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An analytical network process model for risks prioritization in megaprojects

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Abstract

Megaprojects are large, complex, and expensive projects that often involve social, technical, economic, environmental and political (STEEP) challenges to project management. Despite these challenges, project owners and financiers continue to invest large sums of money in megaprojects that normally run high risks of being over schedule and over budget. While some degree of cost, schedule and quality risks are considered during project planning, the challenge of understanding how risks interactions and impacts on project performance can be modelled analytically still remains. The consequences learnt from past experiences in megaproject practice indicate that there was a lack of analytic tools to effectively manage large risks across project lifecycle and more specifically, there was a lack of understanding on the priorities of all STEEP risks for individual megaprojects. In order to find a solution to tackle this specific technical problem, this research puts forward a new Risk Priority Index (RPI) as an innovative analytical approach to ranking risks for the construction and development of megaprojects. The new method adopts results from an analytic network process (ANP) model, which was built up based on data collected from the Edinburgh Tram Network (ETN) project. It provides an interactive quantitative way for developers to prioritise potential risks across the project supply network so as to initiate in advance mitigation strategies against the consequences of STEEP risks on megaproject performance at the construction phase which can normally cause significant overruns on cost and time.

Keywords: Risk assessment; Analytical Network Process; Megaproject; Decision making

Highlights

- This paper provides details on how to model social, technical, economic, environmental and political (STEEP) risks in megaproject at construction phase and the authors developed an analytical method to prioritise risks.
- The paper made it clear through a case study that the higher the complexity of STEEP risks, the higher the possibility of the megaproject under construction runing over time and budget together with quality problems.
- Results from an analytic network process (ANP) model described in the paper were built up based on data collected from the Edinburgh Tram Network (ETN) project over three years during construction.
- The new tool described in the paper can be used as an interactive quantitative approach in project risk analysts to prioritise potential risks across the project supply network so as to initiate in advance mitigation strategies against the consequences of STEEP risks on megaproject performance.
- The paper provides researchers with risk areas and sub areas and a methodology to quantify the qualitative effects of risks factors on megaprojects during construction.

1. Introduction

Construction, like many other industries is a free-enterprise system, and has sizeable risks built into its structure (Ball, 2014; Fulford and Standing, 2014; Guo et al., 2014). From the initiation to the closing stages, construction process especially that for megaproject development become complex and characterized by a number of uncertainties that can influence the project negatively, e.g see (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, uncertainty 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. Although certain risks from natural disasters are quantifiable using modern technology, they remain difficult to incorporate into the megaproject decision-making process. As a result, many construction projects fail to achieve their time, cost and quality goals (Brookes, 2015). Evidence suggests that large and complex projects such as highways, bridges, and airport expansion 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 control and manage the identified risks. Poole (2004), asserts that the track record of transportation infrastructure industry is terrible during development and has lots of credibility problems. Salling and Leleur (2015) and Proost et al. (2014) emphasised that project costs for transportation megaprojects are often grossly underestimated, and traffic, often overestimated. For example, in Flyvbjerg et al. (2003b), as many as 258 highway and rail projects ($90 billion worth) in 20 countries did not perform well on budgets as estimated. Flyvbjerg et al. (2003b) revealed that nearly all (90%) of these projects suffered cost overruns, with the average rail project costing 45% more than what were projected, while it was over 20% in average for highway projects. Based on a continuous research, Flyvbjerg et al. (2003b)underscored that cost overrun has not decreased over the past 70 years and seems to be a global phenomenon. Other examples are the 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 in megaproject development. For example, the Big Dig 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. This indicates clearly that construction cost estimating on major infrastructure projects has not improved in accuracy over the past 70 years. According to Salling and Leleur (2015) and Flyvbjerg et al. (2002) the underestimation of cost today is in the same order of magnitude as it was then. Flyvbjerg et al. (2002) therefore regarded the main reason for cost and time overruns in megaprojects as simply the marginalisation of risks during feasibility studies and by assuming what the World Bank calls the "Everything Goes According to Plan" (EGAP) principle. (Davies et al., 2014; Flyvbjerg et al., 2002; Kwak et al., 2014) based on the EGAP assumptions and stressed on the need for new ideas and techniques to be developed to improve this area where no learning seems to have taken place.

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 as well as to underpin effective and consistence communication throughout the construction supply chain. Giezen (2012) and Kardes et al. (2013) believe that a simple 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) in a research argued that the proliferation of techniques and software packages purporting to provide project risk management facilities, have also failed and proposed non-parametric jack-knife resampling technique to rank risks in highway projects and to meet the needs of project managers.

Several researchers including Nieto-Morote and Ruz-Vila (2011) and Karimiazari et al. (2011) proposed the use of risk analysis techniques that are based on estimating probabilities and probability distributions for time and cost risk assessment in projects. However, these techniques do not encourage project participants to develop in-depth understanding of the underlying elements and structures which constitute megaproject risk systems and to render explicit latent concepts and assumptions which are implicit to current risk assessments. The techniques do not allow for risks and uncertainties remedial measures in a complex environment. Also the techniques do not permit lessons learned from previous projects with similar environments to be captured and re-used when developing new projects, and as a result do not facilitate continuous learning and improvement.

Against this background, the authors employed a combination of quasi-ethnography, questionnaire survey and the literature to identify different STEEP risk factors that impacted on the performance of Edinburg Tram Network (ETN) project during construction. The identified factors were then prioritised using the Analytical Network Process (ANP) method to establish the most salient risk variables on the ETN project and to demonstrate the potential benefits of the ANP approach in assessing risks in megaproject construction. The purpose of this research is to establish a logical framework that incorporates ANP method to develop a comprehensive approach to risks prioritization for megaprojects. The interest of prioritizing risk at the construction phase of megaproject development is because the risk management assessment processes in construction project development implementation literature, while acknowledging adaptation as one phase in construction process and delivery, offers inadequate theory to address the problems faced during its implementation in megaproject delivery (Charvat, 2003). Therefore, aiding risks assessment at the construction phase with an analytical tool such as the ANP can remove a number of constraints and impart a sense of fairness into the decision-making process overtime. Also, the approach will enhance the capabilities of existing tools such the over 30 risk management techniques contained in the British Standards codes of practice (BS 31100:2008 Risk management- Code of practice; BS ISO 31000:2009 Risk management- Principles and guidelines, and BS EN 31010:2010 Risk management-Risk assessment techniques) during risk management. It will further lead the construction industry to establish a self-sustaining and grounded risk management procedure for megaproject development and construction.

The objectives of this research are to:

- Identify and describe significant risks across the entire set of social, technical, economic, environmental and political (STEEP) issues related to megaprojects at the construction stage,
- Develop a framework that incorporates ANP for STEEP risks assessment in megaprojects during construction, and
- Prioritize these risk factors based on cross-STEEP interactions.

The research was conducted on the ETN project from 2001 to 2014. Based on data collected on the project, a pairwise comparison of STEEP risks was performed with the Super Decisions® software to derive the risk priority values also known as Risk Priority Index (RPI). The RPIs are values which indicate the level of impact of risks in preventing project success. The RPI was used as an innovative method to rank the level of identified risks influence on the objectives of the ETN project. The risk priority values have been summarised through further discussions. In conclusion, the RPI was proven to be a useful tool for megaproject managers as a means of prioritizing and ranking major risks so that attentions can be focused on key factors that influenced project negatively.

2. Literature review

The purpose of this literature review is to justify the needs for an ANP driven new method in risk assessment in megaprojects. With regard to this target, a literature review was conducted in the following two areas, including

- Risks in megaproject development at construction stage,
- The effectiveness of using ANP in risk assessment, and

Based on this literature review, it was proved that the ANP as an effective risk assessment technique can be applied in megaprojects under a more adaptable set of assessment criteria against STEEP risks, and there is a need for a quantitative method to prioritise STEEP risks in megaproject construction and development.

2.1. Risks in megaproject development at construction stage

A large number of potential risks events with undesirable results may occur in megaproject development and affect the project's success. Risks can strongly influence each stage from the project conceptual design stage through to the handover stage and as such it would be quasi-impossible to draw up a general list of all risks appearing on such large and complex projects, regardless of the project's size, type and content. Generally, the risk management is a vital, an on-going and iterative process use to identify possible risks sources during different phases of projects under development. It allows parties involve in the project development to recognise the existence and impact of uncertainties in the project and hence, to consider appropriate strategy to mitigate their effects in the project. Due to complexities, large resource requirements, long time horizons, and exposure to interrelated and pervasive drivers of risk, megaprojects by their nature, are faced with unique risks and tend to stretch available resources to the limit and sometimes beyond during development (Boateng et al., 2013; Brookes, 2015; Gharaibeh, 2013). According to Chen et al. (2011) and Boateng et al. (2013) such risks arise from the STEEP aspects of the external macro business environment. Scholten (2006) estimated that problems of such external factors have had a strong impact on 17% of projects supported by European Cohesion Funds and a small to negligible impact on 41% only. The main external factors identified by Scholten were public protest, archaeological factors/habitats, weather conditions, economic growth (faster/slower than expected) and land purchase.

In construction, the word “delay’’ refers to something happening at a later time than planned, expected, specified in a contract or beyond the date that the parties agreed upon for the delivery of a project (Pickavance, 2005). Delay can lead to many negative effects such as disputes and legal actions between megaproject owners and contractors, project cost overruns, loss of productivity and revenue, and contract termination (Anderson Jr and Polkinghorn, 2008; Han et al., 2009; Salunkhe and Patil, 2014). Although schedule delays seem to be embedded in all projects, identifying the main causes and preventing these problems from occurring are better than resolving subsequent delay-related disputes. Increasingly, realistic ‘construction time’ has become important because it often serves as a crucial benchmark for assessing the performance of a project and the efficiency of the contractor (Kim and Huynh, 2008; Nasir et al., 2012; Nassar and AbouRizk, 2014).

