2015

MODELLING ECONOMIC RISKS IN MEGAPROJECT CONSTRUCTION: A SYSTEMIC APPROACH

Boateng P[1]; Ahiaga-Dagbui D.D[1]; Chen Z[2], Ogunlana S.O[2]

[1] Scott Sutherland School of Architecture and Built Environment, Robert Gordon University, Aberdeen, AB10 7QB, Scotland, UK

[2] School of the Built Environment, Heriot-Watt University, Edinburgh, Scotland, EH14 4AS, UK

AUTHOR'S COPY –

Boateng P; Ahiaga-Dagbui D.D; Chen Z, Ogunlana S.O (2015) Modelling Economic Risks in Megaproject Construction: a systemic approach, In: *Procs 31st Annual ARCOM Conference*, Raiden A and Aboagye-Nimo E (Eds), Association of Researchers in Construction Management 7-9th Sept, 2015 Lincoln, UK.

MODELLING ECONOMIC RISKS IN MEGAPROJECT CONSTRUCTION: A SYSTEMIC APPROACH

Boateng P[1], Ahiaga-Dagbui D.D, Chen Z, Ogunlana S.O

Megaprojects present significant economic risks to their financiers and sponsors. Factors such as inflation, cash flow issues, material and energy price hikes and change in government policies can cause such capital intensive projects to overrun planned budget and schedule allocations. Where the project is a commercial asset, delayed completion time and cost overruns usually have significant impact on the profitability of the project as well as the estimated returns on investment over the operational phase of the project. Understanding the dynamics of specific risks can thus be very crucial in designing containment measures to deal with their likely impact on the project. Using a case-study of the Edinburgh Trams project in Scotland, the dynamics of identified economic risks in transportation megaprojects is presented. Through the combination of interviews, questionnaires and non-participant observation, different economic risk factors were first identified. The identified factors were then prioritised using Analytical Network Process (ANP) to establish the most salient economic variables on the Tram project. Some of these factors include material and energy price increases as a result of the 2008 recession, as well as inflation and changes in government funding policies. The selected factors from the ANP were then modelled within a System Dynamics (SD) framework to appraise their measured economic impact on the project to gain a fuller understanding of the interrelationships between the variables in the system. The mean impact of economic risks on Edinburgh Trams was estimated to be about 22%.

Keywords: analytical network process, cost overrun, economic risk, Edinburgh Trams, megaproject, system dynamics, risk management.

INTRODUCTION

An estimated USD 57 trillion investment will be needed to finance infrastructure development around the world by 2030, according to a report by Dobbs *et al* (2013). This represents an ambitious increase in infrastructure spending when compared to historical trends. Unfortunately, a significant number of capital intensive projects experience considerable multi-year and multi-million schedule and cost overruns (see, Ahiaga-Dagbui and Smith 2013, Ahiaga-Dagbui and Smith 2014a). One of the most cited sources of cost and schedule overruns in the literature is the ineffective management of risk and uncertainty (Creedy 2006, Okmen and Öztas 2010) largely due to a poor understanding of the systemic and dynamic nature of projects (Eden *et al.* 2005). Arguably, the nature of construction projects make them particularly prone to the effects of risk and uncertainty – each project is unique, often complex and dynamic; projects are exposed to the vagaries of the weather (not in a controlled environment); ground conditions are largely unpredictable; large public projects for

[1] P.Boateng@rgu.ac.uk

example usually take several years from conception to eventual project completion, making predictability rather challenging. However, even though risk and uncertainty seems to pervade the construction industry, all too often, they are either ignored or dealt with in a completely arbitrary manner using rules-of-thumb or contingency funds (Ahiaga-Dagbui and Smith 2014b). Project risk matrixes or registered have also been extensively used to identify or quantify risk. However, these do not account for the interactions or dynamics between risk factors. The crucial skill in risk management is not to be able to list or rank different factors as though they were stand-alone, but to be able to see the connections and dynamics between these various factors. As suggested by Ackermann *et al* (2007) different risks occurring at the same time, example, could form a portfolio where the impact of the whole is greater than the sum of the parts. Boateng *et al.* (2013) also found that the inability of project managers to assess risk dynamically in large projects are mostly a major cause of cost and time underperformance of megaproject construction. The aim of this paper, therefore, is to assess the dynamics of key economic risks on large infrastructure projects using a case study of the Edinburgh Tram Network which was completed in 2014. Data from triangulated sources of questionnaires, interviews and non-participant observations was modelled within a framework of Analytical Network Process and System Dynamics.

