Socio-ecological risks management dynamic simulation in megaproject development of the Edinburgh Tram Network

Abstract

Purpose: The inherent risks and their interactive impacts in megaproject development have been found in numerous cases worldwide. Although risk management standards have been recommended for the best practice in engineering construction projects, there is still a lack of systematic approaches to describing the interactions. Interactions such as social, technical, economic, ecological and political (STEEP) risks have complex and dynamic implications for megaproject construction. For a better understanding and effective management of megaprojects such as the Edinburgh Tram project, the dynamic interaction of concomitant risks must be studied.

Design/Methodology/approach: A systems dynamic methodology was adopted following the comprehensive literature review. Documentary data were gathered from the case study on Tram Network Project in Edinburgh.

Findings: A casual loop of typical evolution of key indicators of risks was then developed. A hypothesised model of social and ecological (S.E.) risks was derived using the system dynamics (S.D.) modelling technique. The model was set up following British Standards on risk management to provide a generic tool for risk management in megaproject development. The study reveals that cost and time overruns at the developmental stage of the case project are caused mainly by the effects of interactions of risk factors from the external macro project environment on a timely basis.

Originality/value: This article presented a model for simulating the socio-ecological risk confronting the management and construction of megaprojects. The use of system dynamics provided the opportunity to explain the nature of all risks, particularly the S.E. risks in the past stages of project development.

Keywords: Megaproject; Risks; System dynamics; Tram project

1. Introduction

The rapid population growth and urban development have invested in transportation infrastructures moved from mission impossible to critical. Amongst the different forms of transportation, the investment in trams attracted the attention of Governments (Nazin et al., 2017). The government's desire to construct is tram line was also due to the tram’s desirable features, including higher passenger capacity, better comfort, and low emission of pollutants compared to other forms of transportation. Thus, most countries invest in creating new trams networks or extending their existing tram system (Naweed & Rose, 2015; Marti et al., 2016). Unfortunately, Tercan (2021) discovered that the investment in trams and other forms of transportation infrastructures experiences cost and time overruns. Furthermore, Farran (2003) indicated that the transportation infrastructures project does not perform according to budgets as estimated. Lopez (2003) attributed the underperformance of investment in tram transportation development to the risks associated with the construction of megaprojects.

In megaproject construction, risks are usually complex and uncertain (Ugwu et al., 2019). They are often referred to as the presence of potential or actual threats or opportunities that influence a project's objectives during construction, commissioning, or at the time of use (Gray, 2006). The management of trams networks is faced with enormous socio-ecological risk. A majority of them emanate from sharing road space with other traffic users and difficulty in controlling trams (Naweed & Rose, 2015). Nazin et al. (2017) submitted that trams drivers have difficulty controlling the vehicle due to the heavy nature of most trams and negotiating the road with other existing road users. Although, enormous studies have been conducted regarding maintenance and safety challenges (Farran, 2000; Marti et al., 2016; Tercan, 2021). There is a paucity of literature regarding socio-ecological risk management simulations for trams transport infrastructures.

Despite the coming of age of risk management as a profession, there is little or no model capable of simulating the inherent risk of constructing tram infrastructures. In support of the aforementioned, Baker et al. (1998) established that “there is no global (project risk management) industrial standard” or procedures that exist for what constitutes a risk assessment. A wide range of risk management standards has been discussed in the literature and project management. Some of these standards include the B.S. 31100:2008; BS ISO 31000:2009; BS EN 31010:2010; B.S. 6079-3:2000, and BS IEC 62198:2001 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 (AIRMIC et al., 2002) and CIRIA guide to the systematic risk management for construction (Godfrey, 1996). Although these risk management standards were put forward to guide the best practice for a complex system like megaproject construction, they have not been critical enough to manage or mitigate risks from the external project environment. The conventional Standards still lack systematic approaches to describe all the interactions among the social, technical, economic, ecological and political (STEEP) risks concerning all complex and dynamic conditions through megaproject construction that can be disastrous and cause chronic project failure during construction. Therefore, this study aims to develop a socio-ecological risk management simulation using system dynamics with a focus on megaprojects.

This study aims to apply System Dynamics (S.D.) modelling for social and ecological (S.E.) risk management during megaprojects development based on the above consideration. The aim will be achieved through the following objectives:

- Develop SD risk assessment model to support the over 30 risk assessment techniques in the British Standards of risk management: B.S. 31100:2008; BS ISO 31000:2009; and BS EN 31010:2010.
- Demonstrate the effectiveness of the new S.D. model using an experimental case study

The significant contribution of this paper includes a set of risk assessment tools for macro external project risks and an S.D. model designed for S.E. risks impact on megaproject development. It is expected that the constructed S.D. models will serve as promising strategic decision tools to megaproject developers for an experiment during policy-making and to implement them in real situations. As a result of the aim of this paper and concerns raised by the literature review, the following section presents methodologies used for modelling and assessing S.E. risks for similar megaproject cases.

