

Risk mapping in construction projects

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Several risk identification and assessment methods have been proposed in the literature to facilitate project risk management. In majority of the proposed methods, risk-related parameters are assessed independently. On the other hand, several authors highlighted the importance of interdependence of risk-related factors and argued that rather than individual risk factors, to achieve better simulation of project conditions, risks should be assessed considering their interdependencies. Some authors suggested using cause-effect diagrams, risk paths and risk maps with the aim of visualization of risks. The purpose of this paper is to propose a new risk mapping methodology and a tool for international construction projects.

This paper presents the preliminary findings of a two-year on-going research project entitled as “Development of a Knowledge-Based Risk Mapping Tool for International Construction Projects” which was sponsored by the Turkish government and carried out in collaboration with a partner construction company. An ontology that relates risk and vulnerability factors to cost overrun was developed and a risk map structure that patterns interrelated risk factors was designed in the initial stages of the project. Using the data of Turkish contractors doing business abroad, risk-related parameters were identified and classified as “vulnerability”, “risk source”, “risk event” and “risk consequence” with respect to their hierarchical order and 36 different risk paths were identified. Currently, using the ontology and the risk path structure, a risk mapping tool is being created in collaboration with the partner firm. How the tool may help the users to learn from previous risk events, assess risk and vulnerability in a forthcoming project and visualize potential risk paths are currently being tested. In this paper, the risk mapping methodology will be explained and experience gained during the tool development stage will be presented.

Introduction

Within the literature, several risk identification and assessment methods have been proposed to facilitate project risk management. In majority of the proposed methods, risk checklists and risk breakdown structures are introduced to identify potential risks of a project, which in turn lead to risks to be assessed individually. On the other hand, “generally risks affect, magnify or diminish each other and have mutual influence on a project” Ren (1994). Several researchers such as Kim *et al.* (2009), Ashley and Bonner (1987), Dikmen *et al.* (2007) emphasized the vital role of consideration of independency among risk-related factors and claimed that rather than individual risk factors, risks should be assessed with the consideration of their interdependencies, to achieve better simulation of project conditions. Within this context, authors have made some encouraging efforts for demonstration of risk interdependencies using influence diagrams, flow charts, cause-effect diagrams, risk paths and risk maps.

Although, in recent literature, there is a consensus regarding the importance of consideration of risk interdependencies, these attempts do not provide interactions among risk paths and demonstrate an overall risk map structure that covers risk paths generated from cause-effect relationships of risk factors. This study attempts to suggest a risk mapping methodology and a tool from which 36 interrelated risk paths, which were generated from interrelations among risk-related parameters, associated with project cost overrun can be visualized. First, a literature review was undertaken to comprehend previous approaches regarding with the risk interdependencies and risk paths. Second, a risk mapping methodology and a tool was proposed which has been currently developing based on the

previous studies of this research. To revise the proposed methodology and the risk map and present how the risk paths emerge in real construction projects, 37 different risk events in real project cases were identified and stored in the lessons learned database with the collaboration of a construction partner firm. Also, in the further steps of the research, lessons learned database will be used during the risk assessment process of the tool.

Research Background

Overview of risk-related concepts

Risk

In literature, the word “risk” is used in different meanings with different words such as hazard or uncertainty (Al-Bahar and Crandall, 1990). Jannadi and Almishari (2003) defined risk as a combination of the probability, the severity, and the exposure of all hazards of an activity. Chapman (2001) accepted risk as the “likelihood of occurrence and the degree of impact of a negative event adversely affecting an activity”. Barber (2005) defined risk as “a threat to project success, where the final impact upon project success is not certain”. As will be introduced in further sections of the paper, in this study risk-related factors are categorized into vulnerability factors, risk sources, risk events and risk consequences, according to their places within the risk paths.

Risk Sources

Risk source is defined as any factor that has a potential to cause harm to a project either owing to an adverse change from initial project conditions or an unexpected situation (Fidan *et al.*, 2011).

Risk Event

A risk event is the occurrence of a negative happening (Standards Australia, 2004). Risk factors lead to risk consequences through the occurrence of risk events. Risk events can be described as variations (increases or decreases) in quality and quantity work, productivity, performance, and schedule such as delays, interruptions or progress payments.