THE SYSTEM DYNAMICS

System Dynamics (SD) is based on information feedback structure which provides an avenue to understand the structure and dynamics of complex systems. According to Coyle (1996), SD has the capability to model the way information, actions and consequences interact to generate dynamic behaviours, diagnose the cause of faulty behaviours and to tune its feedback loops to get better behaviour. SD is particularly suitable for analysing highly dynamic systems that consist of multiple interdependent components involving several nonlinear relationships. Boateng *et al* (2012) used SD to model the impacts of critical weather conditions on construction activities and to describe its approach in assessing risks in megaproject during construction. Zhang *et al* (2014) developed an improved sustainable development ability (SDA) prototype model using SD to assess construction projects in terms of their sustainable development value over a project's life cycle. Ackermann *et al* (2007) developed a Risk Filter framework for identification and assessment of risks for a multinational project-based organisation using a systemic approach. Love *et al* (2002) have similarly developed an SD model which enables project managers to understand change and rework in construction project management systems. In this paper, the SD is combined with Analytical Network Process (ANP) to allow expert judgments to be synthesised into numerical values given their specific subjectivity inputs and to prioritize economic risks based on their relative impact on the performance of the project. The risk prioritization results derived from the ANP were integrated into the SD stock and flow modelling process at the risk simulation stage to analyse the behaviour patterns of risks and the level impacts of those risks on project performance over time.

CASE STUDY: THE EDINBURGH TRAMS PROJECT

The case study project is the recently completed Edinburgh Trams Project (ETN) in the UK. The construction involved new bridges, retaining walls, viaducts, a tram depot and control centre, electrical sub-stations to provide power to the overhead lines at 750 volts, track laying and tram stops. The project was procured mainly using a turnkey contract. The Client, City of Edinburgh Council (CEC), used a private limited company known as Transport Initiatives Edinburgh (TIE) to deliver the tram system. TIE is a company wholly owned by CEC who were responsible for project-managing the construction of the tramway from 2008. The role of Tie was to administer, integrate and coordinate the consultants and principal contractor, a consortium of Bilfinger Berger and Siemens (Rowson 2008). By February 2011, contractual disputes and further utility diversion works resulted in significant delays to the project beyond the originally planned programme. In late 2011, TIE was released from managing the ETN Project. Turner and Townsend (T&T), 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 under the management of T&T. After major scope reduction due to large cost overruns, the project was eventually completed three years late at a reported £776 million as against the initial project cost estimate of £375 million (Railnews 2012, City of Edinburgh Council 2014).

DATA

The data for this research was derived from triangulated sources i.e. interviews, a questionnaire survey and structured-case study of the Edinburgh Trams Project. The data was collected between April 2011 and December 2013. 300 questionnaires were distributed to members of the project's client team, site management team, consultants, subcontractors and suppliers. The project was visited twice a week throughout the data collection period for onsite non-participatory observations. Documentary evidence were also obtained from Audit Scotland, the main contractor, Bilfinger Berger (BBS), as well as other key participants involved in the project. Also, unstructured interviews were conducted and used primarily to determine the economic risk dynamics that influenced the cost, time and quality performances of the project. Coyle (1996) advocated such an approach for identifying and establishing dynamic relationships as the triangulated data sources allow for the generation of a rich database to develop the SD models.