2. Literature review

The literature review focuses on the two main areas of endeavour: (a) STEEP Risks in megaproject development and (b) cost and time overruns in megaprojects construction. These two areas are selected because of their documented history in impacting mega construction and engineering projects:

2.1 *Risks in megaproject development*

Risks in the developmental phases of megaprojects occur within a complex web of numerous social, technical, economic, ecological, and political (STEEP) environments of all global dimensions (Chen et al., 2009 and 2011). As a result, such large projects become: (1) extremely complex, consisting of multiple interdependent components, (2) highly dynamic, (3) involve multiple feedback processes, (4) have non-linear relationships and (5) require both "hard" and "soft" data (Sterman, 1992). Brief definitions of each of the STEEP risks are as follows:

- *Social Risks:* These include national and local-level factors that contribute to social (in) stability (such as levels of governance, security and population size) as well as project-specific issues (the nature of the project approval process, the outcomes of similar projects previously conducted in the area, bad sub-contractor qualification, communication and low labour productivity, inexperience project manager, confusion of personnel management).

- *Technical risks**:*** These risks are mainly treated that prevent the operations of the contracting companies from developing, delivering, and managing their services and supporting operations.

- *Economic risks:* Risks to constructing the Tramline projects due to the adjustments of national economic policy, inflation, fluctuation of price, interest rate and exchange rate due to the relatively long period of delivery of such projects.

- *Ecological risks:* These are natural risks such as unfavourable climatic conditions (continuous rainfall, snow, temperature, wind), force majeure (thunder and lightning, earthquake, flood, and hurricane) that have a tremendous influence on the project and the bad environmental conditions (such as pollution, and traffic) of construction activities on the physical environment.

- *Political risks:* Tram network projects, mostly belonging to a state (country) or the government, are easily influenced by the adjustment of state laws, regulations, and government policy.

Together, these STEEP risks (Figure 1) interact to influence relationships and generate risk landscapes of unprecedented complexities.

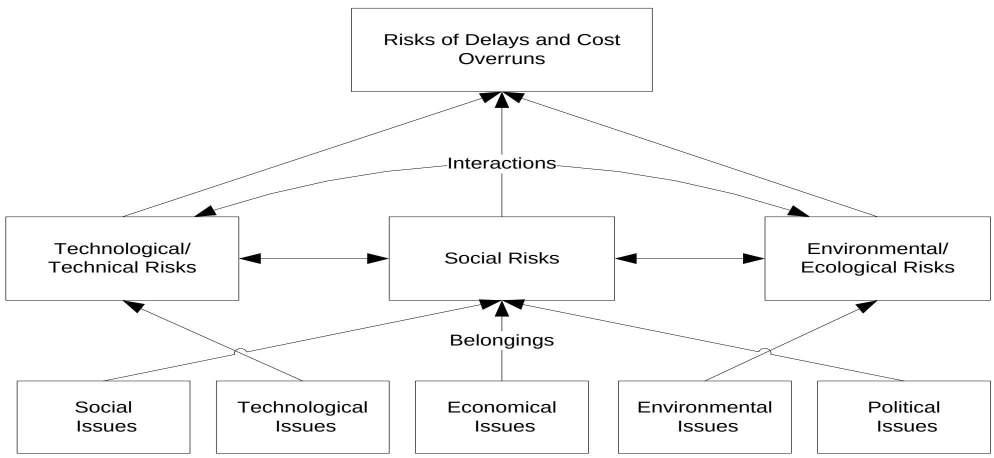


Figure 1: The effects of Interactions and belongingness of STEEP factors in megaproject dev.

A further increase in such interactions with one another could produce system disturbances with severe consequences (Winch, 2010) and would generate failures within project interrelated subsystems (Boateng et al., 2012). Ke et al. (2010) stated that such failures would result in crippling losses of public invested funds. In addition, valuable project time will be uncorrelated and lost (Kytle and Ruggie, 2005).

2.2 *Cost and time overruns in megaprojects construction*

Evidence suggests that such megaprojects are usually money pits where funds are swallowed up without delivering sufficient returns. Cost escalations in megaprojects are due to unbalanced subjective beliefs and information in assessing risks and uncertainties and taking corrective actions to control and manage the identified risks (Collyer and Warren, 2009; Egbelakin *et al.*, 2021)). For example, in Poole (2004), the transportation infrastructure industry has been revealed to have a major credibility problem. It has a bad track record on megaproject development. The project costs are often grossly underestimated, and traffic is often overestimated. These problems are well documented in the literature for many recent rail projects across the globe.

A study was carried out by Danish academic 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). The study revealed that transportation infrastructure projects do not perform according to budgets as estimated. According to the study, the vast majority (90%) suffered cost overruns, with the average rail project costing 45% more than projected and the average highway project 20% more. Traffic forecasts were also far from accurate, with rail projects generating 39% less traffic than forecasted (though highway projects averaged a 9% underestimate of traffic). Based on continuous research, Bent Flyvbjerg emphasised that cost overrun has not decreased over the past 70 years and seems to be a global phenomenon.