In this study, research literature from all around the world has been collated and consolidated for the better understanding of the overall picture of the issues. According to the World Bank (2009), for many projects completed worldwide between 1999 -2005, the overrun varied between 50% - 80%. In the past few years, the number of claims submitted to the American Arbitration Association (AAA 1998) reached almost 25% of the 1.7 million claims submitted over the past 74 years (Sepasgozar et al., 2015). In the United Kingdom, a report by the National Audit Office entitled “Modernizing Construction”, published in January 2001, revealed that 70% of government construction projects were delivered late. Similar research conducted by the Building Cost Information Service (BCIS) found that nearly 40% of all studied project had overrun the contract period (BCIS, 2012). Fallahnejad (2013) point out in a study that the most common factors of these delays are related to financial and payment problems, improper planning, poor site management, insufficient experience, and shortage of materials and equipment and other STEEP factors such as natural disaster like flood and earthquake (Boateng et al., 2012). In Ali-Mohammed (2010), a study conducted on Highway and Bridge megaprojects at Bahrain revealed that, predominant factors (risks) such as traffic congestion, utility diversion, consultant's supervision fees, land acquisition, environmental considerations and accuracy of existing services locations among the rest contributed to delays and disruptions in the project development. Lo et al. (2006) revealed that natural ground conditions, poor communication, manpower problem, insufficient knowledge on work are the delay related risks in construction project in Hong Kong. Yang and Wei (2010) evaluated delays in construction and concluded that the phenomena are universal and are almost always accompanied by cost and time overruns. Therefore, it is essential to identify the actual causes of delay in order to minimize and avoid the delays and their corresponding expenses.

Following the review on delays in megaproject construction is project cost overruns. Cost overrun is common in megaproject construction. Its forms are normally a source of conflict among clients, consultants and contractors on the issue of project cost variation. According to Abdul Rahman et al. (2013) these cost overruns create significant financial risk to clients. In spite of the financial risks involved, several construction projects in large scales are still witnessed to be developed and completed over budget. For example, Flyvbjerg (2009) conducted studies on a sample of 258 transport projects and revealed that, cost overruns in transport projects revealed that 9 out of 10 projects have cost overruns. Across 20 nations and 5 continents, the average overrun is found to be 45%, 34% and 20% for rail, bridges and tunnels, and road projects, respectively. This cost overrun is constant for over 70-year period and cost estimates have not improved over time.

The next example is a research conducted by Flyvbjerg, (2009) on the Danish Great Belt rail tunnel. This tunnel was opened in 1998 and happened to be the second-longest underwater rail tunnel in Europe. However, before it was opened, the cost of construction was about 120% over budget and proved nonviable. Only by cross-subsidizing the tunnel with revenues from a nearby motorway bridge made it possible to pay for the tunnel (Flyvbjerg, 2009). Another example is the Boston's "Big Dig" (a/k/a "Central Artery/Tunnel Project"). This project has been a thorn in the side of the city and its commuters for over twenty years. The project's purpose was to build a 2 mile stretch of underground highway through the heart of Boston, replace the existing above-ground highway with green space, and to build a tunnel from Boston beneath the Boston Harbour to Logan International Airport in East Boston. At its height the project employed it employed over 5,000 workers. The "Big Dig" has been troubled from the start by shoddy workmanship, as evidenced by problems with sub-standard materials, paving fraud, grout heaves, leaking tunnels and defective anchor bolts in the Ted William and I-90 tunnels. Originally proposed at $2.2 Billion, the project cost was estimated in 1985 at $6.0 billion but was adjusted for inflation as of 2006. By 2006, the project costs have risen to $15 Billion (143% cost escalation), with 73% of the cost being subsidized by Massachusetts taxpayers (Smith, 2010).

Other example of cost overruns revealed in literature is a study conducted by the UK National Audit Office in 2007 to examine how the costs of building and improving roads were estimated and monitored from early forecasts through to the final cost of schemes. The UK Department for Transport had approved expenditure of over £11 billion between 1998 and 2021 for the development of new and existing trunk roads and motorways in the UK by the Highways Agency and under £1.7 billion on major road schemes which were proposed and developed by the local authorities. By 2006, the 36 schemes by the Highways Agency had been completed and had cost 6% more than estimated. By 2006 the 20 schemes by the local authorities completed had also cost 18% more than initially estimated. In addition, nine project cost data sourced from EVA-TREN (2008, p.45) and Cost Action TU1003 megaproject portfolio of case studies (2012) revealed that, among megaprojects from the European Union, the total construction cost deviations for some selected high-speed rail links fall between 8% and 116%. These projects include Inter-City Express of Frankfurt-Cologne (116%), Eurotunnel (69%), Madrid-Seville Alta Velocidad Española (23%), Paris-Lille Train Grande Vitesse (25%), Lyon-Marseille TGV (8%) and the Oeresund Fixed Link (63%). Others are the Edinburgh Tram Network Project (42%), Seville-Madrid HSR (71%) and Madrid-Barcelona HSR (50%).

The last example is the case study adopted for this research (Edinburgh Tram Network Project). It is a tramway system which is currently under construction in Edinburgh, Scotland. With an original budget at a cost of £375 million in 2003, the cost of this tram system was revised by the City of Edinburgh Council (Project owners) to £776 million in 2011. It was originally scheduled to enter service in February 2011 but had to be postponed to summer 2014 due to budget problems. In February 2011, Edinburgh Evening News published that the German engineering contractors responsible for the delivery of the project have revealed a 72% of the construction work remaining with just 38% of the budget left. Based on further relevant body literature, a list of STEEP risks are identified and presented in Table 1. These risks and their consequence on megaproject performance at the construction phase must not be underestimated. They can impact the overall project management processes hugely, and in regard could cause project programme delay, project cost overrun, quality deficiency and lost in project income to both the supply-side and demand-side stakeholders.

<Insert Table 1>

2.2. The effectiveness of using ANP in risk assessment

The ANP is an extension of the Analytic hierarchical Process (AHP). It has significant power in multi-criteria decision making (MCDM) when an extensive number of factors are involved. In the ANP, a decision problem is transformed into a network structure. This network structure is built based on comprehensive decision problems with links between the different factors in the decision problems. The network structure is composed of different clusters (groups of elements) and elements that are connected with each other. These connections represent the different relationships that exist between the clusters and elements in the decision problem. Unlike the AHP where decision problems are formed in hierarchy, the ANP network does not have the same linear structure. The clusters are not organised and arranged in a particular order and directions. Besides, the ANP network allows interdependency (inner dependence, outer dependence, and feedback) among the decision clusters and even among elements within the same cluster (Saaty, 2000 and 2005). Based on it capabilities, the ANP has been adopted in this research to handle feedbacks and interdependencies that exist in complex systems like the STEEP risks system in megaproject development. Fig. 1 illustrates the differences in relationships and links between AHP hierarchy and ANP network. Inner dependencies indicate the dependences of elements of a cluster on each other while the outer dependencies designate feedback between clusters from one level to another level and can be expressed either from one cluster directly to another one or either by transiting influence through intermediate clusters along a path that sometimes returns to the original cluster, forming a cycle.

<Insert Fig. 1>

Besides this research, the ANP has been applied to solve a wide range of MCDM problems. Some of the recent applications of the ANP are include resource allocation and levelling (Cannemi et al., 2014), risk assessment and decision analysis (Chen et al., 2011; Ergu et al., 2014); location analysis (Yeh and Huang, 2014); resource allocation (Liang and Wey, 2013), outsourcing decision making (Tjader et al., 2014) and sustainability assessment of urban projects (Bottero et al., 2015). In addition, the ANP has been widely used in solving many other complicated decision problems. Chung et al. (2005) used ANP to select product mix for efficient manufacturing in a semiconductor fabricator. Saaty and Vargas (2013) used ANP model to forcast financial crisis while Yurdakul (2003) used ANP model to evaluate a long term performance of production systems. Many other applications of ANP have also been discussed in various conferences and in detailed literature review (Sipahi and Timor, 2010).

3. Research Methodology

Fig. 2 is a schematic that describes the overall flow of the proposed analytical framework used in this research. It comprises of the ANP. Data for project risks originate from literature, source documents of past and similar projects and case studies. The database is the channels used to categorize identified risks within the organization to store information about projects. This information is used to facilitate the data transfer into the ANP. The ANP is the tool used to synthetize expert judgments into numerical values to give their specific subjectivity inputs of risk effects on project performance.

The purpose of the ANP is to prioritize list of potential risks based on their relative importance in the organization. The ANP is composed of risk prioritization survey based on experts' decisions, the analytical network model development and the risk prioritization index calculation. The experts' decisions are the preset choices made by the experts based on the the risk prioritization survey for selecting potentially "high risks" using a Likert type scale of 1 to 5 to score the level of STEEP risks impact on megaproject objectives (cost, time and quality) in the construction phase. A weighted quantitative score (WQS) method is used to translate experts' decisions during prioritization surveys into synthetize numerical values to derive the mean scores of importance. The mean scores are significantly distinguished based on participant's experience, background and as well as their information in regard to a case study project (Edinburgh tram network project). These decisions are subject to adjustment due to changing priorities. The analytical network is the decision model that allows structuring the decision into criteria, sub-criteria and options. Its purpose is to categorize the decision model in a logical and intuitive tree to model the existing decision hierarchy and to adapt to emerging changes. Finally, the risk prioritization index (RPI) calculation is the platform where the analytical framework is combined with the experts' decisions to produce independent assessments on project priorities without further input from the experts. The results issued from the RPI calculation are listed as the top ‘n’ priority risks and are used to facilitate in-depth decision making during risks assessment in the construction phase of megaproject development.

<Insert Fig. 2>

3.1. Questionnaire survey

Using risk information obtained in literature review (see Table 1), a survey questionnaire was formed to collect data from stakeholders including project managers, construction workers, consultants, and local residents who were involved in the ETN project at the construction stage. Respondents were asked to rate the level of impacts caused by STEEP risks on project cost, time and quality from very low to very high, where 1 represents very low; 2 = low; 3 = average or moderate; 4 = High and 5 = very high, so that their opinions can be standardized to provide a fair idea of what could be the perceived levels of risk impacts on the objectives of the ETN project.