Risk Consequence

“Risk consequence describes the outcome of a risk event that causes deviation in project objectives”. (Fidan *et al.*, 2011). Consequences of risk factors can be determined with respect to project objectives such as cost, time, quality and safety (Al-Bahar and Crandall, 1990; Zhang 2007).

Vulnerability

A system’s vulnerability represents the extent or the capacity of this system to respond to or cope with a hazard or a risk event (Zhang, 2007). “A system’s vulnerability can be described from multiple aspects, such as its exposure to a hazard, its capacity to resist hazard impacts, and the possibility of slow recovery from hazard impacts” (Watts, 1993). Vulnerability can be confused with risk (Ezell, 2007).

Literature survey on risk identification considering cause and effect relations

Risk identification is the first step of risk management process, in which potential risks associated with a construction projects are identified (Zou *et al.*, 2007; Akinci and Fischer, 1998). Within literature, several checklists and risk breakdown structures were suggested to identify and classify potential risks which have probability to have adverse effect on project objectives. Azhar *et al.* (2008) identified 42 cost overrun factors and arranged them into three categories: macro economic factors, management factors, business and regulatory environment. Assaf and Al-Heiji (2006) investigated 73 causes of delays construction projects in Saudi Arabia. Abd El-Razek *et al.* (2008), proposed 32 causes of delays of construction project in Egypt. Enhassi *et al.* (2009) suggested 110 delay factors/causes, which were classified into 12 groups, resulting into time overruns and cost overruns in construction projects in the Gaza Strip. Aibinu and Odeyinka (2006) identified 44 delay factors related with the client, quantity surveyor, architect, structural engineer, services engineer, contractor, subcontractor, supplier and

external factors. Perry and Hayes (1985) identified 29 primary sources of risks in a construction project associated into 9 risk groups: physical, environmental, design, logistics, financial, legal, political, construction and operation. Chan and Kumaraswamy (1996) identified 83 factors that may cause time delays in Hong Kong construction projects and classified them into eight categories; project-related, client-related, design team-related, contractor-related, materials, labor, plant and equipment and external factors. Long *et al.* (2004) presented 62 risk factors in large construction projects in Vietnam related with the financier, owner, contractor, consultant, project attributes, coordination and environment problems. Mustafa and Al-Bahar (1991) identified 32 risks in construction projects and classified them into six groups: acts of god, physical, financial and economical, design and job site-related risks.

Although these checklists, help decision-makers to identify potential risk factors; they “stay at a simple level of details, such as just listing the risks to limit the quantification and prioritization of interrelated risks” (Han *et al.*, 2008) and underemphasize the importance of interdependencies among them (Ward, 1999). On the other hand, identifying risks as individual factors and neglecting the sequences of their occurrence and cause-effect relations will not be a realistic approach. (Eybpoosh *et al.*, 2011). Within this context, authors such as Chapman (2001), Kim *et al.* (2009), Ashley and Bonner (1987), Dikmen *et al.* (2007) have discussed the necessity of consideration of risk interdependencies among risk factors and attempted to facilitate demonstration of cause-effect relations among them.

Chapman (2001) proposed studying risk relationships by classifying them as, dependent risks in series and independent risks in parallel and suggested precedence, influence diagrams, knowledge maps or flow charts to represent these relationships. The study of Chapman (2001) is one of the important contributions examining cause-effect relations among risks, risk paths generated from these relationships and graphical representation of these paths. Additionally, Han *et al.* (2008) analyzed the causality between risk variables, sorted them as risk sources (causes) and events with respect to their hierarchical order and constructed series of risk paths from its source to event, to incorporate a scenario-based risk checklist. Ashley and Bonner (1987) utilized influence diagrams to represent interrelationships between macro risks (political source variables) and micro risks (project consequence variables) and their either direct or indirect affect on project cash flow variables (cost of labor, material, overhead costs and project revenues). Akinci and Fischer (1998) used knowledge maps for demonstration of relationships among uncontrollable risk factors (i.e. economic factors, political risk factors, client related factors and subcontractor related factors) and cost overrun variables (i.e. unit cost, estimated quantity, and final unit cost). To assess the cost overrun risk rating of an international construction project, Dikmen *et al.* (2007) incorporated influence diagramming and fuzzy risk rating approach for risk identification and risk assessment purposes. Authors used influence diagrams for representation of hierarchical order and interactions of major sources of country and project risks that relates cost overrun.