Further 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 estimated the cost US$ 2.6 billion for the project, but it was completed at the cost of US$ 14.6 billion. Additionally, completion was delayed from 2002 to 2005. The cost escalation indicates that construction cost estimating on major infrastructure projects has not increased in accuracy over the past 70 years (Yabuku and Ming Sun 2009). The underestimation of cost today is in the same order of magnitude that it was then (Flyvbjerg, 2006b, 2007). According to Flyvbjerg et al. (2003), there is a need for new ideas and techniques to be developed to improve this area where no learning seems to have taken place. Flyvbjerg, however, proposed a reference class forecasting approach to cope with complex problems in megaprojects through three steps: (i) reference class identification for past but similar projects; (ii) the establishment of a probability distribution for selected reference class parameter to be forecasted; and (iii) comparing a specific project with the reference class distribution in order to establish the most likely outcome for the specific project.

2.3 *Application of system dynamics in construction*

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. Systems Dynamics is largely based on soft systems thinking (learning paradigm). It is well suited to ambiguous managerial problems and requires better conceptualisation and insight (Sushil 1993) than conventional methods such as PERT/CPM techniques can provide. As indicated in table 2, S.D. has been successfully used in construction project-related research (Nasirzadeh et al., 2008).

Table 1: Applications of system dynamics in research into construction project management

Researchers	Year	Summary
De-Marco, A. & Rafele, C	2009	A feedback process to understand construction project performance
Nasirzadeh, Afshar and Khanzadi	2008	An approach for construction risk analysis
Mugeni-Balyejusa, B.	2006	Modelling changes in construction projects.
Howick, S.	2003	Disruption and delay in complex projects for litigation
Ogunlana, Sukhera and Li,	2003	Performance enhancement in a construction organisation.
Love, Holt, Shen, Li and Irani.	2002	The need for understanding how particular dynamics can hinder the performance of a project management system.
Park, M.	2002	Change management for fast-tracking construction projects
Chritamara. S and Ogunlana. S.	2002	Modelling of design and build construction projects
Rodrigues, A. and Bowers, J.	1996	A comparative analysis between two approaches to project management.

Source: authors' review of literature

Unlike the conventional approach (PERT/CPM), where planners use human judgement to interpret their mental models, the S.D. approach, according to Sterman (1992), uses computer models to overcome the limitations of the mental models. Sterman established that the S.D. computer models are explicit and open to all to review; capable of computing 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 entire system (Lê and Law, 2009). Table 3 indicates some capability differences between the two approaches, making S.D. a preferred choice over the PERT/CPM in megaproject planning against S.E. risks.

Table 2: Capability differences between PERT/CPM and the System dynamics tools

Capability	PERT/CPM	System dynamic
Capturing corrective managerial actions	Low	Very high
Realistic actions for project acceleration	Low	Very high
Detailing level	High	Very high
Risks and uncertainty management	High	Very high
Evaluating impact of uncertainties	High	Very high
Evaluating decision level	High	Very high
Estimating accurate project cost, duration & resources	High	Very high
Work schedule	High	Very high
Project control and monitoring	Yes	Yes
Showing interrelationship	Yes	Yes
Accounting for feedback effects	Yes	Yes
Work specification	Yes	No
Assigning responsibilities	Yes	No
Handling multi interdependent components	No	Yes
Productivity impact consideration	No	Yes
Handling multiple feedback processes	No	Yes
Handling non-linear process relationship	No	Yes
Computational capability for predictions	No	Yes

3. Research Methodology

The methodology employed in designing an objective and reliable risk assessment model for megaproject during construction is based on a comprehensive literature review for data collection, case study and S.D. application for data analysis.

3.1 *Case study*

A systematic gathering of empirical data on the Edinburgh Tram Network Project (ETNP) was carried out to understand the subject of the study. The reason was to ensure unbiased judgement during analysis and for validation purposes. The choice of ETNP was based on the fact that its development has been faced with numerous challenges relating to cost, time and specification and therefore has encountered cost and time overruns. The results were initially used to describe and justify the S.D. methodologies adopted for this research and provided defining features beyond the surrounding context. The method further elaborated on detailed findings and made an accurate observation and rigorous collection of evidence on the S.E. risks impacts on the case project.

At the time of data collection, the project had been under development for four years and suffered time delays, cost overruns and other risks such as contractual disputes and utility diversion problems. Data were obtained from project documents, online published Audit reports of the City Council, structured interviews and technical summaries. Information sought was basic project information, risks encountered, and actual project performance relating to time, cost, and specifications. A total of 20 people were interviewed for the project. The respondents (interviewees) were selected using a convenience sampling that supported the selection of respondents involved with megaprojects. The interviewees comprised Local business owners, operators, customers and project managers. The respondents were asked to provide their personal information, details about the mega project like duration, cost and estimated budget. The risk emanating from the project was also ascertained from the interview questions.

The interview conducted revealed that the project was improperly forecasted than initially expected and, as a result, must face cost and time overruns. After long legal battles between the developer and the owner, the project was completed in 2014, three years ahead of the original completion date in 2011 from line two to line one. The interviews were done to gain insight into all risks relating to the project to verify the model structures and obtain soft data that could not be obtained from project documents and published reports. The results explain why delays and cost overruns occur in megaproject development by determining causes and effects through feedback loop diagrams. Table 2 provides a summary of the initial basic information of the project.