4. Research Findings

4.1. Findings from literature review

Based on Table 1, STEEP risks areas and sub-areas are re-defined in hierarchy as shown in Fig. 3. The social risks include national and local-level factors that contribute to social (in) stability (such as levels of governance, security and population size) as well as specific social factors such as grievances, multi -level decision making bodies, disputes, legal Actions, stakeholder's pressure to modify project scopes, treats to person & asset security and other social issues (construction disruptions, need to relocate, pedestrian and bicycle safety, reduction in property values, choice of travel modes, waste generation and population and accessibility difficulties). This type of risks add more dimensions to megaproject during construction because if the developers do not communicate well with the community around the project, they will lose many privileges that might enlarge their expenses and as a result will amplify risk of cost and time overruns overtime.

The technical risks are mainly treats that prevent the operations of the contracting companies to develop, deliver, and/or manage its services, and to support operations. Also risks to constructing megaprojects as a result of the adjustments of national economic policy, inflation, fluctuate of price; interest rate and exchange rate due to the relative long period of delivery of such projects are economic risks. Currency exchange rate and its availability are essential to megaproject construction because of the materials and equipment that are imported from foreign countries. In addition, changes in energy and material prices, local inflation and taxation amplify economic risks. Environmental risks include natural risks such as unfavourable climatic conditions such as continuous rainfall, snow, temperature, wind; force majeure such as thunder and lightning, earthquake, flood, and hurricane, etc. that have tremendous influence on the project; and adverse environmental impacts such as pollution and traffic caused by construction activities on the physical environment. Finally, the political risk includes political power effects on businesses. Megaprojects mostly belong to a state (country) or a government and as such, are easily influenced by the adjustment of state laws, regulations, and government policy. This type of risk affects greatly megaprojects because it controls materials, equipment, and labour prices and availability.

<Insert Fig. 3>

4.2. Questionnaire survey and participants

Out of 300 instruments delivered, 145 completed questionnaires were successfully retrieved representing a 48.30% response rate. Of the 145 completed research instruments, 5 were partially answered and as a result, were screened out of data analysis. Hence, 140 were actually used in developing the substantive analytical risk assessment model.

Out of the 140 valid respondents, 99 (71%) play a role as contractors' team member (Project engineer, Project manager, and Site engineer, etc.), 17 (12%) as consultant's team member, 16 (11%) as client's team member while 8 (6%) did not provide any detail regarding the role they play in the ETN project. About 132 (94%) of the respondents involved in infrastructure related works such as earthworks, demolishing works, concrete/masonry works, track laying and steel works while 6 (4%) and 2 (1%) involved in utility diversions and administrative support works respectively. Majority of 71 (51%) respondents worked on the project between 3-5 years, 60 (43%) for 1-2 years, 4 (3%) for less than a year while 5 respondents, representing 4% worked on the ETN project for more 5 years.

4.3. Participants' opinions

To standardize the results gained from each participant of the questionnaire survey, STEEP risks and their respective potential risk variables were tabulated, coded and summarized into clusters and risks type as shown in Tables 2-4. By using the WQS method, Respondent's Mean Scores of Importance (RMSI) were calculated and the results summarised into a manageable form to aid the ANP pairwise calculations. In this regard, the results achieved by WQS are derived by the Equation 1.

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

Where

- MV indicates the value of mean scores of importance for each criteria/sub-criteria calculated by WQS.
- E refers to the experimental WQS for each sub/criteria expressed as a percentage year of experience multiplied by each participant's score of importance.
- i_c is the participant's score of importance for each sub/criteria with respect to cost.
- i_t is the participant's score of importance for each sub/criteria with respect to time.
- i_q is the participant's score of importance for each sub/criteria with respect to quality.
- n is the total number of participants in this research.

<Insert Table 2, 3, & 4>

5. Risks prioritization

The application of the ANP to risks in the ETN project requires the objectives to be sorted into homogenous clusters to enable logical problem structuring. Given the challenges in complex megaproject development, the proposed structure is arranged in five main levels of potential risk influence on project performance as defined by the study conducted by Chen et al. (2011) and Boateng et al. (2012). These five potential risks are 1) the social risks, 2) the technical risks, 3) the economic risks, 4) the environmental risks, and 5) the political risks. The impacts of these five potential risks on project cost, time and quality of the ETN project during construction phase are then arranged in hierarchical form with factors under each potential risk assigned weights leading to prioritization within the opinions of the decision makers through the pairwise comparisons of criteria. The project goals' level includes items such as list of high risks.

5.1. Modelling in ANP

Due to the missing consideration of cross-interrelation between hierarchies of AHP model, the ANP technique has been proposed in this study. In ANP structure, the same criteria used in AHP models are structured and re-modelled with consideration of their possible dependencies and feedbacks. As represented in Fig. 4, the ANP network structure for STEEP risks prioritization consists of 43 decision elements grouped into 5 decision clusters (social, technical, economic, environmental and political risks). The decision clusters are represented by nodes, while the dependencies amongst the clusters are represented by two-way arrows and looped arc. The two-way arrow depicts outer dependence, e.g. between the clusters ‘social risks and ‘technical risks’. On the other hand, the looped arc represents inner dependence amongst elements in a decision cluster. For example, comparing elements within the decision cluster ‘economic risks’. This implies that for each option such as the economic risk cluster, a different ANP network is developed. The outer and inner dependencies are defined with respect to a control criterion. The control criterion in this case implies identifying through prioritization which of the potential risks has the highest consequences on cost, time and quality. The significant of the inner dependencies of the five risk clusters is that risk variables in each cluster interact with each other within the overall model illustrated in Fig. 4. This suggests that various risk variables which influence project cost, time and quality are interrelated within a chain of cause and effects network to make a domino. These cause and effects domino within the five risk clusters generate a problem behaviour on project performance (time, cost and quality) and require a methodology like the ANP to structure and model such cross-interrelation of risk dependencies and feedbacks.

Ideally, the ANP network structure is developed based on expert judgment and requires an intuitive understanding of the decision problem (Saaty, 2005). In this paper, the decision problem is characterized by three aspects namely the goal, control criterion and options. Hence the overall goal considered in this paper is to prioritize the decision elements and criteria necessary for selecting the highest potential risks and the individual risks under each cluster. The risk prioritization model for each potential risk cluster is developed separately on the basis of the priority weights derived through the ANP methodology. These include ANP sub models for (a) Project Objectives, (b) Potential risks (STEEP clusters), (c) Social risk cluster, (d) Technical risk cluster, (e) Economic risk cluster, (f) Environmental risk cluster and (g) Political risk cluster (See Fig. 5). These network structures illustrate how the project objectives (Criterion) and the potential risks (Options) fed up through the system to give synthesized priority values of risks in this research. In the context of this study, the ANP offers a high flexibility of modelling and prioritizing risks and more clearly provides a break down of risk attributes without limit to probabilities, but also to all possible potential consequences in more specific criteria.

<Insert Fig. 4 & 5>

5.2. Pairwise comparison

After the ANP structure development, the pairwise comparison matrix for each sub-network model is performed. The PairWiser approach (Chen et al., 2011) was used to transform the rounded mean scores of importance indicated in Tables 2 to 4 into the Super Decisions® software to derive the risk priority values for the STEEP risk sub-areas.

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. As indicated in Fig. 4, there are two scenarios of pairwise comparison in the "Potential Risks" cluster. One scenario is with respect to clusters "Potential Consequences on cost, time and quality" and "Goal", while the rest are with respect to the elements in the cluster "Potential Risks" itself. The question asked with respect to "Goal: risk prioritization" for example, is that, what element in cluster "Potential Risks" is more risky than the others? Answers to questions of this sort are obtained by performing pairwise comparisons for all risks with the Super Decisions® software. A summary of the results for the pairwise comparison is illustrated in Table 5.

From the ANP computation, project cost, time and quality are each revealed to have equal synthesized priority weights of 0.33 (33%). This suggests equal importance of these objectives to respondents during construction of the ETN project. Further analysis of the results suggests that, respondent's answers to the prioritization on project objectives during the survey are consistent. Otherwise, the evaluation could have been re-considered by an expert team. It can therefore be concluded that the project cost, time and quality are the appropriate project objectives for the specific development. As shown in the cluster priorities column of Table 5, technical risks can be judged as the most risky for developers of the ETN project, followed by economic risks and the political risks having high level of impact of 30%, 25% and 17% respectively on the performance of ETN project with the least being the social and the environmental risks with impact level of 13% and 16%. Similarly, priorities with respect to risk sub-areas are indicated in the cost, time and quality columns of the local priorities values. The synthesized priority weights (W) for the STEEP risk sub-areas with respect to cost (W_C), time (W_T) and quality (W_Q) is the multiplication of the priority weight of 0.33 for each project objectives by their corresponding local priority weights for individual sub risks with respect to cost (w_c), time (w_t) and quality (w_q) as shown in Table 5. Hence the synthesized priority weight (W) for S_{v1} is 0.33 x 0.06 = 0.02 in approximation.

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

For the ETN project, the consistency of respondents' judgment on the level of STEEP risks impacts on the project was obtained automatically during the pairwise comparison for each risk with the supper decisions software. Thereafter, the CRs were compared with a consistency threshold of 0.1 to judge whether the comparison conducted is consistent. Where $CR \leq 0$, it meant that respondents' judgments satisfy the consistency. If not, then that means the experts had conflicting judgments and therefore, the inconsistent elements in the comparison matrix had been identified and revised; otherwise, the result of risk assessment and decision analysis would have been unreliable. It also means that where $CR \leq 0.1$, there was reasonable level of consistency. Table 6 presents the λ_{max}, CI, RI and CR values achieved for all risks in this research.