SUMMARY OF QUESTIONNAIRE AND ANALYSIS

Out of 300 instruments delivered, 140 completed questionnaires were successfully retrieved, representing a 46.67% response rate. Among the 140 responses, 99 (71%) play a role as contractors' team member (Project engineer, Project manager and Site engineer), 17 were part of the consultant's team, 16 were from client's team while the remaining 8 did not provide any detail regarding the role they play in the ETN project. Majority (51%) of respondents worked on the project between 3-5 years, 43% for 1-2 years, 3% for less than a year, while 5 respondents (4%) had worked on the project for over 5 years.

To standardize the results gained from each survey participant, the identified economic risk variables were coded and tabulated (See Table 1). Using a Weighted Quantitative Score (WQS) method, Respondent's Mean Scores of Importance (RMSI) were calculated and the results summarised to aid the ANP pairwise calculations. In this regard, the results achieved by WQS are derived by the Equation 1.

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

Where

MV = value of mean scores of importance for each criteria/sub-criteria calculated by WQS.
E = experimental WQS for each sub/criteria expressed as a percentage year of experience multiplied by each participant's score of importance.
C = participant's score of importance for each sub/criteria with respect to cost.
T= participant's score of importance for each sub/criteria with respect to time.
Q= is the participant's score of importance for each sub/criteria with respect to quality.
n = total number of participants in this research.

Based on the rounded mean scores of importance, a pairwise comparison of the economic risk sub-areas was performed with the Super Decisions® software to derive the risk priority values. The pairwise comparison is a process of comparing risk variables in pairs to judge which of each variable has a greater amount of quantitative impact on the project performance. From the ANP computation, project cost, time and quality are each revealed to have equal synthesized priority weights of 0.33 (33%).

Table 1: Extract from Final ANP Decision Making Priority Results for economic risk factors

		Risk Priorities									
Economic risks		**Mean Values (MV_{Risks}) = $\frac{1}{n}\left(\sum_{i=1}^{n} E_{i(C,T,Q)}\right)$**			**Local Priorities (w)**			**Synthesized Priorities (W) = $w_{(C,T,Q)} * 0.33$**			**Risk Priority Index (RPI)**
Code	**Sub risks**	Cost	Time	Quality	Cost (0.33)	Time (0.33)	Quality (0.33)	C	T	Q	
					$w_{(c)}$	$w_{(t)}$	$w_{(q)}$	W_C	W_T	W_Q	$\sum W_{(C,T,Q)ij}$
$\mathbf{E_{V1}}$	Ch. in funding;	8.51	7.18	6.31	0.20	0.14	0.14	0.07	0.05	0.05	0.17
$\mathbf{E_{V2}}$	Taxation;	3.90	2.41	2.42	0.03	0.02	0.03	0.01	0.01	0.01	0.03
$\mathbf{E_{V3}}$	Change in gov.	7.01	6.81	5.84	0.09	0.14	0.14	0.03	0.05	0.05	0.13
$\mathbf{E_{V4}}$	Wage inflation;	3.38	2.34	2.35	0.02	0.02	0.03	0.01	0.01	0.01	0.03
$\mathbf{E_{V5}}$	Inflation change;	2.91	2.08	2.03	0.02	0.02	0.03	0.01	0.01	0.01	0.03
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

Values of CI, RI, CR and inconsistency (I) for the pairwise comparison matrix	**Criteria**	**λ_{max}**	**CI**	**RI**	**CR**	**I**
	Cost **(C)**	12.49	0.040	1.54	0.03	0.00
	Time **(T)**	12.35	0.030	1.54	0.02	0.00
	Quality **(Q)**	12.20	0.020	1.54	0.01	0.00