Table 3: Basic information of Edinburgh tram network project

Project Title	**Edinburgh tram network project**
Purpose	- To support the local economy by improving accessibility. - To promote sustainability and reduce the environmental damage caused by traffic. - To reduce traffic congestion. - To make the transport system safer and more secure. - To promote social benefits.
Scope	- To connect Edinburgh Airport to the City Centre - To link with development areas in North and West Edinburgh
Contractual Framework	- 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 dimension	- Total length: 24 km in two phases - Phase 1a: 18.5km, is under development (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	- Originally planned date........... 2011 - Expected new date................ 2014

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

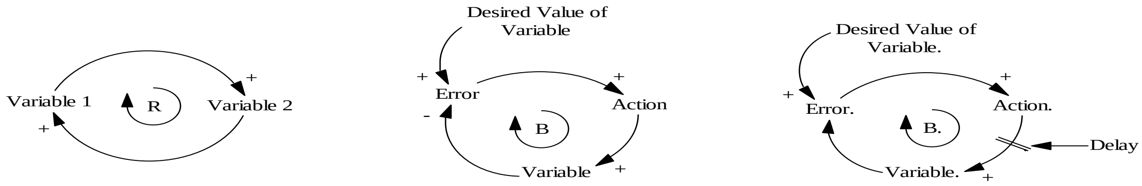
3.2 *The systems dynamics*

The systems dynamics (S.D.) methodology is adopted in this study. The SD methodology is a field created at MIT by computer pioneer Jay Forrester in the mid-1950s to model and analyse complex social systems' behaviour in an industrial context (Sterman, 2000). It was designed to help decision-makers learn about complex systems' structure and dynamics, design high leverage policies for sustained improvement, and catalyse successful implementation and change (Omotayo *et al.*, 2020; Obiri *et al.*, 2021). In recent years, S.D. has been used by researchers and project managers to understand various social, economic and environmental systems in a holistic view (Iheukwumere, Moore and Omotayo, 2021; Rodrigues 1996; Towell 1993; Sycamore 1999; Mawby 2002; Love 2002; Ogunlana 2003 and Naseena 2006).

The system dynamics approach is primarily based on the cause-effect relationship. This cause-effect relationship is explained with the help of stock, flow, and feedback loops (Park et al., 2009). Stocks and flows are used to model workflow 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 involving 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 2). Systems can be modelled qualitatively and quantitatively. The models are constructed from three basic building blocks: positive feedback or reinforcing loops, negative feedback or balancing loops, and delays. Positive loops (reinforcing loops) are self-reinforcing, while negative loops (balancing loops) tend to counteract the change. Delays introduce potential instability into the system.



2a. A Reinforcing Loop **2b. A Balancing Loop** **2c. A Balancing Loop with a Delay**

——►	A casual relationship
+ (-)	Signs at the arrowheads indicate that the effect 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 2a,b and c: The three components of system dynamics models.

Figure 2a 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), leading to an additional increase in variable one, and so on. The "+" sign does not mean the values increase, only that variables one and two will change in the same direction (polarity). If variable one decreases, then variable two will decrease. In the absence of external influences, variable one and variable two will grow or decline exponentially. Reinforcing loops generate growth, amplify deviations, and reinforce change.

A balancing loop (Figure 2b) 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 and desired values 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; this is used to model the time that elapses between cause and effect and is indicated by a double line (Figure 2c). Delays make it difficult to link cause and effect (dynamic complexity) and may result in unstable system behaviour.

4. Discussions

5.1 *The model structure*

The model is divided into five social, Technical, economic, ecological, and political subsystems (Figure 3). Each of these subsystems consists of numerous variables and equations. Based on the paper's objective, the social and environmental (S.E.) subsystems are only considered in this study. The social and environmental subsystems were considered because past studies like Chen et al., (2011), Boateng et al., (2012) and Egbelakin et al., (2021) have discovered that S.E are the major risks affecting megaproject. On the other hand, Boateng et al., (2012) affirmed that numerous research have been conducted in relation to economic and political subsystems. Also, López (2003) affirm that the European economy pose less risk to the management of tram. Table 4 indicates complex variables under each of the two subsystems considered.

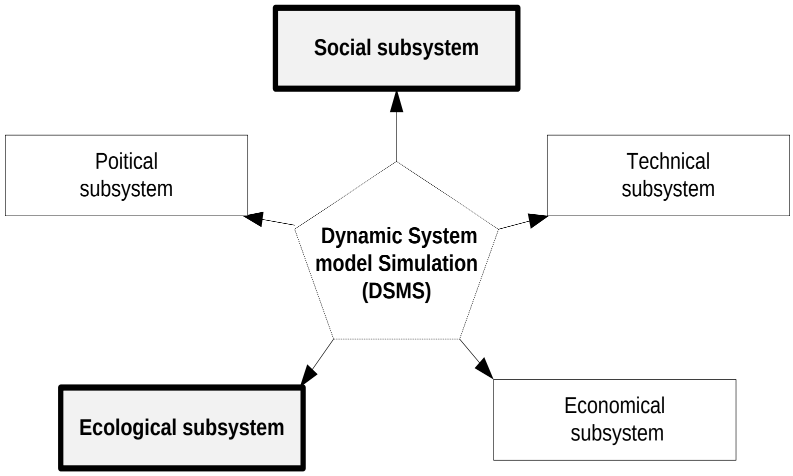


Figure 3: Model

5.2 The model boundary chart

The model is bounded in the construction phase and for the developer. The boundary chart (see Table 4) is a chart which summarises the scope of a model by categorising the variables of identified S.E. risks into endogenous and exogenous. Table 4 revealed that each subsystem social and ecological have its endogenous and exogenous variables.

