of constraints and communicate a sense of dependability into the decision-making process in megaproject over the time of project delivery. This implies that it provides a complete technical framework to facilitate understanding the criteria used for evaluating and assigning ratings to system elements, and the dynamic interrelationship among those elements. The simulation results derived from using the new approach can serve as reliable outputs for the project management team to depend on in making better decisions through computational risk assessment. This also implies that the SDANP approach to risk assessment can go beyond the strict decision metaphor and can be applied to support systematic thinking, group decision making, and most importantly modelling of complex dynamic project systems. Finally, it is the authors' expectation that the new approach can demonstrate how the adaptation of advanced techniques in risk analysis and simulation can significantly tackle persistent problems in cost and time overruns in megaproject delivery, and it can therefore provide a strong support for professionals to enhance their self-sustaining and grounded risk

management procedures to eliminate big risks and their adverse impacts in mega construction and development projects.

1.4 Structure of the book

This book comprises of six chapters and these have been organised as follows:

Chapter 1: Introduction. This chapter provides an overview of the book, giving why it is needed and placing its contents in a context that demonstrates its importance with regard to a timely contribution to the body of knowledge in megaproject risk management and its usefulness for practice. The introduction covers the background and scope of the book based on a statement of a recent research into megaproject risks and simulation by developing a dynamic systems approach and it also provides useful information regarding how this book can be used in megaproject risk management.

Chapter 2: The Edinburgh Tram Network (ETN) Project. This chapter provides an extensive review of the history of the Edinburgh Tram Network (ETN) project, which is used as a case project in this book to aid the development of the new dynamic systems approach to megaproject risk analysis and simulation. The state-of-the-art review summarises historical information about the case project for a better understanding of the complex environment of megaproject risks. In addition, this chapter provides an experimental procedure for both academics and practitioners to learn lessons from the history of a specific megaproject in an effective way with regard to risks analysis.

Chapter 3: Megaproject risks Assessment Framework. This chapter provides an entire framework of qualitative risks analysis for megaprojects. The risk analysis framework is to deal with the inherent STEEP risks in megaproject construction and development. Under the risk analysis framework, this chapter focuses on the ETN project to demonstrate the method and scope of the quantitative risks analysis for megaprojects. In addition, the chapter delivers a critical review of the entire case project and to identify mistakes and pitfalls which have led to risks of project cost and time overruns and quality deficiency at the construction phase of the project.

Chapter 4: Megaproject Risk quantification. This chapter provides technical details on the development of an analytic network process (ANP) model for quantitative risks analysis for megaprojects and utilise the case project to demonstrate the procedure and effectiveness of using ANP in risk quantification. The chapter provides a novel algorithm called Risk Priority Index (RPI) for project risk ranking based on STEEP analysis. With regard to the result of using RPI in the case project, hypotheses on project risks are made and further tested to demonstrate its usefulness. In addition, this chapter provides a guide for using RPI in risk prioritization for megaproject construction and development.

Chapter 5: Risk simulation. This chapter provides technical details on the development of a set of system dynamics (SD) models for risk simulation on megaprojects and utilise the case project to demonstrate the procedure and effectiveness of using SD in STEEP risk simulation. With regard to the result of using SD in the case project, this chapter further provides a comparison study on cost and time overruns in the case project to demonstrate the usefulness of the risk simulation method. In addition, this chapter provides a guide for using SD in risk simulation for megaproject development and construction.

Chapter 6: Conclusions. This chapter provides a technical summary of the book with regard to the value and contribution of the dynamic systems approach to megaproject risks analysis and simulation. It also provides an overall guide on the application of the dynamic systems approach by major stakeholders in megaproject construction and development. In addition, the chapter discusses limitations of current research described in the book and make comments on further research into megaproject risks analysis and simulation.

1.5 Originality and value

An original contribution to knowledge is an important concern of the research described in this book. The problem is that the concept of originality could be subject to individual judgment or preference. Several researchers have documented various ways to demonstrate originality. Some of the ways include the 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 book demonstrates the use of advanced techniques and an innovative technical framework to quantitatively describe the dynamic effects of STEEP risks on the performance of a megaproject.