Carr and Tah (2001), represented the relationships between risk factors (causes of risks), risks (risk events) and their consequences on project performance measures with the use of cause and effect diagrams. Authors demonstrated risk inter-dependencies among risk-related concepts via risk dependency chains, and included in the risk analysis system to “allow for the fact that in practice, risks are not always independent of each other”. Kim *et al.* (2009) proposed a “path diagram” for demonstration of relationships and interactions among 64 “performance influencing variables” (observed variables), 14 “major variables directly affecting project performance without hierarchical structure” (latent variables) and project performance.

Problem Determination

Although those aforementioned studies have highlighted the importance of consideration of risk interdependencies and contributed to the structuring cause-effect relations among risk-related factors with using knowledge maps, influence diagrams and risk paths, mostly they failed to cover interactions among risk paths and demonstrate an overall risk map structure of the generated risk

paths. In practice, cause-effect relationships among risk factors lead to “a network form rather than a one-way hierarchical structure” (Fidan *et al.*, 2011). In this study, it is claimed that, risk paths should be structured in a network form, such as a risk map, to enable the demonstration of interactions among them.

Research Objective

In this on-going study, it is argued that in practice there are interdependencies among risk factors, and their cause-effect relationships generate interrelated risk paths. The main objectives of this study can be summarized as follows;

- 1) To propose a risk mapping methodology for international construction projects,
- 2) To develop a risk mapping tool that uses the proposed methodology and incorporates “a lessons learned database” to help decision-makers to assign risk ratings.

Research Methodology

This paper presents the preliminary findings of a two-year on-going research project entitled as “Development of a Knowledge-Based Risk Mapping Tool for International Construction Projects”. The project was sponsored by the Ministry of Science, Industry and Technology and carried out in collaboration with a partner construction company. The risk-vulnerability ontology proposed in Fidan *et al.* (2011) and a risk map structure presented in Eybpoosh *et al.* (2011) constitute the foundation of the risk mapping tool. Fidan *et al.* (2011) identified potential risk-related factors of international construction projects using the data of Turkish contractors doing business abroad and classified them as vulnerability”, “risk source”, “risk event” and “risk consequence” with respect to their hierarchical order. Additionally, authors defined “risk consequence” as project cost overrun and constructed an ontology that relates risk and vulnerability factors to cost overrun. Based on the conducted risk-vulnerability ontology, Eybpoosh *et al.* (2011) identified 36 interrelated risk paths using the data of 166 projects carried out by Turkish contractors in international market and developed a risk map structure which comprehends and demonstrates the interactions of risk paths. Interdependency coefficients of vulnerability, risk sources, risk event and risk consequence on the related risk paths and total effects of each vulnerability factor and risk path on cost overrun were assessed using Structural Equation Modeling (SEM).

In this study, using the ontology and the risk path structure, a risk mapping tool is being created in collaboration with the partner firm. Additionally, it was aimed to incorporate a lessons learned database to enable users learn from previous projects, assess risk and vulnerability factors and investigate potential risk paths that may generate in a forthcoming project.

Prior to the development of the risk mapping tool, validity of the ontology reported in Fidan *et al.* (2011) and the risk map structure demonstrated in Eybpoosh *et al.* (2011) were justified in collaboration of the partner firm. The partner firm was established in August 2001 with the aim of incorporating project management and IT sector to develop project management models and tools. The firm facilitates project management consultancy for both Turkish and international construction projects with the experience of firm staff that had carried out international projects with leading Turkish construction firms.

This on-going study adopts case study approach to investigate interdependencies among risk factors and demonstrate how the risk paths emerge in real projects with using experience of the partner firm. Within this context, to identify real risk event histories, the experts in the partner firm were requested to give some information about the risk events they faced in previous projects and triggering factors that affected the occurrence of these events. Consequently, 37 different risk events in real project cases were identified and stored in the lessons learned database within the tool. Through the case reviews, risk-related parameters were classified as risk sources, risk events etc. with respect to their sequence of occurrence and hierarchical order in the ontology.

Development of the risk mapping methodology and the tool

Structure of the risk map

Figure 1 demonstrates the risk map that constitutes the foundation of the risk mapping tool. The risk map is composed of 36 interrelated risk paths that were generated from 28 risk-related parameters. (Eypoosh *et al.*, 2011).