Table 4: S.E. Model boundary chart

Model subsystem	**Model variables**	
	Endogenous	Exogenous
Social	− Multi-player/level decision making − Social issues − Social acceptability − Social grievances − Legal action	− Need to relocate − Pedestrian and bicycle safety − Accessibility to families, friends and community resources − Choice of travel modes

	– Workstream interruptions – Error generation	– The linkage between residence and job – Land and property value – Stakeholders' satisfaction – Regulatory environment
Ecological	– Ecological issues – Social & ecological effects	– Adverse climatic conditions – Waste generation – Traffic – Pollution (air, water, dust) – Noise

Endogenous variables are those represented within the model with values determined or influenced by one or more of the independent variables in the system. Although such variables impact the model's outcome, changes in the model do not affect them. On the other hand, exogenous variables are factors outside of each subsystem's model. The variables include the S.E. risk factors that impact ETNP during construction.

5.3 Model construction

A typical system dynamics model goes through some standard steps. Although there will be variations depending on the nature of the problem and the style of the modeller, the main steps for modelling in this study are summarised (see Figure 4) in seven steps as follows:

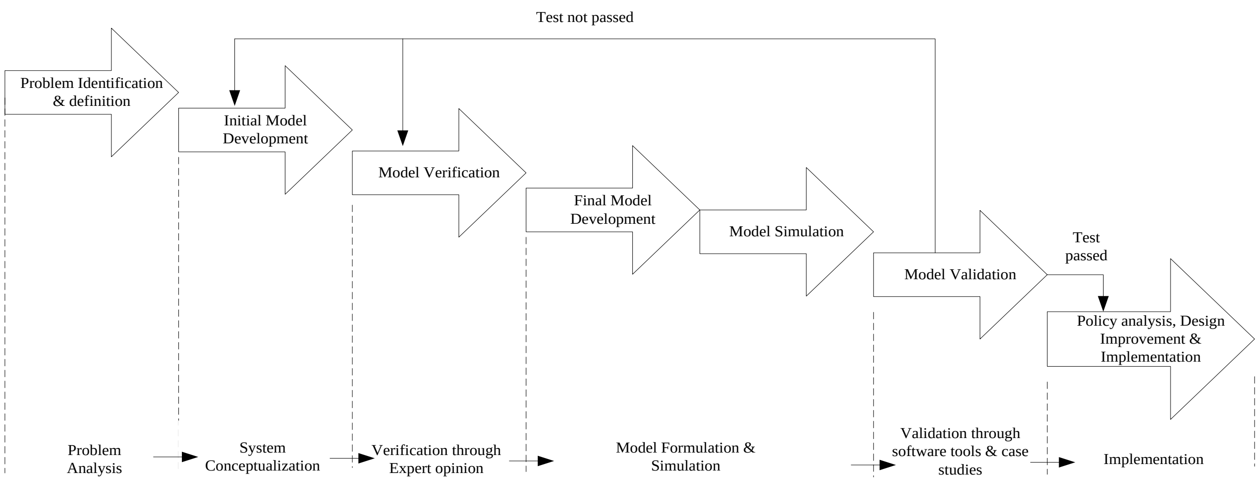
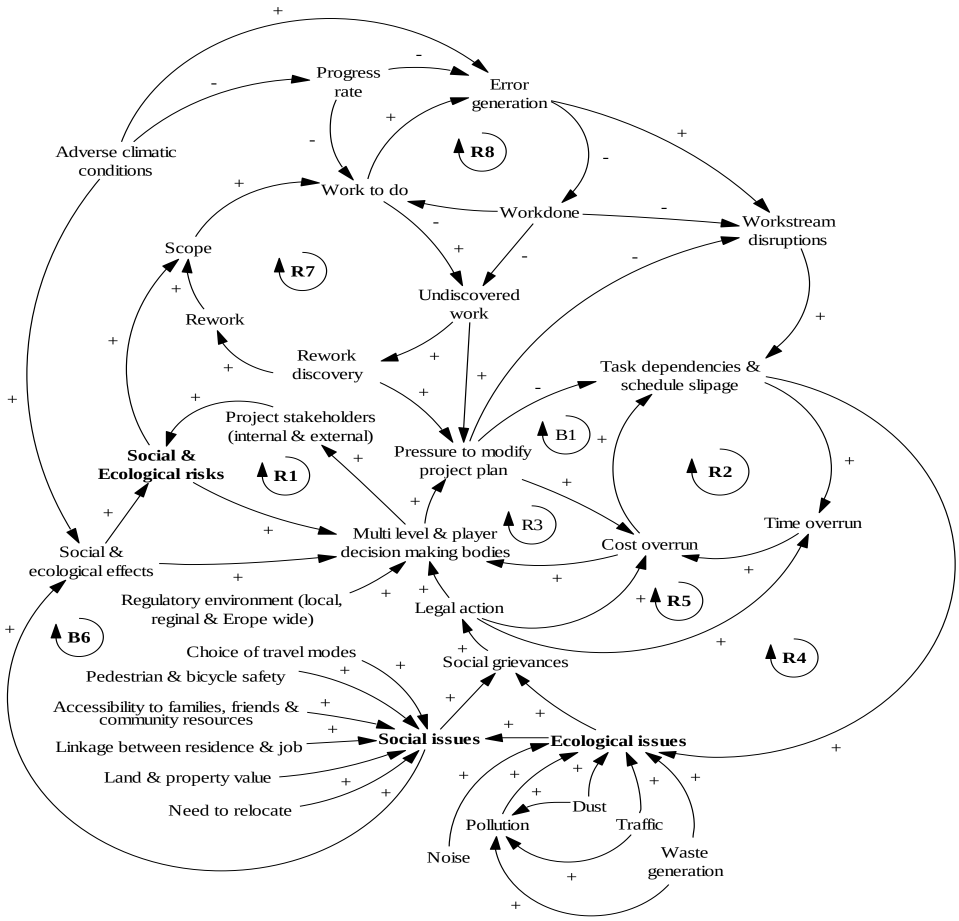