The local priority values suggest equal importance of the project objectives to respondents during construction of the ETN project. Consistency of respondent's judgment on the level of economic risks impacts on the project as obtained during the pairwise comparison for each risk with the Super Decisions® with a consistency threshold of 0.1 to judge whether the comparison conducted is consistent. Where consistency Ratio (C.R) ≤ 0, it meant that respondents' judgments satisfy this consistency. If not, the experts had conflicting judgments and therefore, the inconsistent elements in the comparison matrix have to be identified and revised. Analysis of the results in Table 1 indicates that respondent's answers to the prioritization on project objectives during the survey are consistent. Table 1 further presents the maximum Eigenvector (λmax), Consistency Index (CI), Relative Index (RI) and Consistency Ratio (CR) achieved for the economic risk factors in this research. The final Risk Priority Index (RPI) for the economic risk sub-areas is the addition of the synthesized weights of cost (WC) Time (WT) and quality (WQ).

Consequently, the RPI for EV1 is 0.17 (17%). The RPI for each risk variable is the final risk priority index that could be used as an indicator to attract a developer's attention to potential risks that have the highest level of impacts on project objectives. The values could also be imported into the SD to simulate the behaviour of such risks overtime so that appropriate mitigations procedures could be initiated.

DYNAMIC MODELLING OF RISK

The following steps were adopted to in this research to model the dynamics of economic risk during construction phase of the case study:

i. Problem identification and definition
ii. Initial model development
iii. Model verification (using expert opinion)
iv. Final model development and simulation (analysis of model behaviour)
v. Model validation using software tools and a case study
vi. Policy analysis, model use or implementation.

After the ANP's pairwise comparison, a model boundary was formed and a dynamic hypothesis, also known a causal loop diagram (CLD) was developed. The model boundary is used to define the limit within which the economic risk model will operate. It is a representation of "how far in the future should a modeller consider and/ or how far back in the past lie the roots of the problem?" Sterman (2010). The CLD contains risk variables that were identified to generate the problem behaviour on the cost and time performance of ETN project. Based on a verified CLD, a stock and flow diagram was finalised in December 2013, by an expert panel comprising 3 project managers, 2 site engineers, 1 system dynamic expert and a risk analyst. A stock is the term for any entity that accumulates or depletes over time whereas a flow is the rate of accumulation of the stock. Figure 3 illustrates the stock and flow model (SFM) which was developed based on a validated CLD. The SMF is developed with material price, economic risks, risk of project time overrun, risk of project cost overrun and quality deficiency in focus. However, the latter is excluded from the analysis in this paper due to lack of data from the real system for validation.

In the SFM, variables such as 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 indicated on Figure 1. It can further be noted that economic risks variable is affected by the economic certainties. Similarly, risks of project time and cost overruns are influenced by escalation in project time and escalation to project cost to stock risks of project time and cost overruns respectively. Further, consideration on the SFM show that a number of variables influence risk of project time and cost overrun through escalation of project time and cost overruns. Due to space limitation, the governing equations used to calculate the system parameters for this model are not provided in this paper.

After the model equation formulation, two assessment tests were conducted to check the structural conditions of the model. First, structure verification was performed to compare the structure of the model directly with structure of the real system that the model represents. To pass the structure-verification test, the model structure must not contradict knowledge about the structure of the real system. As a result, a review of model assumptions was carried out with the help of two Project Managers who are highly knowledgeable about corresponding parts of the real system. Second, a dimensional consistency test was conducted on the SFM. This test was conducted to satisfy the dimensional consistency of the model. By inclusion of parameters with little or no meaning as independent structural components, often reveals faulty model structure when this test is performed. Messages from Vensim's built-in function indicated that the dimensional tests conducted on the economic risks model are consistent.

