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VISUALISATION OF COMPLEXITY AND RISK IN MEGA CONSTRUCTION PROJECTS

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ABSTRACT

Visualisation facilitates representation and communication of information to help make sense of it and make informed decisions. In construction project management domain, there is a growing interest for applying visualisation to present construction data and track performance in a more effective way. However, regarding project risk management, current visualisation approaches are not capable of portraying the effects of complexity and risk factors on each other and on project performance. Demonstrating these interactions is particularly important for mega construction projects, which are theoretically regarded as complex. Hence, there is a need to develop visualisation method(s) to conceptualise the complexity and risk-related events and visualise their impact on project performance. In accordance with this overall purpose, this study aims to lay the groundwork for the exploration and identification of effective visualisation method(s) suitable for mega-projects. This research study helps explain conceptual relationships between complexity events, risk factors and project performance criteria by taking into account the other risk-related concepts such as vulnerability and resilience. Findings of this study can enable mega project practitioners to understand risk propagation behaviour in complex environments, to make managerial decisions proactively and to improve risk communication.

Keywords: Visualisation, complexity, risk, mega construction projects, project management.

INTRODUCTION

Construction projects have characteristic problems such as time and cost limitations, physical constraints, ambiguity in scope, multitude of stakeholders and difficulties in communication. These issues have a direct impact on the success of the projects and make them difficult to be managed. In order to deal with such problems, the construction project teams utilise numerous tools and techniques. Visualisation is one of the methods, which provides faster and easier understanding of a particular information. For this reason, it is frequently used for knowledge sharing and reporting purposes. Despite its benefits in varied areas of project management, the use of visualisation in risk management is scarce. Project management literature shows a growing interest in risk-related concepts. Yet, there are significant shortcomings in terms of consolidation of these concepts and demonstrating their relationships (Thome 2015). Current visualisation approaches in risk management are not capable of portraying the effects of complexity and risk factors and facilitating the decision making of project teams.

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Understanding the dynamics of risk events and developing effective risk management strategies are particularly important for mega projects. Complexity factors inherent to construction projects are more common in mega construction projects. For this reason, they are theoretically regarded as complex projects (Hu, et al. 2015). Complex nature of the mega projects is the main reason why they exhibit substantial performance problems. To illustrate, cost deviations range from 8% to 116% for nine high-speed train line projects selected from mega-projects in the European Union (Boateng, et al. 2015). Another example reveals that average cost of seven mega projects conducted in Korea has been increased by USD 2.9 billion, whereas duration has been extended by about 3.6 years (Han, et al. 2009). These numbers yield that risks and complexity factors must be effectively managed in order mega projects to be successful.

The objective of our research is to develop a method to visualise risk and complexity in mega construction projects. The initial question to address the overall objective of our research is how the complexity and risk factors as well as their interrelations can be conceptualised so that their impact on the project performance can be effectively visualised. Hence, in this study we present the ideas developed to lay the groundwork of this on-going research study and address this question. The conceptual background and the research plan are explained in the following sections.

BACKGROUND

Mega projects

Mega projects are characterised by their huge budget, requirement of advanced construction methods, interaction between various parties, as well as substantial economic, environmental and political influences. With these aspects, they are typical examples of complex projects. It is necessary to develop approaches specific to mega projects to be able to manage complex issues encountered in these projects. For this reason, distinctive features that indicate whether a project is a mega project need to be identified. The U.S. Federal Highway Administration (FHWA) defines mega projects as major infrastructure projects that requires capital of more than USD 1 billion or projects that draw public and political attention with their significant cost (Capka 2004). Even though cost threshold is accepted as a main determining factor for mega projects, there are also different approaches in the literature. Some researchers indicate that ratio of project budget to the gross domestic product (GDP) of the country should be considered as another determining factor. Study of Hu et al. (2015) indicates that a mega project in United States typically constitutes the 0.01% of the GDP. Some studies, on the other hand, assert that project duration should also be taken into consideration when defining mega projects. According to Han et al. (2009), cost of mega projects in Korea is over USD 1 billion and they have duration of more than 5 years.