Figure 4: Basic steps of the S.D. approach for assessing risks in megaproject during construction

Regarding table 4 and findings from previous research, the overall structure of S.E. risk variables is constructed using a casual loop with Vensim DSS software, as shown in figure 5. The Vensim DSS software was used because of its capacity for managing large and mode complicated models. The endogenous and exogenous variable were inputted into the software to generate the loop needed for visualisation of the model. It is beneficial to visualise how chains of numerous interrelated variables affect one another (Ogunlana et al., 2003) by following the direction of the arrows. A positive (+) sign indicates the increasing relationship between two variables, while a negative (-) sign indicates a decreasing relationship.



'———►.. A casual relationship

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

R denotes Reinforcing loop and B, the Balancing loop

Figure 5: Causal loop diagram for social and ecological risks influence cost and time during megaproject construction.

Figure 5 indicates that S.E. risks are jointly determined by Social & Ecological effects and project stakeholders. The arrows that represent the causal relationship sufficiently connected with the social & ecological subsets. Also, the positive sign was noticed on all the causal loops. This implies that Social & Ecological effects can positively influence multi-level/player decision making bodies to cause greater influence through project stakeholders in a feedback loop. In addition, higher social & ecological issues will induce an increase in influence through social grievances and legal actions, resulting in project costs and time overruns. This is because a positive sign was discovered for all the casual loop relationship. In compensating for cost and time overruns, management actions will need to be amplified to modify project plans to bring the project on track, mitigate task dependencies & schedule slippage (see also figure 6) and workstream activity disruptions of error generation during adverse climatic conditions.

Meanwhile, there is a reinforcing loop among task dependencies & schedule slippage, ecological issues, and cost overrun. Such circular cause and effect relationships and other complexities such as uncorrelated divergence views of regulatory bodies and stakeholders provide the foundation for building social &ecological risk assessment models via system dynamics.

5.4 *Dynamic hypothesis*

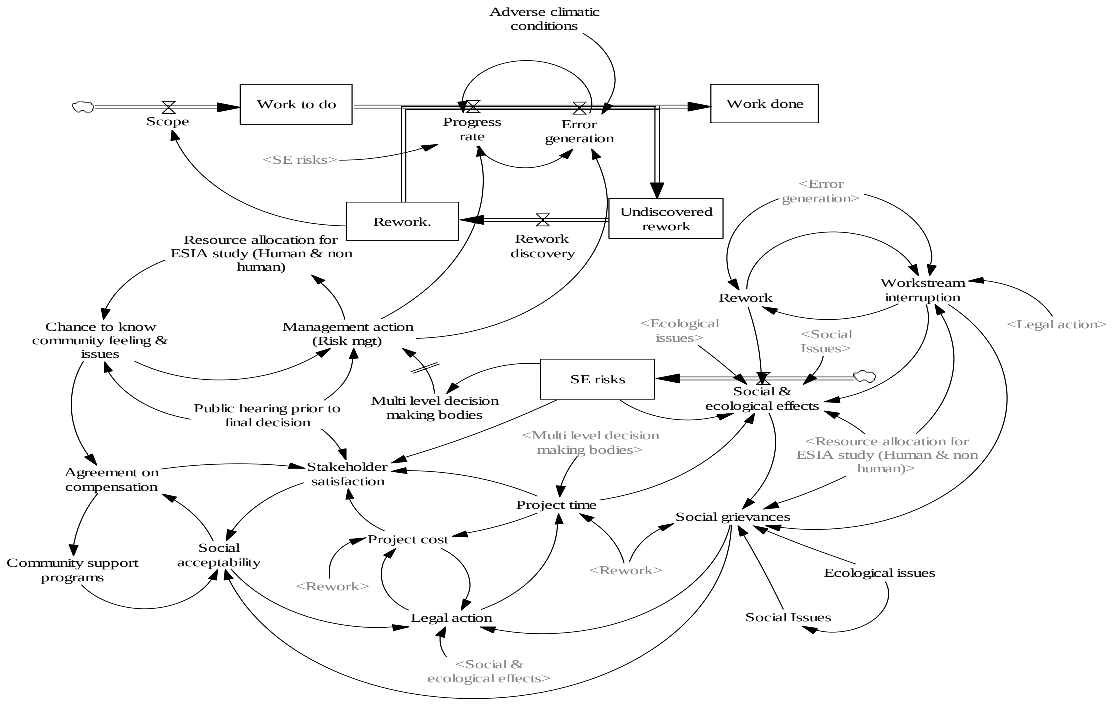
To assess the relationships between social and ecological risk parameters, a simple stock and flow diagram is known as a dynamic hypothesis (see figure 6) was developed based on the simple loop diagram in figure 5 to address the systematic issues of S.E. risk impacts on project cost and time during megaproject construction stages. The SD model was set up following British Standards on risk management to provide a generic tool for risk management in megaproject development: risk management planning, risk identification, qualitative and quantitative risk analysis, risk response planning, and risk monitoring and control.