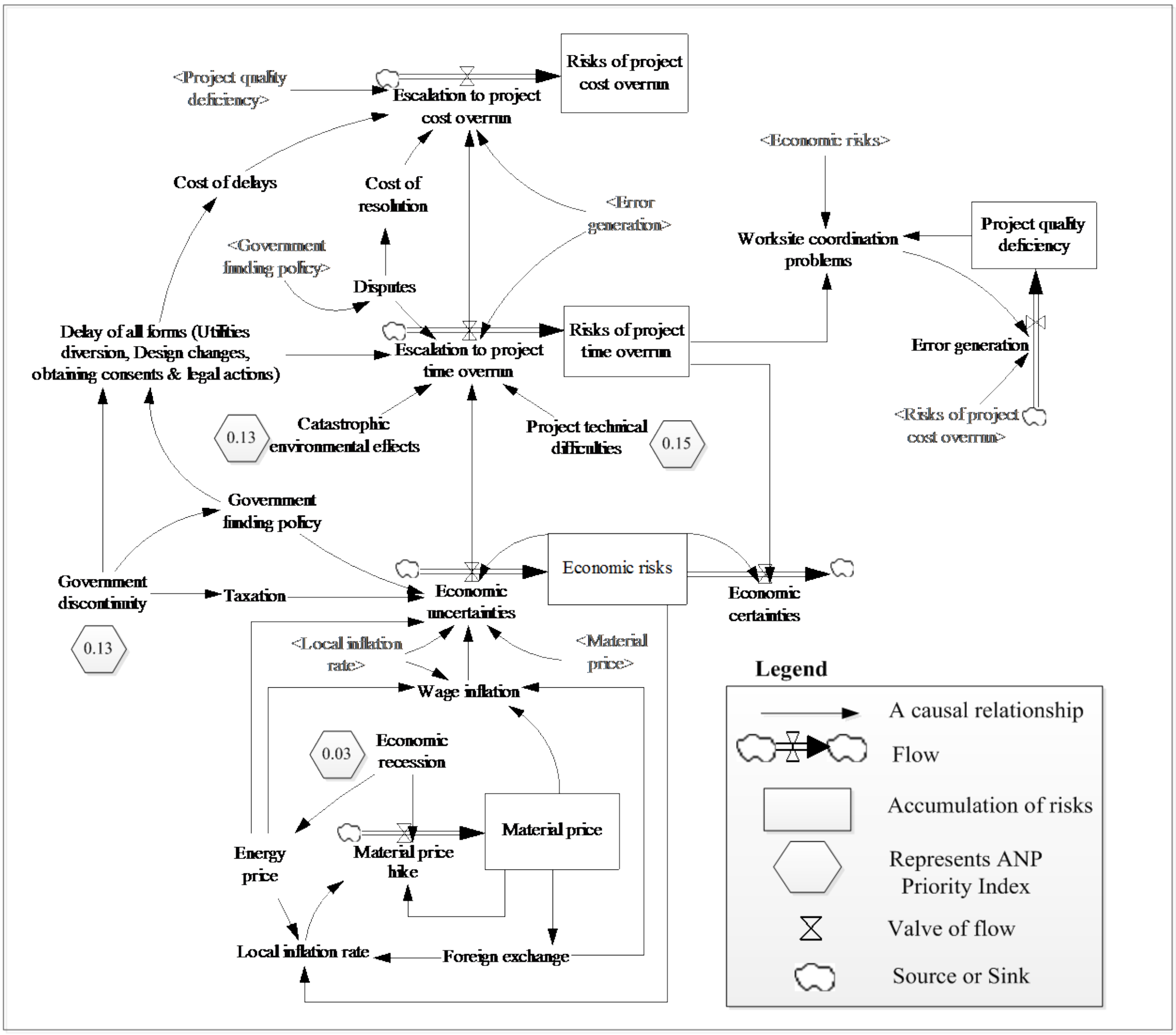

Figure 1: Stock and flow diagram for economic risks

DYNAMIC SIMULATION RESULTS AND DISCUSSION:

In system dynamics simulation, trend analysis is given priority 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 modelling, the ANP input to the system to conduct simulation is represented in Table 2.