Complexity

There are different approaches in the literature regarding the description of complexity. Bakhshi et al. (2016) analysed 420 articles published between 1990 and 2015 in order to identify project complexity and listed 14 different complexity definitions found in the literature. According to this list, definition of the Hatch and Cunliffe (2012) is the most cited work, which describes complexity as existence of several different elements that possess various interactions and feedback loops with each other. In terms of project management perspective, complexity is a feature that
makes it difficult for project teams to understand, predict and keep under control the project system even if they are fully informed about the project (Vidal and Marle 2008). Understanding the impacts of complexity on the projects has long been a popular topic in the field of construction management. In this respect, there are several approaches on assessment and quantification of the project complexity. Many studies have addressed complexity with a conceptual framework. Danilovic and Browning (2007) utilised rectangular domain mapping matrices that combine square design structure matrices to demonstrate the complexity elements and their interdependencies. Vidal and Marle (2008) developed an integrated project complexity framework that consists of project size, project variety, project interdependence and elements of context. With a similar approach, Geraldi et al. (2011) proposed a framework encapsulating structural complexity, uncertainty, dynamic, pace and socio-political complexity dimensions. Bosch-Rekveldt et al. (2011) identified 15 Technical, 21 Organizational and 14 Environmental complexity elements in their TOE framework by integrating literature findings with semi-structured interview data obtained from 6 case study projects. Kardes et al. (2013) presented an integrated framework for risk management in mega projects. Zhu and Mostafavi (2017) proposed the Complexity and Emergent Property Congruence (CEPC) framework that assesses the level of complexity with ability of the project system to cope with complexity. Some studies, on the other hand, have analysed the complexity through the work schedule of the projects (De Reyck and Herroelen 1996; Nassar and Hegap 2006). These studies calculate a project complexity score based on the inputs such as activity number, level of detail and shape of the schedule network. Sinha et al. (2011) developed a metric that measures complexity of a project activity. There are also studies that calculate the complexity score through the factors contributing to project complexity. Vidal et al. (2011) used analytic hierarchy process to calculate relative complexity score between different projects. Gransberg et al. (2013) calculated ‘complexity footprint’ score for 18 transportation projects to graphically display project complexity with a radar diagram consisting of technical, cost, context, financing, and schedule dimensions. Nguyen et al. (2015) utilised fuzzy analytic hierarchy process to estimate complexity level of projects by aggregating 36 project complexity factors under the headings of socio-political, environmental, organizational, infrastructural, technological and scope. He et al. (2015) proposed a complexity measurement model consisting of 28 factors to determine complexity level of a mega project in China by using fuzzy analytic network process. Mirza and Ehsan (2016) developed a method to compute ‘Project Execution Complexity Index’ on a scale of 0 to 10 for three different project types, namely research and development/technology projects, infrastructure development projects and other projects. Finally, a few studies have analysed the complexity through statistical data. Dao et al. (2017) identified 34 complexity indicators by means of statistical analysis of the data collected from surveys. Ahn et al. (2017) estimated the relationship between interface management and project complexity by quantitative analysis of data collected from 45 large-scale engineering and construction projects.

**Complexity and risk**

Focusing solely on complexity factors and their interactions may not be enough to address managerial problems encountered in mega projects. In addition to complexity, risks also need to be taken into consideration. There are various arguments on how risk and complexity affect each other. A research on developing complexity taxonomy carried out on 58 articles by Padalkar ve Gopinath (2016) reveals that two different
views stand out. According to the first view, uncertainty is accepted as a part of complexity and these concepts are handled together. Proponents of the second view, on the other hand, indicate that complexity is the source of uncertainty and consider them as two separate concepts (Qazi, et al. 2016). Nevertheless, there is a two-way relationship between these views. Complexity creates a vulnerability, which increases the risks. Increased risks lead to more interaction between project stakeholders, which results in increased managerial complexity. Due to this cyclical relationship, complexity escalates risk propagation behaviour and makes projects more difficult to manage (Fang and Marle 2013).

Visualisation

While managing complex mega projects, project teams not only need to access and acquire relevant project information, but also visualise them to make better decisions. However, the way relevant information is acquired (e.g., tabular or text format) or the way decision-makers prefer to visualise information may not always yield an effective way to present the information. In other words, the type and characteristics of information items may not be suitable for that preferred visualisation. Visualisation should be employed to reveal the meaning, connections and consequences of relevant information items a meaningful way, based on their characteristics. For this reason, it is necessary to promote an approach that effectively helps decision-makers to visualise the factors of complexity and risk as well as their impacts on projects. Information visualisation can lead to new insights and improve problem-solving capabilities by means of a more efficient decision-making (Dull and Tegarden 1999).