Step1. Risk management planning

Figures 5 and 6 allow feedback loops concerning project delay and project cost overruns. These figures provide defined structure levels of risk management within the activities of project risk planning. They can be used by planners to proactively test and improve the existing project plan, such as forecasting and diagnosing the likely outcomes of the current plan. This is because the figures show the information and material flow needed for each subsystem and activities. Thus, the information provided by the figure can be used by planners in simulating a real-life scenario.

Step2. - Risk identification

The SD models can support risk identification qualitatively through the influence diagrams. Given SE as specific risks, it is possible to identify which feedback loops favour or counter the occurrences of such risks. For example, in the loop (Public hearing to final decision, management action, Resource allocation for ESIA study and chance to know community feelings & issues) (see Figure 6). The public participation in the Environmental and Social Impact Analysis (ESIA) drives public feelings and their feedback on the direct or indirect impacts of the project magnitude to be understood. This can help the Project management team formulate and agree on compensatory packages to give to the affected community by the construction. In addition, effective community support programs and stakeholder satisfaction will minimise legal actions by society and NGOs, thereby creating a good relationship within the project environment.



A casual relationship

+ (-) Signs at the arrowheads indicate that the effect 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

Rate or flow

Accumalation of tasks and SE risks

Figure 6: Dynamic hypothesis demonstrating social and environmental risk management in megaproject construction.

Step3. - Risk analysis

The influences shown in the models can further assist project managers of similar tram network projects in assessing S.E. 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. A simulation model (see figure 7) can best identify and capture the full impacts of potential risks on the project regarding risk likelihood, magnitude, and impacts. Figure 7 supports decision making as it shows the relationship between the sensitivity, equilibrium and base run for legal action, multi-level decision making, resource allocation, time and cost overruns. Figure 7 assist in showing the direction and association between the sensitivity and base run for each variable. 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 S.E. risks occurrences and impacts on similar megaprojects during construction.