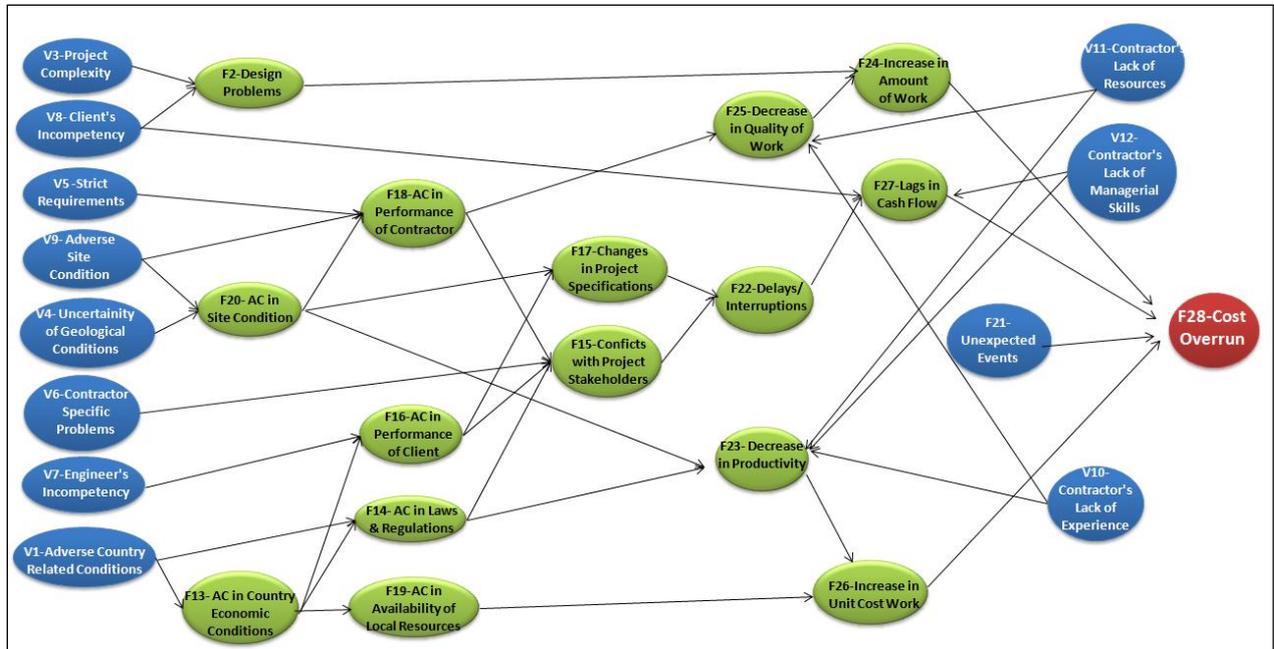


Figure 1 Risk Map of the Tool

Risk paths

Table 1 demonstrates the 36 interrelated risk paths which were structured based on the cause-effect relationships among risk factors in the study of Eypoosh *et al.* (2011). The categorizations of risk factors, such as vulnerability, risk source, risk events or risk consequence, are also represented in Table 1.