A number of studies have been carried out in the domain of Human Computer Interaction (HCI) and the potential benefits of information visualisation have been explored (Keim 2002; Myatt and Johnson 2009). Yet, researches in HCI domain may not be directly applicable to construction project management field due to field-specific characteristics such as complexity of projects, various perspectives and needs of stakeholders, and the content of the information. Hence, the findings of HCI domain need to be adapted to construction industry by assessing the benefits and limitations of current visualisation techniques. In order to help the construction project stakeholders visualise the relevant information effectively, the abilities of different visualisation techniques in reflecting project complexity and risk information should be examined. Traditionally, the analysis and visualisation of risks regarding various project management fields are performed using certain types of techniques such as table checklists, failure mode-effects and criticality analysis, reliability block diagrams, event tree analysis, fault tree analysis, analytic hierarchy process, cognitive maps, network analysis, and social-network analysis. (Beretta and Bozzolan 2004; Aven 2008; Zhou, et al. 2008; Kang, et al. 2011; Ackermann, et al. 2014; Yang and Zou 2014; Hyun, et al. 2015; Clark-Ginsberg 2017). In addition to these techniques, specific to construction industry, Building Information Modelling (BIM) can enable the early detection of predictable and unpredictable risks and improve to risk communication by visualising the project in a 3D virtual environment (Eastman, et al. 2011).

Limitations of existing studies on risk-complexity visualisation of mega projects

Mega projects have recently received a growing attention in the project management literature (Boateng, et al. 2017). Studies on this subject mainly focus on the identification and characterisation of mega projects. In order to achieve success in
mega construction projects, patterns of emerging risks and interaction of risk related issues and complexity should be taken into account as well. However, studies on management of risk and complexity in mega construction projects are quite limited, despite the low success rates that they are suffering from (Kardes, et al. 2013). Researches on this subject are not enough to enable project teams to understand the impacts of complexity factors and make managerial decisions proactively. Studies proposed to describe complexity factors and their influences, on the other hand, are lacking of demonstrating the interactions between complexity and risk. The conceptual models developed to address this shortcoming are insufficient in terms of pointing out and measuring the effects of uncertainty, risk and complexity factors (Qazi, et al. 2016). Furthermore, there is a need for a method that facilitates visualisation of interactions between complexity, risk and project success. Visualisation techniques may help stakeholders to access and understand project information in an efficient manner. Various commercially available software tools are utilised in construction industry to support different tasks associated with project management such as construction monitoring, collaboration and communication, cost control, schedule control, and information management. However, there is a lack of supporting tools to map and visualise risks. Traditional risk visualisation is performed through either complicated numerical analysis results (statistical evidence) reducing its practicality, or simplified diagrammatic representations failing to highlight the systematic relationships. Development of a method capable of visualising both the interactions of risk-related concepts and their impacts on the project performance can overcome existing problems and improve risk communication. The research plan that will be followed to develop a visualisation method for risk and complexity will be discussed in the following section.

RESEARCH PLAN

General overview of the proposed research plan is depicted in Figure 1. It is composed of four main steps supported by some actions illustrated as inputs.

![Figure 1: Steps of the Research Plan](rics.org/cobraconference)
The research plan is based on capturing the complexity and risk knowledge through experiences and lessons learned in past projects. For this purpose, interviews will be carried out with project managers who have conducted mega projects before. Obtaining the information through formatted questionnaires is believed to restrict experts from expressing their thoughts comprehensively. Semi-structured interviews, on the contrary, enable them to explain the context in a way they prefer. Hence, prior to interviews, open-ended questions will be determined in accordance with the literature findings. Table 1 points out some mega projects recently held in Turkey. Stakeholders of these projects are potential participants of the interviews.