5.3. Risk Priority Index (RPI)

The RPI is a value which indicates the level of impact of risk on project success measured in percentage. The RPI is an innovative method used in this research to rank the level of influence of identified risks on the objectives of the ETN project. The final Risk Priority Index (RPI) for the STEEP risks sub-areas is the addition of the synthesized weights of cost (W_C) Time (W_T) and quality (W_Q) (See Table 5). Consequently, the RPI for S_{V1} is 0.06 (6%). 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. A megaproject developer has the flexibility to re-categorize and select the appropriate risks under each risk cluster based on the situation in a geographical setting and the type of project under development.

<Insert Table 5 & 6>

6. Discussions

According to the results given in Table 5, all STEEP risks have been ranked with regard to the priority in relation to the significance of risk impacts in the megaproject. Further discussions are provided in this section to further clarify the correction of the results, and will focus on the first prioritised risk factor in each STEEP cluster to briefly draw a conclusion on the major reasons that have caused significant cost and time overruns in the ETN project.

Disputes: When it comes to ETN project, changes and disputes were more varied and dynamic than most might think. It is therefore not surprising that the ANP prioritisation result revealed "disputes" to have the highest priority index of 0.27 (27%) of the total impact of social risks on the cost, time and quality objectives of ETN project. Disputes in ETN project arose in many ways: the City of Edinburgh Council (owner) through its representative Transport Initiative Edinburgh (Tie) and the main contractor (Bilfinger Berger Siemens) responsible for the infrastructural contract (INFRACO) made claims against each other and the public often felt left out of decision-making forums. Changes and disputes as at 2011 reported by Audit Scotland revealed that Tie paid £23.8 million in respect of 198 out of 816 notices of claims submitted by the main contractor (BBS). These and other contractual disputes resulted in project cost overruns, safety issues, inconveniences to the public, time consuming ligation and significant delays to the project beyond the originally planned programme.

Failure to meet specified standards: The result in Table 5 established that ETN project failed to meet specified standard. Road surfaces around the Tram tracks in some parts of the Edinburgh City were reported to be crumbling, raising safety problems. In September 2011, the main street also known as Princes Street was closed to all traffic for around 10 months to allow repairs on the crumbling tarmac around the tram lines before they had been used. In May 2013, it was further revealed that more than 150 metres of concrete track bed was not laid to the correct specifications between Shandwick Place and Haymarket suburbs and as a result, needed replacement. BBS later admitted the deficiency with regard to the concrete track bed and began to remedy it. These and other project specification issues not stated in this research led to the 0.15 (15%) impact level of the project specification failures on the ETN project revealed by the ANP prioritization result indicated in Table 5.

Project delays of all forms: Despite the level of sophistication available for the determination of risk and uncertainty associated with the ETN project, the ANP prioritisation result indicated in Table 5 revealed that 0.19 (9%) of the project suffered delays of all forms with respect to the economic risks impact on the objectives of the project. These delays were due to ground, environmental, political and social related problems, utilities diversions, contractual disputes, rework and unforeseen conditions met during construction.

Unfavourable climate conditions: RPI for factors under the environmental risks cluster indicates that "unfavourable climatic conditions" was ranked first and has 0.79 (79%) impact level on the objectives of ETN project during construction. The result underpins environmental related track repair works carried out on the Princes Street and the Haymarket during the early 2011 and mid-2013. The repairs were believed to have been caused by the extreme weather conditions suffered in 2009 and 2010 which both the contractors and project owners had no control over. This points out to the fact that significant risks of project time and cost overruns and quality deficiency in the project are largely related to unfavourable climatic conditions.

Political indecision: As indicated by the RPI, political indecision among the ten political risks considered accounted for 0.21 (21%) of risk impact level on the objectives of ETN project. As in any major national project, the ETN Project had been marred with political issues from the early stages of the project's life. Political disputes between the Scottish National Party (SNP) on one side, who have opposed the project and other political parties including Labour, Liberal Democrats, Conservatives and Green Party on the other who have generally backed the scheme, had been on the increase. The SNP councillors did not see themselves bound to support the project and as such lost some opportunities in tackling the project even though they were part of the administration sponsoring it. The political disagreement became stronger and ran through the middle of the ruling coalition on CEC until the Scottish Government cancelled a proposed Edinburgh Airport Rail Link in favour of making the trams the means of linking the City Centre and the main line rail network to the Edinburgh airport. The Scottish Government later committed itself to building a new station on the Edinburgh-Fife/Aberdeen line at Gogar to link with the trams and the airport.

7. Conclusions and Recommendations

This section of the paper proposes the use of ANP methodology to prioritize risks in transportation megaprojects at construction stage. Risk sources were identified in literature, from experts' opinions, source documents of past and existing megaprojects under construction and accordingly were categorised into clusters. A model for calculating RPIs was designed and its components were explained and discussed in detailed throughout this paper. The developed models were applied to STEEP risk to evaluate their level of impacts on project cost, time and quality. Prioritization results revealed that technical risks have the highest average effect score (0.30) in the hierarchy risks areas considered in this research. The results further shown that economic risks have the second highest effects score (0.25) followed by political risks (0.17), environmental risks (0.16) and social risks (0.13). Based on the ANP RPIs, the results suggest that, a developer that pursues transportation megaprojects needs to consider seriously technical risks in the construction phase of the project life cycle. Additionally, the interactions of all risks in emerging economy, political and social environments of any nation initiating megaprojects can be very critical to supply-side stakeholders to deal with. Therefore, the developed model can be implemented to facilitate a company's decision on risk management based on the level of STEEP risks impact on project performance.

The relevancies of this research are that:

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

This paper has demonstrated an example using the ETN project to illustrate the steps of ANP in project risk prioritisation. However, the authors take the view that contractors, consultants and companies should improve their individual sets of STEEP risks criteria, especially when they have to put further effort into examining the complex nature of a megaproject construction. In this regard, our decision model is a reference point for them. It should be noted that an effective risk prioritisation method helps to ensure optimal resource utilization and greater contribution of projects toward company's missions and goals.The conclusions in this paper are limited to the data collected. Yet, if data set is extended to cover more transportation megaprojects and risks areas, it might truly represent the level of STEEP risks impact on megaprojects performance so that general conclusions can be drawn.

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References

Abdul Rahman, I., Memon, A.H., Karim, A., Tarmizi, A., 2013. Significant factors causing cost overruns in large construction projects in Malaysia. Journal of Applied Science, 13, 286-293.

Adam, A., Josephson, P.-E., Lindahl, G., 2014. Implications of cost overruns and time delays on major public construction projects, Proceedings of the 19th International Symposium on the Advancement of Construction Management and Real Estate, 7-9 Nov 2014, Chongqing.

Ali-Mohammed, B.A., 2010. Risk and Stakeholder Management in Mega Projects beyond the Realms of Theory. Ministry of Works and Housing, Kingdom of Bahrain.[Online]. [Accessed 25 October, 2014]. Available from: www.works.gov.bh/media/Researchs/pw04p06.pdf.

Anderson Jr, L.L., Polkinghorn, B., 2008. Managing conflict in construction megaprojects: Leadership and third-party principles. Conflict Resolution Quarterly, 26, 167-198.

Ball, M., 2014. Rebuilding construction: Economic change in the British construction industry. Routledge.

BCIS, 2012. “BIS Construction Price and Cost Indices”. Building Cost Information Services, UK. [Online]. [Accessed 3 June 2015]. Available from: http://www.bcis.co.uk.

Boateng, P., Chen, Z., 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, 208-224.

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

Bottero, M., Leal-Filho, W., Platje, J., 2015. A multi-methodological approach for assessing sustainability of urban projects. Management of Environmental Quality: An International Journal, 26.

Brookes, N.J., 2015. Mankind and Mega-projects. Frontiers of Engineering Management, 1, 241-245.

Cannemi, M., García-Melón, M., Aragonés-Beltrán, P., Gómez-Navarro, T., 2014. Modeling decision making as a support tool for policy making on renewable energy development. Energy Policy, 67, 127-137.

Charvat, J., 2003. Project management methodologies: selecting, implementing, and supporting methodologies and processes for projects. John Wiley & Sons.

Chen, Z., Li, H., Ren, H., Xu, Q., Hong, J., 2011. A total environmental risk assessment model for international hub airports. International Journal of Project Management, 29, 856-866.

Chung, S.-H., Lee, A.H., Pearn, W.-L., 2005. Analytic network process (ANP) approach for product mix planning in semiconductor fabricator. International Journal of Production Economics, 96, 15-36.

Davies, A., MacAulay, S., DeBarro, T., Thurston, M., 2014. Making Innovation Happen in a Megaproject: London's Crossrail Suburban Railway System. Project Management Journal, 45, 25-37.

Diab, M.F., Nassar, K., 2012. Using risk assessment to improve highway construction project performance, The Proceedings of the ASC Annual 48th Annual International Conference, Birmingham, England April 11th-14th.

Dimitriou, H.T., 2014. What constitutes a “successful” mega transport project? Planning Theory & Practice, 15, 389-430.

Eizakshiri, F., Chan, P.W., Emsley, M.W., 2015. Where is intentionality in studying project delays? International Journal of Managing Projects in Business, 8, 349-367.

Ergu, D., Kou, G., Shi, Y., Shi, Y., 2014. Analytic network process in risk assessment and decision analysis. Computers & Operations Research, 42, 58-74.

Fallahnejad, M.H., 2013. Delay causes in Iran gas pipeline projects. International Journal of Project Management, 31, 136-146.

Flyvbjerg, B., 2009. Survival of the unfittest: why the worst infrastructure gets built—and what we can do about it. Oxford review of economic policy, 25, 344-367.

Flyvbjerg, B., 2014. What you should know about megaprojects and why: An overview. Project Management Journal, 45, 6-19.

Flyvbjerg, B., Bruzelius, N., Rothengatter, W., 2003a. Megaprojects and risk: An anatomy of ambition. Cambridge University Press.

Flyvbjerg, B., Holm, M.S., Buhl, S., 2002. Underestimating costs in public works projects: Error or lie? Journal of the American planning association, 68, 279-295.

Flyvbjerg, B., Skamris Holm, M.K., Buhl, S.L., 2003b. How common and how large are cost overruns in transport infrastructure projects? Transport Reviews, 23, 71-88.