Table 1 Risk paths

ID	Vulnerability	Risk Source	Risk Event	Risk Consequence
1	Adverse Country Related Cond.	» AC in Country Econ. Cond. » AC in Availability of Local Resource »	» Increase in Unit Cost of Work »	Cost Overrun
2	Adverse Country Related Cond.	» AC in Country Econ. Cond » AC in Laws and Regulations »	» Decrease in Productivity » Increase in Unit Cost of Work »	Cost Overrun
3	Adverse Country Related Cond.	» AC in Country Econ. Cond » AC in Laws and Regulations » Conflicts with Project Stakeholders	» Delays and Interruptions » Lags in Cash Flow »	Cost Overrun
4	Adverse Country Related Cond.	» AC in Country Econ. Cond » AC in Performance of Client » Conflicts with Project Stakeholders	» Delays and Interruptions » Lags in Cash Flow »	Cost Overrun
5	Adverse Country Related Cond.	» AC in Country Econ. Cond » AC in Performance of Client » Changes in Project Specifications	» Delays and Interruptions » Lags in Cash Flow »	Cost Overrun
6	Adverse Country Related Cond.	» AC in Country Economic Conditions » AC in Performance of Client » Changes in Project Specifications	» Increase in Amount of Work »	Cost Overrun
7	Adverse Country Related Cond.	» AC in Laws and Regulations »	» Decrease in Productivity » Increase in Unit Cost of Work »	Cost Overrun
8	Adverse Country Related Cond.	» AC in Laws and Regulations » Conflicts with Project Stakeholders	» Delays and Interruptions » Lags in Cash Flow »	Cost Overrun
9	Project Complexity	» Design Problems »	» Increase in Amount of Work »	Cost Overrun
11	Uncertainty of Geological Cond.	» AC in Site Condition » Changes in Project Specifications »	» Delays and Interruptions » Lags in Cash Flow »	Cost Overrun
12	Uncertainty of Geological Cond.	» AC in Site Condition » Changes in Project Specifications »	» Increase in Amount of Work »	Cost Overrun
13	Uncertainty of Geological Cond.	» AC in Site Condition » AC in Performance of Contractor » Conflicts with Project Stakeholders	» Delays and Interruptions » Lags in Cash Flow »	Cost Overrun
14	Uncertainty of Geological Cond.	» AC in Site Condition » AC in Performance of Contractor »	» Decrease in Quality of Work » Increase in Amount of Work »	Cost Overrun
15	Strict Requirements	» AC in Performance of Contractor » Conflicts with Project Stakeholders »	» Delays and Interruptions » Lags in Cash Flow »	Cost Overrun
16	Strict Requirements	» AC in Performance of Contractor »	» Decrease in Quality of Work » Increase in Amount of Work »	Cost Overrun
17	Contractor Specific Problems	» Conflicts with Project Stakeholders »	» Delays and Interruptions » Lags in Cash Flow »	Cost Overrun
18	Engineer's Incompetency	» AC in Performance of Client » Conflicts with Project Stakeholders »	» Delays and Interruptions » Lags in Cash Flow »	Cost Overrun
19	Engineer's Incompetency	» AC in Performance of Client » Changes in Project Specifications »	» Delays and Interruptions » Lags in Cash Flow »	Cost Overrun
20	Engineer's Incompetency	AC in Performance of Client » Changes in Project Specifications	» Increase in Amount of Work »	Cost Overrun
21	Client's Incompetency	» » »	» Lags in Cash Flow »	Cost Overrun
22	Client's Incompetency	» Design Problems »	» Increase in Amount of Work »	Cost Overrun
23	Adverse Site Conditions	» AC in Site Condition »	» Decrease in Productivity » Increase in Unit Cost of Work »	Cost Overrun
24	Adverse Site Conditions	» AC in Site Condition » Changes in Project Specifications »	» Delays and Interruptions » Lags in Cash Flow »	Cost Overrun
25	Adverse Site Conditions	» AC in Site Condition » Changes in Project Specifications »	» Increase in Amount of Work »	Cost Overrun
26	Adverse Site Conditions	» AC in Site Condition » AC in Performance of Contractor » Conflicts with Project Stakeholders	» Delays and Interruptions » Lags in Cash Flow »	Cost Overrun
27	Adverse Site Conditions	» AC in Site Condition » AC in Performance of Contractor »	» Decrease in Quality of Work » Increase in Amount of Work »	Cost Overrun
28	Adverse Site Conditions	» AC in Performance of Contractor » Conflicts with Project Stakeholders »	» Delays and Interruptions » Lags in Cash Flow »	Cost Overrun
29	Adverse Site Conditions	» AC in Performance of Contractor »	» Decrease in Quality of Work » Increase in Amount of Work »	Cost Overrun
30	Contractor's Lack of Experience	» » »	» Decrease in Productivity » Increase in Unit Cost of Work »	Cost Overrun
31	Contractor's Lack of Experience	» » »	» Decrease in Quality of Work » Increase in Amount of Work »	Cost Overrun
32	Contractor's Lack of Resources	» » »	» Decrease in Productivity » Increase in Unit Cost of Work »	Cost Overrun
33	Contractor's Lack of Resources	» » »	» Decrease in Quality of Work » Increase in Amount of Work »	Cost Overrun
34	Contractor's Lack of Mngr. Skills	» » »	» Decrease in Productivity » Increase in Unit Cost of Work »	Cost Overrun
35	Contractor's Lack of Mngr. Skills	» » »	» Lags in Cash Flow »	Cost Overrun
36			Unexpected Events »	Cost Overrun

An Illustrative Case Study

37 different risk events in real project cases were identified by the partner firm and reviewed to investigate validity of risk paths. The statements of the expert about the risk events, extracted risk-related factors (Table 2) and risk paths (Figure 2) are presented below.