A conceptual model that represents the relationships between complexity factors, risk events and project performance criteria is needed. The representation developed within the scope of this research is exemplified in Figure 2. It helps conceptualise the subjects so that opinions of the mega project experts can be captured and structured during the interviews. The representation is composed of three main domains. Complexity factors are defined as root causes of risk events. They can directly (C5, C6, C8, C9) or indirectly (C1, C2, C3, C4, C7) influence one or more risk events. However, a risk event does not have to emerge by virtue of a complexity factor. For instance, R2 does not have any dependency on complexity factors. Moreover, as discussed previously, there may be a cyclical relationship between complexity factors and risk events. In other words, sometimes a risk event may trigger different complexity factors or enhance the significance of existing complexity factors. It is also valid for the relationships between risk events and project performance criteria. Although a performance criterion is usually affected by either risk factors or another criterion, sometimes changes in project performance may affect existing risks and create new risks. Such relationships are represented by reverse arrows at the bottom. The sizes of the signs for complexity factors, risk events and performance criteria symbolise their importance (impact or magnitude), while thickness of the arrows stands for significance/strength of the relationship. The representation also takes into account the other risk-related factors, such as vulnerability and resilience. Vulnerability indicates how sensitive the project system is to specific complexity factors. To illustrate, vulnerability level for C8 is too high so that impact of the complexity factor on R1 is multiplied, whereas relatively greater impact of C9 is downsized due to the low vulnerability level. Resilience, on the other hand, is an indicator of how quickly a
project can recover from the effects of undesirable events. According to the given example, ability of the project system to cope with R5 is high enough to diminish its effects on PC1, but this is not valid for R3 where its effects on PC3 increases because of a low resilience level. The representation not only explains risk propagation behaviour in complex project environments but also direct project managers to where they should focus on. For the given example, it can be easily deduced that attention should be given to complexity factors C1, C2, C5, C6, C8 and risk events R1, R2, R4, R5 in order to keep PC1 under control. Furthermore, this conceptual model is not limited to represent the project complexity factors and risk event statically, only at a given point. Multiple representations of the project can be modelled at different project phases or milestones to reflect and track the changes in the complexity of the projects. The validity of the proposed representation and conceptual framework will be tested during the interviews.

At the end of the interviews, by analysing audio records, it is aimed to develop a conceptual map. Qualitative data analysis techniques will be utilised for organising and coding the recordings. A conceptual map will be developed by aggregating findings of the data analysis on the model proposed in Figure 2. Thus, complexity and risk knowledge gathered from different mega project types can be combined in a single model. A two-stage focus group study is planned to be carried out with participants of the interviews to finalise the model. After visualisation needs analysis, alternative visualisation options that can address different needs of the practitioners will be compiled and further tested for effectiveness. Different options that focus on the “time dimension” or “space dimension” are planned to be developed to visualise the impacts of complexity factors and risk events on the project performance. Each visualisation technique will be examined and tested over the existing data and opinions of the experts. Finally, in accordance with the needs analysis conducted in previous steps, a computer-based tool will be designed to visualise the impacts of project complexity and risk factors in mega construction projects. The conceptual map finalised in focus group meetings will be included to the tool as a template data set. Users will be able to update the template data according to the characteristics of their projects. In addition, the tool will use the visualisation technique(s) determined in

![Figure 2: Representation of Complexity Factors and Risk Events](image-url)
focus group meetings to reflect the effects of changes in complexity levels on project performance. Users can also perform scenario analysis by changing threshold values of complexity factors or they can utilise the tool for trend analysis by recording the performance at different stages of the project. It is believed that development of such a tool will help users to make managerial decisions proactively and to improve risk communication in their projects.

SUMMARY AND CONCLUSIONS

In order to perform risk management of construction projects more comprehensively, effective visualisation methods should be developed. This research study proposes a conceptual framework that represents the interactions between project complexity and risk-related factors and their effect on the performance of construction projects. In order to identify their interactions and facilitate effective visualisation, the required steps are as follows: First, the complexity and risk perceptions of experienced mega project stakeholders are acquired, consolidated and reflected to a conceptual map. Then, accuracy of the map and competence of different visualisation options in effectively representing this information are evaluated with a focus group study. Finally, a computer tool that helps identify and visualise the complexity factors, risk events and performance criteria in mega construction projects, and their interactions is developed.

This study constitutes the initial phase of an on-going research project. The presented research plan will be put into practice by initiating the interviews with professionals who have carried out mega projects in Turkey. The overall research will be validated through the testing of the visualisation tool. This study is expected to help mega project practitioners to understand propagation behaviour of risk-related events, to enhance the decision-making and to improve the risk communication between the stakeholders.

REFERENCES