Fulford, R., Standing, C., 2014. Construction industry productivity and the potential for collaborative practice. International Journal of Project Management, 32, 315-326.

Gharaibeh, H.M., 2013. Cost control in mega projects using the Delphi method. Journal of Management in Engineering, 30.

Giezen, M., 2012. Keeping it simple? A case study into the advantages and disadvantages of reducing complexity in mega project planning. International Journal of Project Management, 30, 781-790.

Guo, F., Chang-Richards, Y., Wilkinson, S., Li, T.C., 2014. Effects of project governance structures on the management of risks in major infrastructure projects: A comparative analysis. International Journal of Project Management, 32, 815-826.

Han, S.H., Yun, S., Kim, H., Kwak, Y.H., Park, H.K., Lee, S.H., 2009. Analyzing schedule delay of mega project: Lessons learned from Korea train express. Engineering Management, IEEE Transactions on, 56, 243-256.

Jordhus-Lier, D., 2015. Community resistance to megaprojects: The case of the N2 Gateway project in Joe Slovo informal settlement, Cape Town. Habitat International, 45, 169-176.

Kardes, I., Ozturk, A., Cavusgil, S.T., Cavusgil, E., 2013. Managing global megaprojects: Complexity and risk management. International Business Review, 22, 905-917.

KarimiAzari, A., Mousavi, N., Mousavi, S.F., Hosseini, S., 2011. Risk assessment model selection in construction industry. Expert Systems with Applications, 38, 9105-9111.

Kennedy, L., 2015. The politics and changing paradigm of megaproject development in metropolitan cities. Habitat International, 45, 163-168.

Kim, S.-Y., Huynh, T.-A., 2008. Improving project management performance of large contractors using benchmarking approach. International Journal of Project Management, 26, 758-769.

Kwak, Y.H., Walewski, J., Sleeper, D., Sadatsafavi, H., 2014. What can we learn from the Hoover Dam project that influenced modern project management? International Journal of Project Management, 32, 256-264.

Liang, S., Wey, W.-M., 2013. Resource allocation and uncertainty in transportation infrastructure planning: A study of highway improvement program in Taiwan. Habitat International, 39, 128-136.

Lo, T.Y., Fung, I.W., Tung, K.C., 2006. Construction delays in Hong Kong civil engineering projects. Journal of Construction Engineering and Management, 132, 636-649.

Mentis, M., 2015. Managing project risks and uncertainties. Forest Ecosystems, 2, 1-14.

Mousavi, S.M., Tavakkoli-Moghaddam, R., Azaron, A., Mojtahedi, S.M.H., Hashemi, H., 2011. Risk assessment for highway projects using jackknife technique. Expert Systems with Applications, 38, 5514-5524.

Nasir, H., Haas, C.T., Rankin, J.H., Fayek, A.R., Forgues, D., Ruwanpura, J., 2012. Development and implementation of a benchmarking and metrics program for construction performance and productivity improvement. Canadian Journal of Civil Engineering, 39(9), 957-967.

Nassar, N., AbouRizk, S., 2014. Practical application for integrated performance measurement of construction projects. Journal of Management in Engineering, 30.

Nieto-Morote, A., Ruz-Vila, F., 2011. A fuzzy approach to construction project risk assessment. International Journal of Project Management, 29, 220-231.

Poole, R., 2004. Addressing the "Big Dig Syndrome": Transportation projects have credibility problem. The Reason Foundation, Los Angeles, USA. [Online]. [Accessed 3 June 2015]. Available from: http://reason.org/news/show/addressing-the-big-dig-syndrom.

Priemus, H., 2014. Managing the risks of a large-scale infrastructure project: The case of Spoorzone Delft, Infranomics. Springer, pp. 395-406.

Proost, S., Dunkerley, F., Van der Loo, S., Adler, N., Bröcker, J., Korzhenevych, A., 2014. Do the selected Trans European transport investments pass the Cost Benefit test? Transportation, 41, 107-132.

Renuka, S., Umarani, C., Kamal, S., 2014. A Review on Critical Risk Factors in the Life Cycle of Construction Projects. Journal of Civil Engineering Research, 4, 31-36.

Saaty, T.L., 2005. Theory and applications of the analytic network process: decision making with benefits, opportunities, costs, and risks. Pittsburgh. Pennsylvania: RWS Publications.

Saaty, T.L., Vargas, L.G., 2013. An Analytic Network Process Model for Financial-Crisis Forecasting, Decision Making with the Analytic Network Process. Springer, pp. 75-92.

Salling, K.B., Leleur, S., 2015. Accounting for the inaccuracies in demand forecasts and construction cost estimations in transport project evaluation. Transport Policy, 38, 8-18.

Salunkhe, A.A., Patil, R.S., 2014. effect of construction delays on project time overrun: Indian scenario. International journal of Research in Engineering and Technology, 3, 543-547.

Sepasgozar, S.M., Razkenari, M.A., Barati, K., 2015. The Importance of New Technology for Delay Mitigation in Construction Projects. American Journal of Civil Engineering and Architecture, 3, 15-20.

Sipahi, S., Timor, M., 2010. The analytic hierarchy process and analytic network process: an overview of applications. Management Decision, 48, 775-808.

Smith, M.W., 2010. Boston’s “Big Dig”: A Socio-Historical and Political Analysis of Malfeasance and Official Deviance. NATIONAL SOCIAL SCIENCE JOURNAL Volume 34(2), 148.

Spirkova, D., 2014. Management of Megaproject During the Turbulent Period of Economic and Political Transformation in Slovakia. Journal of US-China Public Administration, 11, 750-762.

Tjader, Y., May, J.H., Shang, J., Vargas, L.G., Gao, N., 2014. Firm-level outsourcing decision making: A balanced scorecard-based analytic network process model. International Journal of Production Economics, 147, Part C, 614-623.

Van de Graaf, T., Sovacool, B.K., 2014. Thinking big: Politics, progress, and security in the management of Asian and European energy megaprojects. Energy Policy, 74, 16-27.

Yang, J.-B., Wei, P.-R., 2010. Causes of delay in the planning and design phases for construction projects. Journal of Architectural Engineering, 16(2), 80-83.

Yeh, T.-M., Huang, Y.-L., 2014. Factors in determining wind farm location: Integrating GQM, fuzzy DEMATEL, and ANP. Renewable Energy, 66, 159-169.

Yurdakul, M., 2003. Measuring long-term performance of a manufacturing firm using the analytic network process (ANP) approach. International Journal of Production Research, 41, 2501-2529.

Figures

Fig. 1. Comparison of Hierarchy (AHP) and Network (ANP) structure.

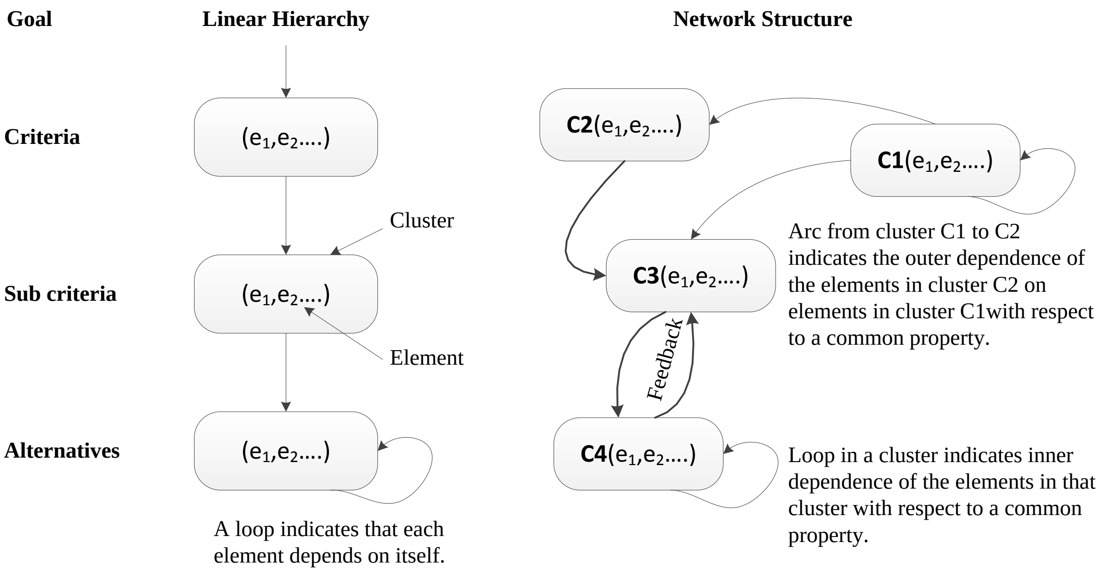
Fig. 2. An analytical process for prioritising risk factors.

Fig. 3. A hierarchy of STEEP risk in the ETN project.

Fig. 4. ANP model structure for STEEP risks prioritization.

Fig. 5. ANP sub models for STEEP risks prioritization.

  a. Sub model for prioritizing project objectives.
  b. Sub model for prioritizing potential 5 STEEP risks.
  c. Sub model for prioritizing social risks.
  d. Sub model for prioritizing technical risks.
  e. Sub model for prioritizing economic risks.
  f. Sub model for prioritizing environmental risks.
  g. Sub model for prioritizing political risks.