Statement of the construction expert

“In an international construction project, there were strict requirements for hiring local labor. In order to provide work permits for foreign laborers, governmental regulations of the host country require having a local partner. This requirement resulted in temporarily unavailability of labor at site. To comply with this requirement, company signed a contract with a local partner and hired local workers. However, the productivity rates of local workers were lower than expected leading to significant delays in the schedule. The complexity of the construction process was high (due to the construction method) and the local partner was not experienced in these kinds of construction projects. Lack of experience and qualifications of the local workers and partner resulted delays and quality problems. During the inspection of the site quality manager, several defects were found leading to extensive rework. Problems with quality, rework and low productivity rates caused time delays and additional costs to the construction company”.

Extracted risk factors

Table 2 Extracted risk factors

Statement	Extracted risk factor	Type
“governmental regulations of the host country require having a local partner”	Strict Requirements	Vulnerability
“This requirement resulted in temporarily unavailability of labor at site”	Contractor’s Lack of Resources	Vulnerability
“Lack of experience and qualifications of the local workers and partner resulted delays and quality problems”	AC in Performance of Contractor	Risk Source
“several defects were found leading to extensive rework”	Decrease in Quality of Work	Risk Event
“lead to rework of some of the constructed items ”	Increase in Amount of Work	Risk Event
“labor productivity rates were lower than expected”	Decrease in Productivity	Risk Event
“Problems with quality, rework and low productivity rates caused time delays and additional costs to the construction company”	Cost Overrun	Risk Consequence

Risk path(s) generated from the case

- [V5-Strict Requirements] – [F18- AC in Performance of Contractor] -- [F25- Decrease in Quality of Work] -- [F24- Increase in Amount of Work] --[F28- Cost Overrun]
- [V11-Contractors' Lack of Resources] -- [F23- Decrease in Productivity] -- [F26- Increase in Unit Cost of Work] --[F28- Cost Overrun]