Table 2: Summary of the ANP Inputs

Code	System Variables	*ANP's RPI (%)
EV3:	Government discontinuity (change)	13
EV8:	Economic recession	03
EV10:	Catastrophic environmental effects;	13
EV11:	Project technical difficulties	15

Also, the outputs indicated on Table 3 revealed the dynamic simulation results under the following time bounds and units of measurements for system variables:

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*
iv *Unit of measurement for system variables = Dimensionless*

It can be observed on Table 3 and Figure 2 that project time and cost are all impacted by economic risks. The mean impact level of economic risks (PR3) on ETN project is revealed to be 21.50%. Time was the most sensitive to the impact of economic risks. The mean scores of project time and cost overruns of 30.74% and 22.36% respectively on the project.

Table 3: Extract of Summary of the Dynamic Simulation Outputs

		Expected Level of Risk in the project (%)					
		Min	Max	Mean	Median	StDev	Norm
PR3	Economic risks	1.72	33.0	**21.5**	26.07	10.73	49. 86
EV1:	Change in government funding policy	2.21	2.21	2.21	2.21	0.00	0.00
EV2:	Taxation	0.39	0.39	0.39	0.39	0.00	0.00
EV4:	Wage inflation	1.01	1.67	1.50	1.57	0.19	12.41
EV5:	Local inflation	3.29	33.7	22.5	26.67	10.37	46.17
EV6:	Foreign exchange	0.24	1.41	0.80	0.77	0.39	49.42
EV7:	Material price	8.00	47.1	26.6	25.65	13.14	49.42
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
EV23:	Worksite coordination problems	15.9	33.5	25.6	26.90	6.29	24.56

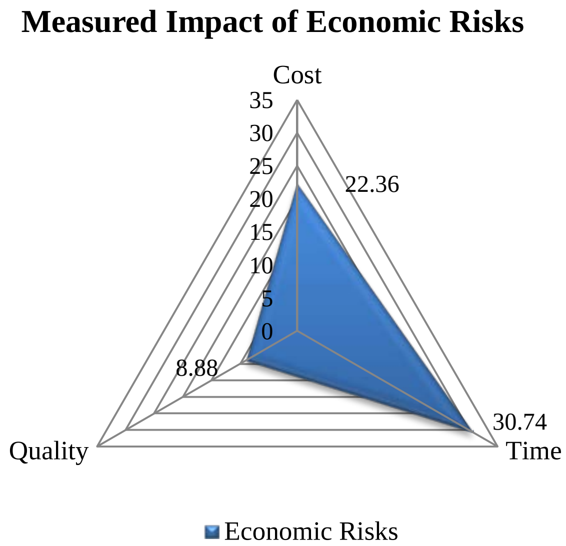

Figure 2: Measured Impact of Economic Risks

Further to the numerical simulation, results from the system dynamic simulation patterns were also generated to investigate the influence of exogenous parameters such as economic recession, government discontinuity, catastrophic environmental effects and project technical difficulties on the project time and cost performances in two ways. First the RPIs used as inputs into the SD were fixed to *no influence* impact level (0%) for the base-runs simulation and secondly to *high influence* impact level

(100%) for the current or actual simulation run based on the actual risk priority index obtained from the ANP pairwise calculations. As seen in Figure 3, the initial dynamic pattern based on the actual simulation run turns to increase steadily even with no risk influence from the exogenous system variables within the first two years of the project before declining after 2010.

However, when the values inputted in the system were replaced with the RPIs, it can be observed that after approximately two years and 48 days (2008-2010.13), the dynamic impact pattern of the economic risks (PR3) increased steadily to reach a maximum point of 33.03% before declining to a minimum value of 1.72% in year 2015. It is important to note that even with no influence from the exogenous system variables, the level of economic risks impact was as close to 32% in year 2010 and 48 days into year 2011 but declined steadily to 0% in year 2015. From a holistic point of view, whether values of the exogenous variables are changed or not, the overall dynamic patterns for the risks of project time and cost overruns would have increased to a considerable level and would then become a critical point for the megaproject developer to assess what the cause might be. This is where the experience of a project manager's ability to plan for effective risks assessment will come into play. Therefore, SD/ANP based simulation should only substantiate or aid managerial decisions.