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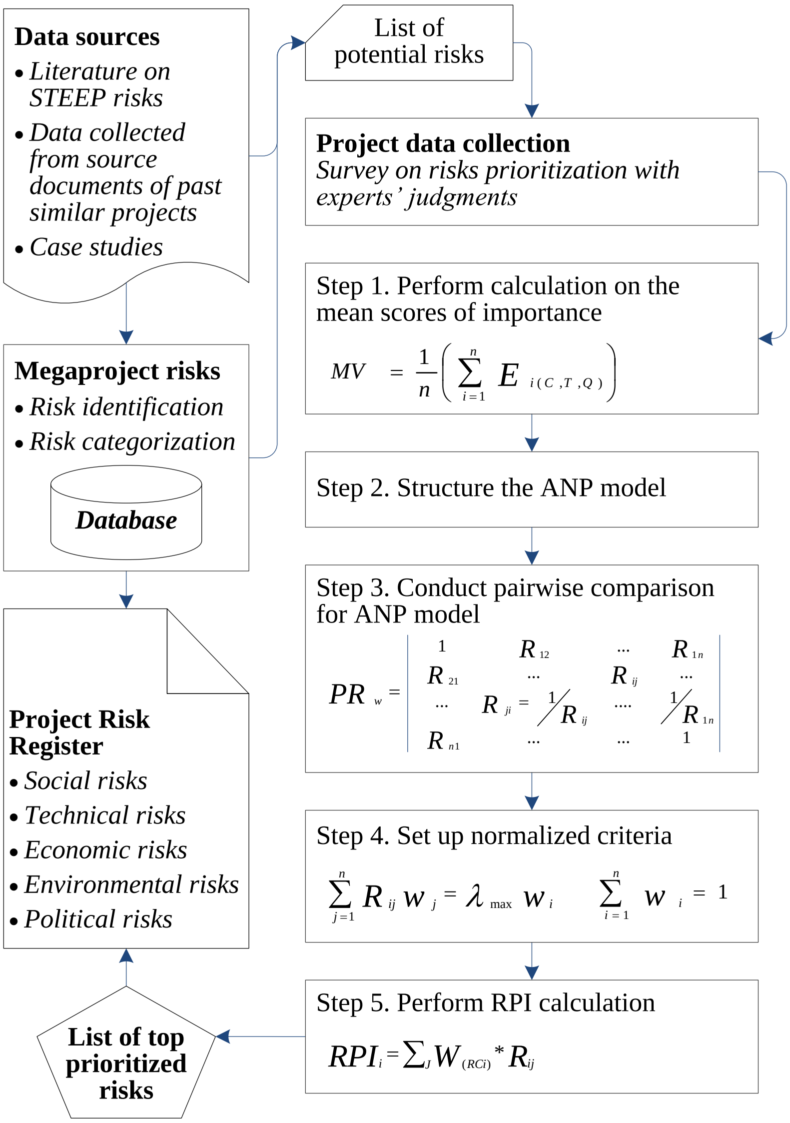


Fig. 2. An analytical process for prioritising risk factors.

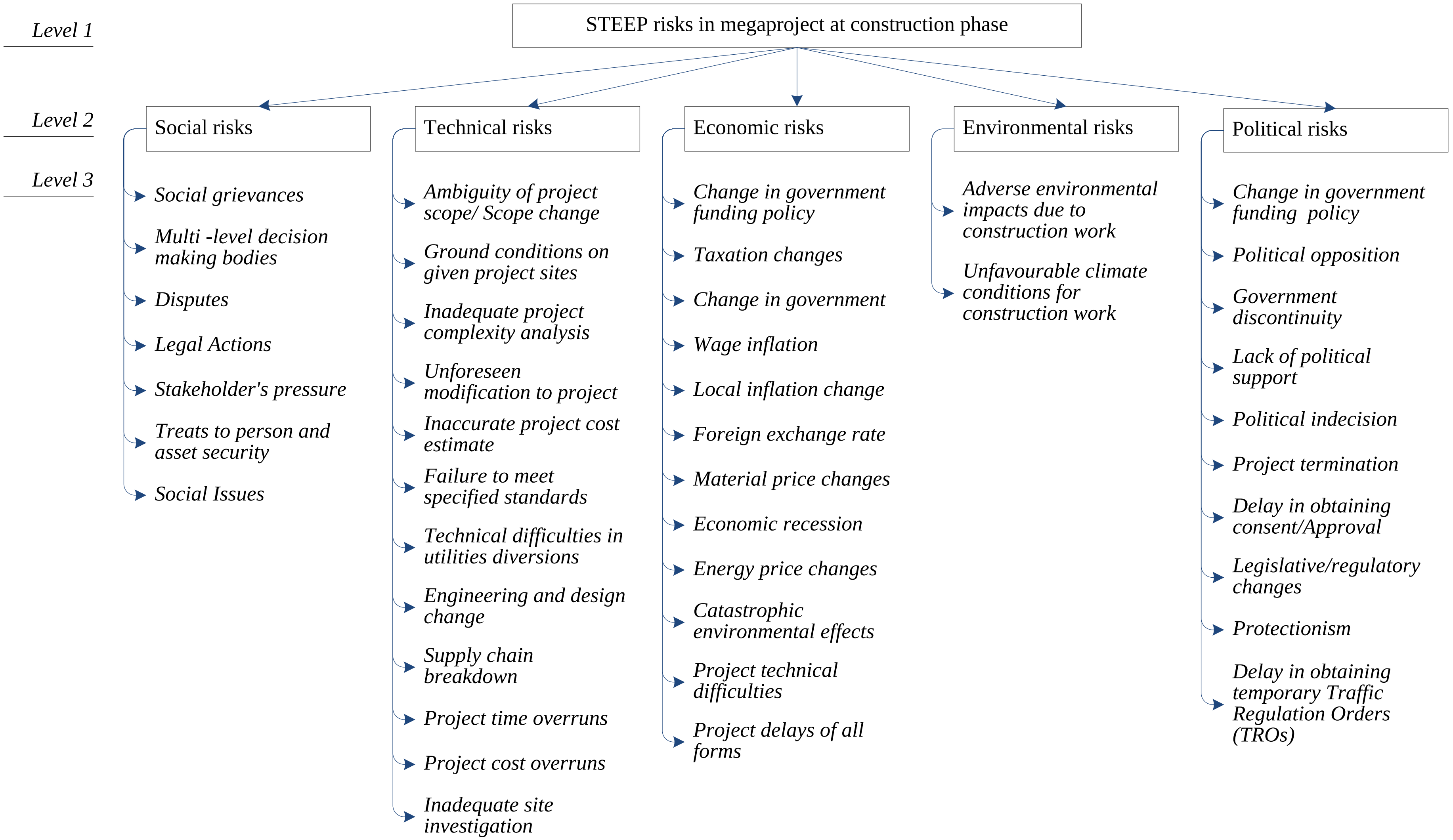


Fig. 3. A hierarchy of STEEP risk in the ETN project.

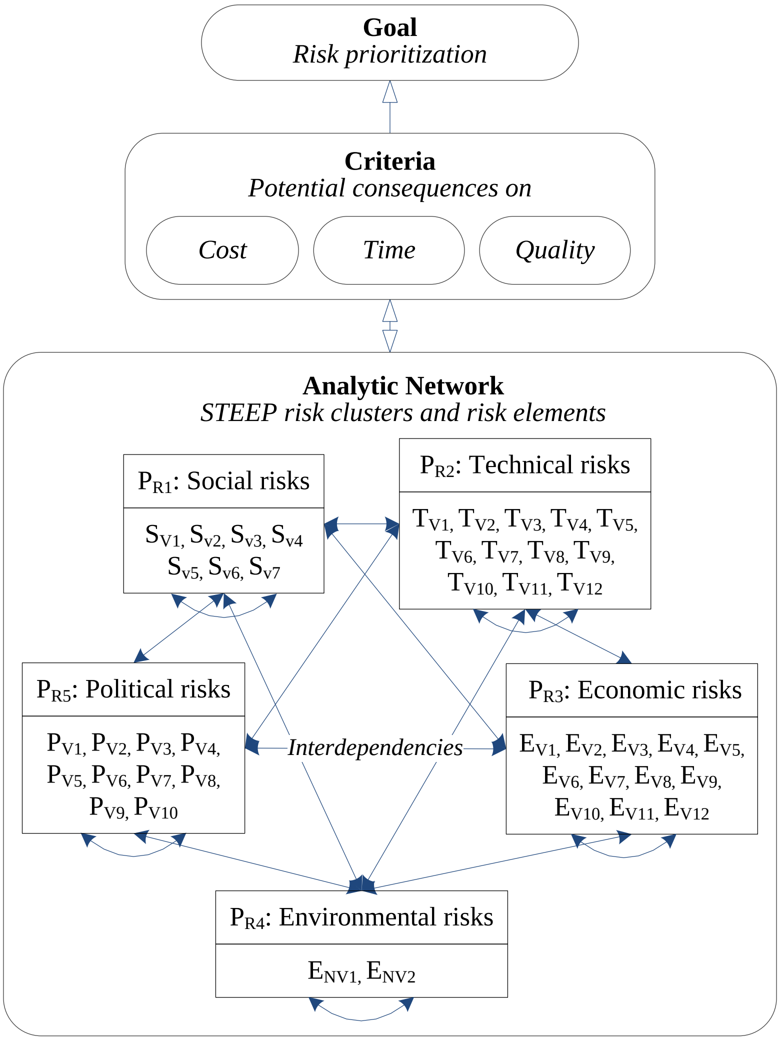
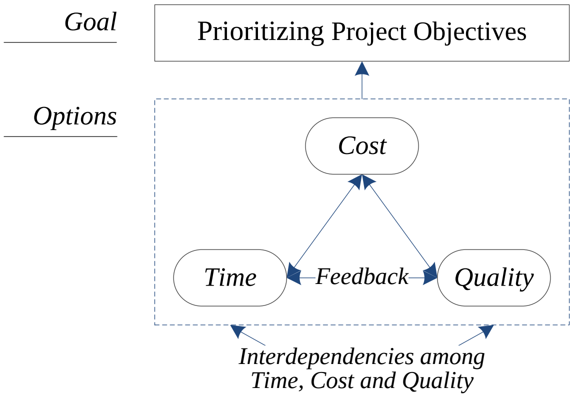
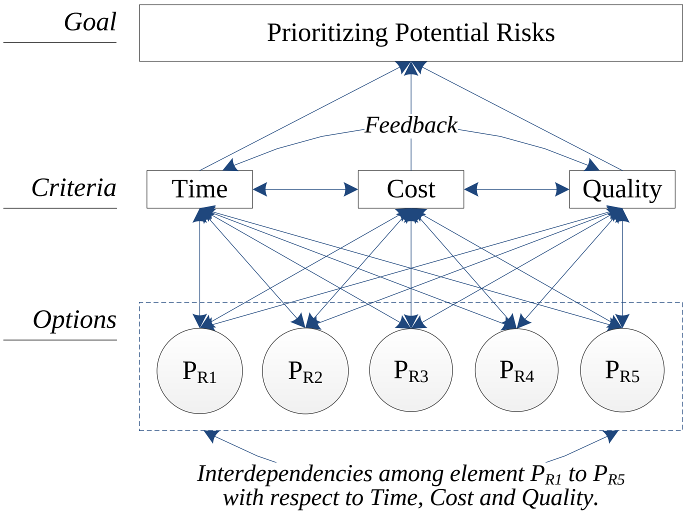


Fig. 4. ANP model structure for STEEP risks prioritization.