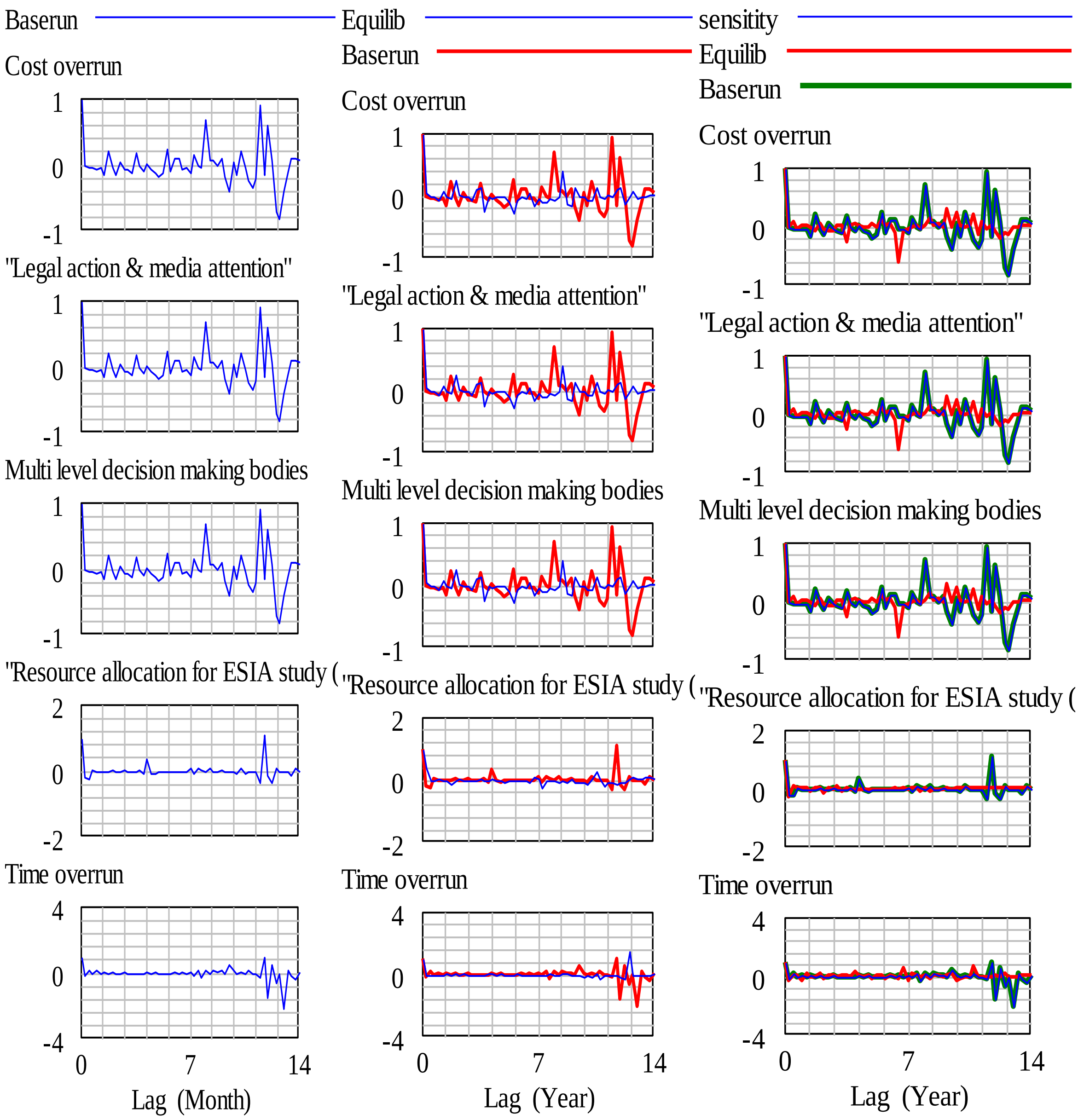


Figure 7: SD-based simulated diagram for legal action, multi-level decision making, resource allocation, time and cost overruns.

Step4. - Risk response planning

The models can effectively support risk response planning in Tramline projects and other similar megaproject development in three ways.

- Provide feedback perspective for S.E. risks identification

- Provide a better understanding of the multiple-factor causes of risks and a trace through the chain to identify other causes and effects.
- Serve as powerful tools to support project managers in devising effective responses.

Step5. - 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 emergencies can be identified to avoid aggravation. In addition, simulated models can provide effective monitoring and control mechanisms for risk diagnosis. This is because of the ability of simulated models to imitate real life scenarios of risk attributed to megaprojects. This assertion was also supported by Love et al (2002) that adopted the system dynamics to understand rework and change management of construction projects. Nasirzadeh et al., (2008) affirmed that system dynamics give birth to simulated models that supports the simulation of construction risk.

6. Conclusions and limitations of the study

With the assistance of a practical survey, this paper has systematically examined major SE risks affecting the megaproject construction using Edinburgh Trams Network Project as a case study. The risk models developed in this paper, supported by examining real risk cases, provide a compelling insight and clear picture of the S.E. risks involved in megaproject development and construction. The understanding of these S.E. risks is essential in order for planners to take proper risk management strategies.

The investigation of several practical risk management strategies demonstrates practical examples of adopting risk management principles to provide useful references to megaproject planners and developers or those overseas firms planning to operate their businesses in the U.K. The findings and analysis in this paper would present valuable data for the initiating government and local partners to understand the S.E. risk environment to construct mega projects. Such understanding is vital for implementing further effective measures to ensure that the right direction of future development creates a more attractive environment for all stakeholders to avoid project delays and cost overruns.

6.1 Contribution to practice and research

The model developed in this study functions as a generic tool for risk management in megaproject development. It also contributes to risk management planning, risk identification, qualitative and quantitative risk analysis, risk response planning, and risk monitoring and control of megaprojects. The utilisation of system dynamics further contributed to the ability of simulating this study for an experiment during strategic decision making or the creation of a government policy. It also contributed to exposing that the cost and time overrun plaguing the development of megaproject can be attributed to the external macro project environment. It contributed to research as it revealed that the dimension of risk affecting a megaproject can be divided into five constructs. The constructs are: social, Technical, economic, ecological, and political subsystems.

However, this study was limited only to the social and environmental (S.E.) owing to the significant effect of S & E. The Social & Ecological (S & E) can positively influence multi-level/player decision making bodies to cause greater influence through project stakeholders in a feedback loop. The social and ecological risk of a megaproject is a function of the stakeholders involved with the project. This implies that the risk emanating from the S & E of a megaproject would depend on the collaboration among the project stakeholders. It can be implied from the findings that further research should be conducted on simulating the impact of collaboration megaproject risk.

6.2 Future Research

Performance enhancement of the existing risk management processes requires further research on Social, Technical, Economic, Ecology and Political (STEEP) risks in engineering projects. The enhancement can be produced through modelling using system dynamics methodology to aid multi-criteria decision making during risk management. Future research will also look into STEEP risks from multiple megaprojects. To support the building of decision making to improve the understanding and accuracy of managing megaprojects using dynamic system models.

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