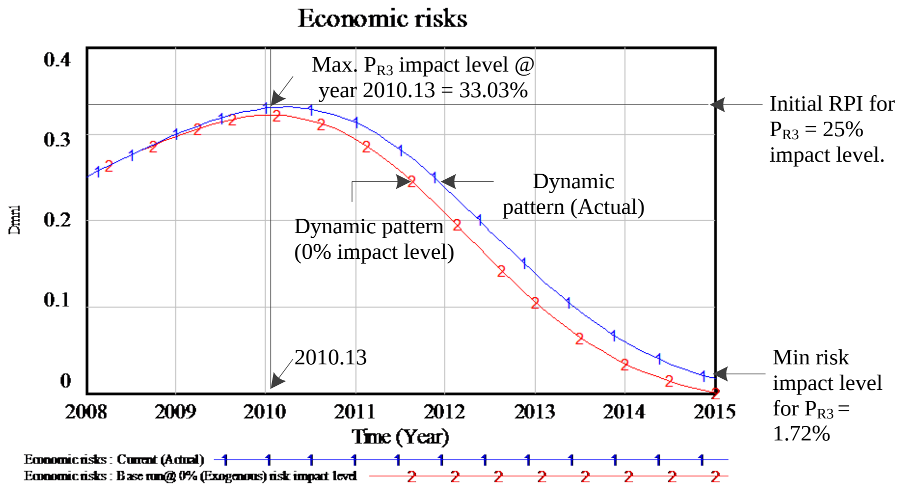

Figure 3: Baserun and actual scenario simulation patterns for economic risks

Up to this point, dynamic simulations have been performed to reveal the level of economic risks impact on the time and cost performance of the case study project. However, the question that still remains is whether one particular project objective experiences greater economic risks impact than those of other 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, a one-way analysis (ANOVA) was used to explore these distinctions using an alpha of 0.001. The impact of the economic risks within the project objectives represents the variability of values for individual project objectives in a sample. In these instances, the economic risk impact within project objectives is a measure of how much an individual objective tends to change over time. The impact of the economic risks between project objectives, by contrast, examines differences between individual objectives and was observed in the multivariate context. By subjecting the results of the level of expected risk impact on the project performance indicated in Table 3 to ANOVA, the results as represented in Table 4 reveal that the F (obtained) is 24.143 and is far exceeding the F-critical value of 7.41 for this test when using an alpha of 0.001. Correspondingly, the observed p-value of 0.000 is well below the chosen alpha of 0.001. By either standard, the result implies that the difference between the levels of economic risks impact on the objectives of the cases study project is statistically non-significant.

Table 4: One-Way Analysis of Variance: The Extent to which Economic Risks Impact on Project Objectives

Variance	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			

CONCLUSION

This paper presents a combined Analytical Network Process (ANP) and System Dynamic (SD) model that can be used to prioritize and simulate economic risk impact on large infrastructure projects. The impact of economic risks such as increase in foreign exchange and inflation, change in government, disputes, change in tax regime and energy price increases on project schedule and cost were investigated on the Edinburgh Tram Network project. The analysis shows how project time and cost were significantly affected by these economic risks, eventually resulting in a 3-year time slippage and about £400 million cost overrun. Although the behaviour patterns of each impact level of the economic risk towards the project performance is different, it can be concluded that the risks of project time and cost overrun are most sensitive to scenarios in which the dynamic patterns of all risk levels changes at the same time. It was quantitatively shown that schedule slippages seldom occur in isolation. They are usually accompanied by cost escalation on the project. This is because project time is usually intricately linked to the scope of the project, and therefore project cost. Time slippage on the Edinburgh Tram project was largely due to major changes in scope leading to significant disputes and perhaps an overly aggressive timescale for the project

It is worth mentioning however that the most accurate industry-specific parameter values were not available for all types of risk. However, our scenarios for the dynamic risk patterns covered the most possible parameter ranges obtained on the case study and the results follow the general patterns expected. Nevertheless, the model helps to prioritize identified risks and conduct comparative simulation of different scenarios to investigate the effect of changes in different variables of interest on project performance. As an innovative way of combining ANP and SD to assess risks, the 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 proposed model could be used by project managers, sponsors and policy makers involved with the procurement of large infrastructure projects to enable a systems thinking approach to project delivery. Later stages of this research will attempt to integrate the impact of other project risk clusters like socio-technical risk as well as environmental and political risk on transportation megaprojects using SD-ANP approach.