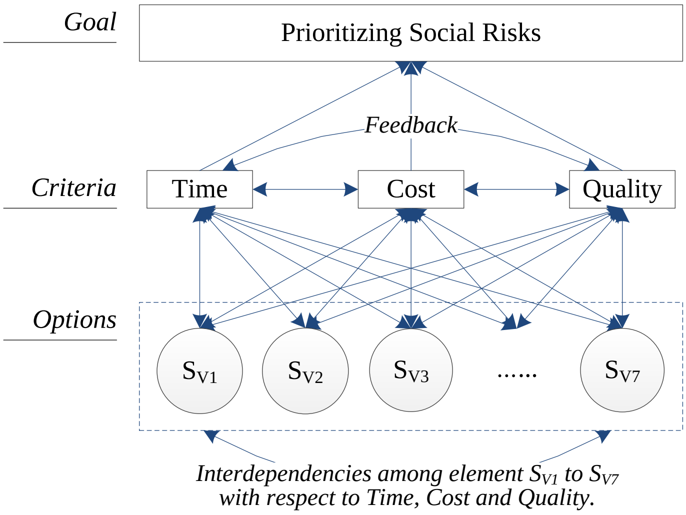
a. Sub model for prioritizing project objectives.

Fig. 5. ANP sub models for STEEP risks prioritization.



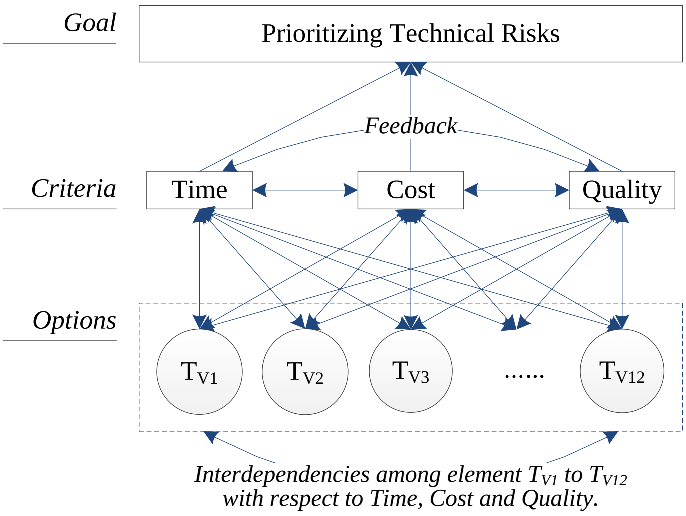
b. Sub model for prioritizing potential 5 STEEP risks.

Fig. 5. ANP sub models for STEEP risks prioritization.



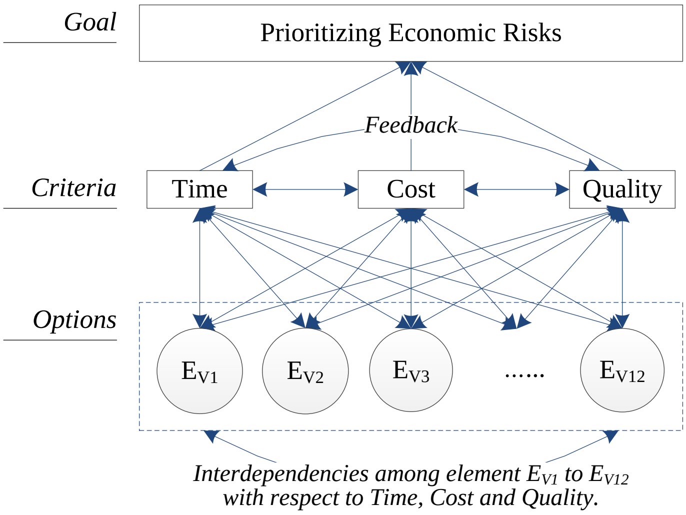
c. Sub model for prioritizing social risks.

Fig. 5. ANP sub models for STEEP risks prioritization.



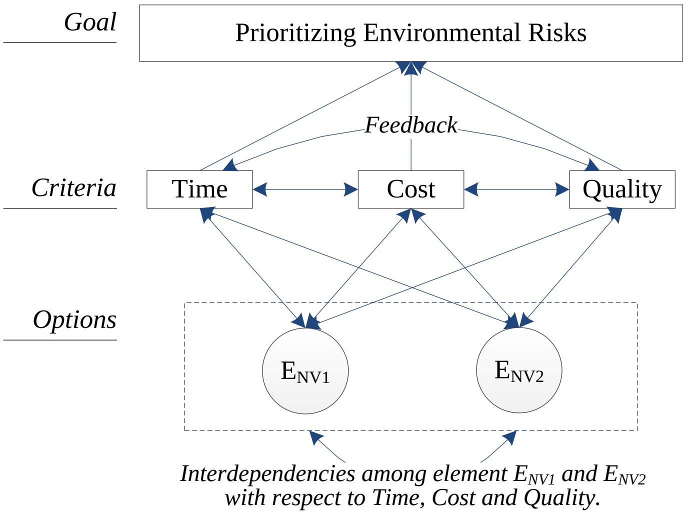
d. Sub model for prioritizing technical risks.

Fig. 5. ANP sub models for STEEP risks prioritization.



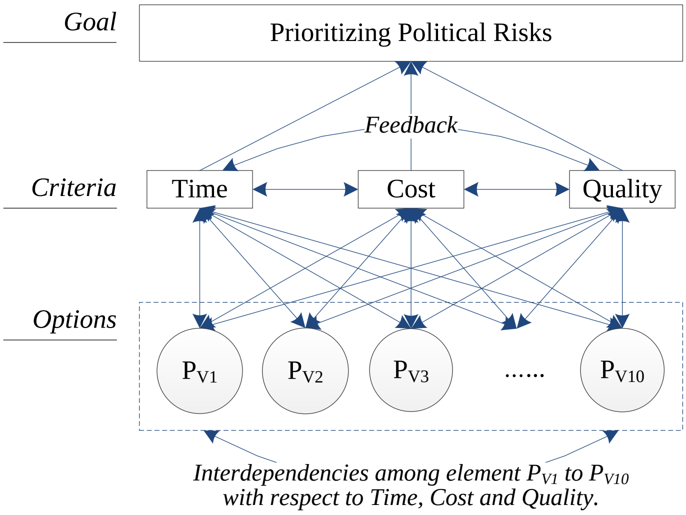
e. Sub model for prioritizing economic risks.

Fig. 5. ANP sub models for STEEP risks prioritization.



f. Sub model for prioritizing environmental risks.

Fig. 5. ANP sub models for STEEP risks prioritization.



g. Sub model for prioritizing political risks.

Fig. 5. ANP sub models for STEEP risks prioritization.

Tables

Table 1
A summary of review on STEEP risks in megaprojects.

Types and sources of risks	References
Social risks	
Inability to obtain land and access rights	Hilber & Robert-Nicoud (2013), Turner et al. (2011)
Compensation costs higher than expected	Hilber & Robert-Nicoud (2013), Turner et al. (2011), Funderburg et al. (2010)
Community and legal actions	Funderburg et al. (2010)
Delays dues to Local labour disputes	Alinaitwe et al. (2007). Case: Vasco da Gama Bridge (EC, 2003)
Threats to personal or asset security	Alinaitwe et al. (2007), Jones and Brinkert (2008)
Vandalism & damage	Alinaitwe et al. (2007), Al-Momani, (2000), Jones and Brinkert (2008)
Third part claims	Galloway (2009)
Costs due to disputes, community and legal action	Alinaitwe et al. (2007), Al-Momani (2000); Jones and Brinkert (2008), Funderburg et al. (2010)
Involvement of too many Multi-level decision making bodies	Winch (2000), Olander and Landin (2005), Bourne and Walker (2006), Miller and Lessard (2001), Jafaari (2004)
Social issues and grievances	Soderholm (2008), Cole (2000), Chen et al.(2005), Cardoso (2005)
Technical risks	
Ambiguity of project scope/ Scope change	Cases: Thailand Underground Rail project (Ghosh & Jintanapakanont, 2004), Edinburgh Tram Network project (Audict Scotland, 2011)
Ground conditions on given project sites	Lo et al. (2006). Case: the Thailand Underground Rail Project (Ghosh & Jintanapakanont, 2004).
Inadequate project complexity analysis	Arain et al. (2004), Audit Scotland (2011), Brockmann (2007), Nielsen et al. (2013),
Unforeseen modification to project	Audit Scotland (2011). Case: Thailand Underground Rail project (Ghosh & Jintanapakanont, 2004).
Inaccurate project cost estimate	Audit Scotland (2011), HS2 Ltd (2009), Nielsen et al. (2013)
Failure to meet specified standards	Arain et al.(2004), Audit Scotland (2011), Nielsen et al. (2013)
Technical difficulties in utilities diversions	HS2 Ltd. (2009), Audit Scotland (2011), Nielsen et al. (2013)
Engineering and design change	Austin (2000), Choo et al. (2004). Case: Thailand Underground Rail project (Ghosh & Jintanapakanont, 2004).
Supply chain breakdown	Haynes (2002), Eglin (2003), Norrman and Jansson (2004), Kane (2001), CIOB (2010), Wolstenhome (2009)
Project time overruns	Yang et al. (2010), Fugar (2010), Megha & Bhatt (2013), Nielsen et al. (2013), Chidambaram et al. (2012), Shaikh and Muree (2010), Kang (2010), Kikwasi (2012), Safeer et al. (2012), Mohd (2010),
Project cost overruns	Yang et al. (2010). Cases: Boston Central Artery / Tunnel project, Great Belt Rail Tunnel project, Shinkansen Joetsu Rail Line project, and Channel Tunnel project (Flyvbjerg et al. 2003; Reilly, 2005)
Project delays of all forms	Yang et al. (2010), Fugar (2010), Desai & Bhatt (2013), Nielsen et al. (2013), Chidambaram et al. (2012), Shaikh and Muree (2010), Kang (2010), Kikwasi (2012), Safeer et al. (2012), Mohd (2010)
Economic risks	
Change in government funding policy	Sturup (2009), Frick (2006); Haynes (2002). Cases: Melbourne City Link project (Hodge, 2004), London Underground project (EC, 2002)
Taxation changes	Case: London Underground project (EC, 2002)
Change in government	Hertogh et al. (2008)
Wage inflation;	Agyakwa-Baah (2009), Frimpong et al. (2003), Denini (2009)
Local inflation change	Agyakwa-Baah (2009), Frimpong et al. (2003), Denini (2009). Case: Channel Tunnel Rail Link project (PAC, 2006a)
Foreign exchange rate	Case: Thailand Underground Rail project (Ghosh &Jintanapakanont, 2004)
Material price changes	Audit Scotland (2004), Haynes (2002)
Economic recession	Sturup (2009), Frick (2006), Haynes (2002)
Energy price change/interest rate	Case: Harnaschpolder Wastewater Treatment project (Smith, 2006)
Catastrophic environmental effects	Case: Great Belt and Oresund Links/Demark project (Flyvbjerg et al., 2003)
Project technical difficulties	Audit Scotland (2004)
Project delays of all forms	Yang et al. (2010), Fugar (2010), Desai & Bhatt (2013), Nielsen et al. (2013).
Cost overruns	Bruzelius et al. (2002), Altshuler and Luberoff (2003), Lee (2008), Fraser