This book makes the following contributions to the body of knowledge in megaproject management:

- A theoretical identification of a set of the interrelated and interactive variables of STEEP risks in megaproject development.
- An original application of ANP method to prioritise all STEEP risk factors in a unique megaproject environment. The ANP model described in this book is capable of dealing with all kinds of feedback and dependence in modelling the complicated situation of interactive risks with uncertainty and dynamic complexity in megaprojects, and provides a reliable and useful ranking list among all STEEP risks to inform calculated decision making based on the effective use of knowledge retrieved from a large group of megaproject experts.
- An original application of SD method to predict the risks of cost and time overruns as well as quality deficiencies in a megaproject during construction based on the complex STEEP interactions of the influencing risk variables. The developed SD conceptual model and its sub-system models reflect the system thinking aspect, and are capable of improving the theoretical knowledge base regarding the complex intrinsic inter-relationships that exist among the STEEP risk influences in megaproject development.
- A new risk assessment framework for megaproject management. The SDANP framework including its 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.
- An innovation to incorporate advanced risk analysis and simulation into megaproject management. The SDANP system models provided in this book 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.
- A unique experimental case study on the ETN project that demonstrates accurate simulation results, comparing with real figures in project delivery; and it also provide a promising result for better understanding and control of cost and time overruns in megaproject delivery.

This book has implications for the learned society and stakeholders involved in megaproject management. For policy makers, it provides an advanced decision making tool upon which different scenarios regarding STEEP risk assessment strategies can be tested before implementing business plans on megaprojects. For academic researchers, it would make a good contribution to the theoretical development of megaproject risk management. It provides an innovative technical framework that offers a platform to incorporate tangible and intangible risk variables into a risk assessing process using ANP for prioritising risks and SD for simulating those risks overtime. For megaproject practitioners, it challenges the paradigm of considering the new SDANP methodology as a successful risk assessment in megaprojects. Being compared with

traditional risks assessment methods, this book provides the promising results obtained from an integrative use of ANP and SD, which has revealed improvements in managing risks against STEEP criteria in megaprojects. In addition, the new SDANP framework described in this book appears to be a superior solution for solving persistent problems in time and cost overruns in terms of the dynamic complexities of various risks at construction and development stages on megaprojects.

1.6 Summary

This chapter provides an introduction to the book by telling readers about technical problems that the book addresses for megaproject risk management, the purpose and scope of this book, the structure of the book, and the originality and value of the book. As described in this chapter, this book provides a competency-based SDANP technical framework and its toolkits to represent a robust mechanism for assessing impact of STEEP risks on the performance of megaproject at the construction and development phases. The framework and its toolkits could be used by megaproject managers to reveal the behaviour of risks and maximise project performance over time. It is contended that the SDANP models have the would-be abilities to improve the performance of PMs anywhere in the world, and could be used as part of a wider sphere of risk management practices and procedures.

The significance of this book in particular aspects relating to the potential contribution to knowledge has been illuminated. In details, this book provides the following to readers within the learned society with regard to demonstrating a useful set of toolkits for risk analysis and simulation in megaprojects:

- A general risk analysis framework for megaproject construction and development, and a practice oriented procedure with a unique quantitative approach to effectively tackle all risks associated with STEEP issues affecting megaproject delivery.
- A comprehensive case study on the ETN project. The case study covers the history and profile of the project, lessons learnt from project delivery. The case study provides a whole story of the ETN project for both academics and practitioners to learn lessons from.
- A technical description about a new dynamic systems approach to quantitative risks analysis and simulation for megaproject delivery. For academics, it provides latest information about research into quantitative risks analysis and simulation for megaprojects. For practitioners, it provides new knowledge and useful tools for risk management in megaproject construction and development.
- A set of practice guides to qualitative and quantitative risk analysis and simulation based on tools developed from real case study within the megaproject environment.

The next chapter elaborates on the ETN project. The project is used as a case study because of its considerable significance and huge socio-economic interest it attracts and to offer appropriate foundation for demonstrating the application and effectiveness of the SDANP framework for dynamic risk assessment in this book.

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