REFERENCES

Ackermann, F, Eden, C, Williams, T and Howick, S (2007) Systemic risk assessment: a case study. *Journal of the Operational Research Society*, **58**(1), 39-51.

Ahiaga-Dagbui, D D and Smith, S D (2013) "My cost runneth over": Data mining to reduce construction cost overruns. In: *Procs 29th Annual ARCOM Conference*, Smith, S D and Ahiaga-Dagbui, D D, Eds.), Reading, UK: Association of Researchers in Construction Management, 559-68.

Ahiaga-Dagbui, D D and Smith, S D (2014a) Rethinking construction cost overruns: Cognition, learning and estimation. *Journal of Financial Management of Property and Construction*, **19**(1), 38-54.

Ahiaga-Dagbui, D D and Smith, S D (2014b) Dealing with construction cost overruns using data mining. *Construction Management & Economics*, **32**(7-8), 628-94.

Boateng, P, Chen, Z and Ogunlana, S (2012) A conceptual system dynamic model to describe the impacts of critical weather conditions in megaproject construction. *Journal of Construction Project Management and Innovation*, **2**(1), 208-24.

Boateng, P, Chen, Z, Ogunlana, S and Ikediashi, D (2013) A system dynamics approach to risks description in megaprojects development. *Organization, Technology & Management in Construction: An International Journal*, **4**(Special Issue), 0-.

City of Edinburgh Council (cited 2014) *The Tram Project*. [Available online from http://www.edinburgh.gov.uk/trams.]

Coyle, R G (1996) *System dynamics modelling: a practical approach*. Vol. 1, CRC Press.

Creedy, G D (2006) *Risk factors leading to cost overrun in the delivery of highway construction projects*, PhD, School of Urban Development, Faculty of Built Envornment and Engineering, Queensland University of Australia.

Dobbs, R, Pohl, H, Lin, D, Mischke, J, Garemo, N, Hexter, J, Matzinger, S, Palter, R and Nanavatty, R (2013) *Infrastructure productivity: How to save $1 trillion a year*, McKinsey Global Institute.

Eden, C, Ackermann, F and Williams, T (2005) The amoebic growth of project costs. *Project Management Journal*, **36**(1), 15-27.

Love, P E D, Holt, G D, Shen, L Y, Li, H and Irani, Z (2002) Using systems dynamics to better understand change and rework in construction project management systems. *International Journal of Project Management*, **20**(6), 425-36.

Okmen, O and Öztas, A (2010) Construction cost analysis under uncertainty with correlated cost risk analysis model. *Construction Management and Economics*, **28**(2), 203-12.

Railnews (2012) Edinburgh tram costs soar again. In: Railnews, (Accessed 14 June 2012), Available (Online) from: http://www.railnews.co.uk/news/2012/06/14-edinburgh-tram-costs-soar-again.html.

Rowson, J (2008) Final contracts awarded for Edinburgh Tram. In: New Civil Engineer (accessed 20 May 2013), available (Online) from: http://www.nce.co.uk/final-contracts-awarded-for-edinburgh-tram/1346152.article.

Sterman, J D (2010) *Business Dynamics: Systems Thinking and Modelling for a Complex World*. Irwin McGraw-Hill.

Zhang, X, Wu, Y, Shen, L and Skitmore, M (2014) A prototype system dynamic model for assessing the sustainability of construction projects. *International Journal of Project Management*, **32**(1), 66-76.