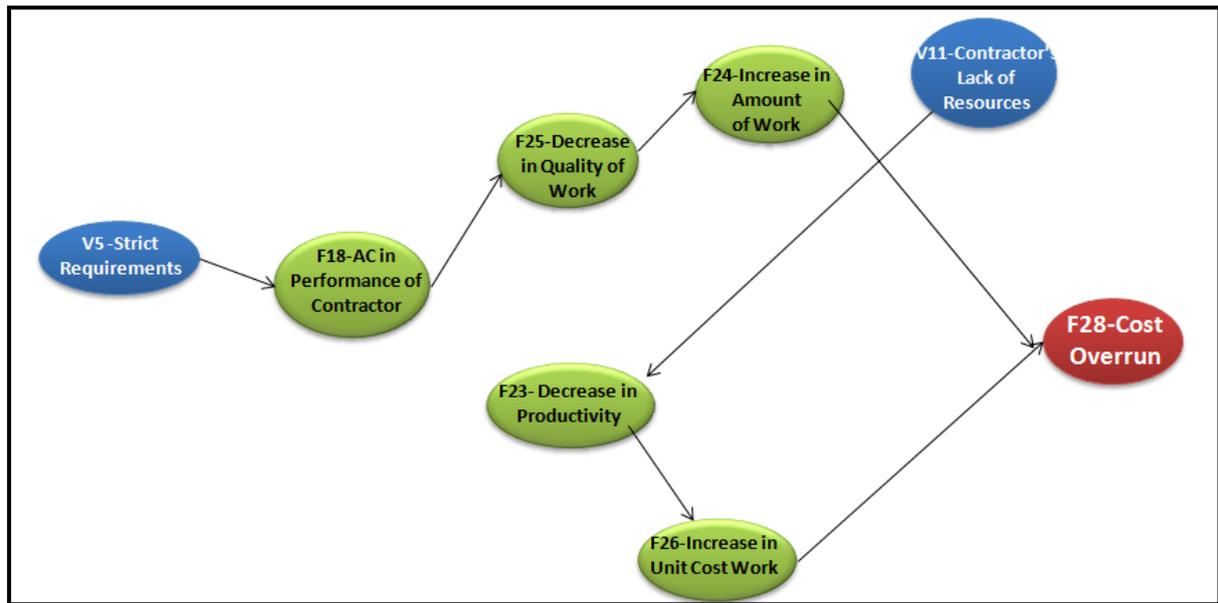


Figure 2 Risk map of the case

The risk mapping tool

As it is mentioned previously, the major aim of the tool is to facilitate a risk assessment methodology that takes into interdependencies between risk and vulnerability parameters, and predicts the cost overrun rating of an international construction project. The process of the risk assessment initial with the determination of the vulnerability ratings by the tool user. It is argued that, if the vulnerability ratings are determined based on experiences of the decision-makers solely, the outcome of the risk assessment can entail a high degree of subjectivity. In this effort, it was decided to incorporate a lessons learned database, with the aim of enabling tool users benefit from the past projects records while defining vulnerability ratings of a forthcoming project. During the assessment process, user should select each vulnerability factor and define a rating considering the retrieved similar cases which were occurred due to same selected vulnerability factors. After all the vulnerability ratings are assessed, the magnitudes of the risk sources, risk events and consequence will be estimated by using the coefficients found by Structural Equation Modeling (SEM). Finally, it is aimed to enable the user to monitor potential risk paths and examine magnitudes of each risk path.

The progresses have been made in so far, cover justification of the risk map and risk path structure methodology and incorporation of “a lessons learned database” that entails risk event histories of past projects. How the tool may help the users to learn from previous risk events, assess risk and vulnerability in a forthcoming project and visualize potential risk paths are currently being tested.

Benefits and Shortcomings of the Tool

The features and expected benefits of the tool, as mentioned by the experts in the partner firm can be summarized as follows:

- Risk maps provide an effective way to visualize risk-related parameters and risk paths that may emerge in real projects.
- The “lessons learned database” in which risk-related information can be codified, stored, updated, retrieved, and transferred enables storing risk information, which otherwise would be lost.
- To increase organizational learning and develop a common organizational behavior regarding risk management by,

- Facilitating systematic risk identification and classification by providing a common language about risk-related information,
- Developing an “organizational memory” in which all members of an organization can store knowledge and experience gained in previous projects via lessons learned database,
- Providing a documentation and report mechanism which enables the user to transfer and share the risk mapping results among organizations.

The major shortcomings of the tool are;

- It still depends on subjective judgments.
- If the number of cases in the lessons learned database is low, then similar cases cannot be retrieved.
- Lessons learned database, should be improved to take into account of complex conditions resulting in risk consequences and in number of cases to retrieve similar cases.

Conclusion

This study proposes a risk mapping process that considers the interdependencies of risk-related parameters and represents risk paths that are generated from the cause-effect relationships among parameters. With the collaboration of the partner firm, the validity of the proposed risk path and risk map structure was justified as well as risk paths that emerge in real projects were represented with the case studies. To enhance case studies, real risk events were identified with using the experience of the partner firm and “a lessons learned database” was developed to store these risk event histories. Case study results show that, rather than individual factors, in practice risks emerge with cause-effect relations that generate risk paths based on the sequence of occurrence of them. It should also be noted that, the aim of this study also covers proposing a risk mapping tool which facilitates assessment of risk-vulnerability parameters considering their interdependencies. Preliminary findings of the research show that although the proposed risk path and risk map methodology are reliable, the major problem is assigning vulnerability ratings as inputs to the tool. Lessons learned database will further be used with the aim of enabling decision-maker to decide on the vulnerability ratings by using the retrieved past project ratings. Thus, in order to improve predictions of the decision maker, as a further aim of this study, the structure of the lessons learned database about risk events will be improved to take into account of complex conditions resulting in risk consequences.

Acknowledgments

This paper presents the preliminary findings of a two-year on-going research project entitled “Development of Knowledge-Based Risk Mapping Tool for International Construction Projects” sponsored by Ministry of Science, Industry and Technology.

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