	(1990), Singh (2009)
Environmental risks	
Adverse environmental impacts due to construction work	Lo et al. (2006). Case: Great Belt and Oresund Links project (Flyvbjerg et al., 2003)
Unfavourable climate conditions	Othman et al. (2006). Cases: Great Belt and Oresund Links project (Flyvbjerg et al., 2003), London Underground project (EC, 2002), Channel Tunnel Rail Link project (PAC, 2002b), Melbourne City Link project (Hodge, 2004), Thailand Underground Rail project (Ghosh & Jintanapakanont, 2004)
Political risks	
Change in government funding policy	Sturup (2009), Frick (2006), Haynes (2002) Cases: Melbourne City Link project (Hodge, 2004), London Underground project (EC, 2002)
Political opposition/interferences	De-Mortanges and Aller (1996). Cases: the Bangkok Elevated Road and Track System (The Work Bank, 1999), the Constanta Water Project (EC, 2004b), Prescom in Targoviste project (EC, 2004b)
Government discontinuity	Hertogh et al. (2008), Flyvbjerg et al. (2003)
Lack of political support	Sturup (2009), Frick (2006), Flyvbjerg et al. (2003) Cases: Bangkok Elevated Road and Track System project (The Work Bank, 1999), Constanta Water project (EC, 2004b), Prescom project (EC, 2004b)
Political indecision	Dada and Jagboro (2007), Ruuska et al. (2009), Haynes (2002)
Project termination	Cases: North-South Expressway (NSE) project, and Kuala Lumpur-Karak Highway project (The Work Bank, 1999)
Delay in obtaining consent/Approval;	Case: Water Infrastructure project in Southern China (Lu, 2004)
Legislative/regulatory changes	Cases: Melbourne City Link project (Hodge, 2004), London Underground project (EC, 2002)
Protectionism	Sears et al. (2010)
Delay in obtaining temporary Traffic Regulation Orders (TROs)	Audit Scotland (2011)

Table 2
Respondent’s mean scores of importance for project objectives.

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

Table 3
Respondent's mean scores of importance for risk clusters.

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

Table 4
Respondent’s mean scores of importance for risk sub-areas.

Risk Cluster	**Type of risks under each Cluster**		**Mean Values (MV_{Risks}) $= \frac{1}{n}\left(\sum_{i=1}^{n} E_{i(C,T,Q)}\right)$**					
	Code	Risks	Cost	Time	Quality	Rounded MVs		
						Cost	Time	Quality
P_{R1}	S_{V1}	Social grievances	5.42	4.51	2.69	5	5	3
	S_{V2}	Multi -level decision making bodies	9.14	7.88	5.51	9	8	6
	S_{V3}	Disputes	9.04	7.81	6.10	9	8	7
	S_{V4}	Legal actions	8.84	7.77	5.85	9	8	6
	S_{V5}	Stakeholder's pressure	7.50	6.13	3.81	8	6	4
	S_{V6}	Treats to person and asset security	4.35	2.92	2.77	4	3	3
	S_{V7}	Social issues	2.76	2.35	2.43	3	2	3
P_{R2}	T_{V1}	Ambiguity of project scope/ Scope change	8.22	7.33	4.27	8	7	4
	T_{V2}	Ground conditions on given project sites	7.15	6.50	2.80	7	7	3
	T_{V3}	Inadequate project complexity analysis	8.91	7.52	5.15	9	8	5
	T_{V4}	Unforeseen modification to project	7.73	6.86	4.25	8	7	4
	T_{V5}	Inaccurate project cost estimate	8.84	6.92	4.44	9	7	4
	T_{V6}	Failure to meet specified standards	8.97	7.03	7.95	9	7	8
	T_{V7}	Technical difficulties in utilities diversions	9.08	8.51	3.97	9	9	4
	T_{V8}	Engineering and design change	6.32	5.68	3.35	6	6	3
	T_{V9}	Supply chain breakdown	5.09	7.13	2.46	5	7	2
	T_{V10}	Project time overruns	9.25	8.18	4.62	9	8	5
	T_{V11}	Project cost overruns	9.03	7.34	4.53	9	7	5
	T_{V12}	Inadequate site investigation	8.91	8.22	5.55	9	8	6
P_{R3}	E_{V1}	Change in government funding policy	8.51	7.18	6.31	9	7	6
	E_{V2}	Taxation changes	3.90	2.41	2.42	4	2	2
	E_{V3}	Change in government	7.01	6.81	5.84	7	7	6
	E_{V4}	Wage inflation	3.38	2.34	2.35	3	2	2
	E_{V5}	Local inflation change	2.91	2.08	2.03	3	2	2
	E_{V6}	Foreign exchange rate	2.81	2.25	2.17	3	2	2
	E_{V7}	Material price changes	6.65	4.59	4.58	7	5	5
	E_{V8}	Economic recession	5.34	3.44	3.02	5	3	3
	E_{V9}	Energy price changes	5.70	3.42	2.90	6	4	3
	E_{V10}	Catastrophic environmental effects	7.12	6.82	5.57	7	7	6
	E_{V11}	Project technical difficulties	8.00	7.34	5.50	8	7	6
	E_{V12}	Project delays of all forms	8.50	7.64	5.59	9	8	6
P_{R4}	E_{NV1}	Adverse environmental impacts	4.66	4.05	2.63	5	4	3
	$E_{NV\ 2}$	Unfavourable climate conditions	8.78	7.27	6.13	9	7	6
P_{R5}	P_{V1}	Change in government funding policy	8.56	7.12	6.01	9	7	6
	P_{V2}	Political opposition	7.49	6.03	4.03	7	6	4
	P_{V3}	Government discontinuity	7.50	7.04	5.77	8	7	6
	P_{V4}	Lack of political support	8.17	7.27	5.49	8	7	5
	P_{V5}	Political indecision	8.76	7.99	6.01	9	8	6
	P_{V6}	Project termination	5.99	5.59	4.17	6	6	4
	P_{V7}	Delay in obtaining consent/approval	6.41	6.29	3.25	6	6	3
	P_{V8}	Legislative/regulatory changes	5.80	4.35	2.66	6	4	3
	P_{V9}	Protectionism	3.20	3.57	2.48	3	4	3
	P_{V10}	Delay in obtaining temporary TROs	6.36	6.22	2.93	6	6	3

Notes:

1. Risk clusters: P_{R1} - Social risks, P_{R2} - Technical risks, P_{R3} - Economic risks, P_{R4} - Environmental risks, P_{R5} - Political risks.
2. TRO - Traffic Regulation Orders

Table 5
Summary of risk priorities.

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

Table 6
Values of CI, RI, CR and inconsistency for all the pairwise comparison matrices.

Risk Cluster	**Criteria**	**Values**				
		λ_{max}	CI	RI	CR	Inconsistency
Social risks	Cost	7.100	0.020	1.350	0.010	0.000
	Time	7.200	0.030	1.350	0.020	0.002
	Quality	7.080	0.010	1.350	0.000	0.001
Technical risks	Cost	12.11	0.010	1.540	0.010	0.000
	Time	12.07	0.010	1.540	0.000	0.001
	Quality	12.23	0.020	1.540	0.010	0.000
Economic risks	Cost	12.49	0.040	1.540	0.030	0.000
	Time	12.35	0.030	1.540	0.020	0.000
	Quality	12.20	0.020	1.540	0.010	0.000
Environmental risks	Cost	2.000	0.000	0.000	0.000	0.000
	Time	2.000	0.000	0.000	0.000	0.000
	Quality	2.000	0.000	0.000	0.000	0.000
Political risks	Cost	10.19	0.020	1.490	0.010	0.000
	Time	10.00	0.000	1.490	0.000	0.000
	Quality	10.08	0.010	1.490	0.010	0.000