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A simulation-based risk network model for decision support in project risk management

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ABSTRACT

This paper presents a decision support system (DSS) for the modeling and management of project risks and risk interactions. This is a crucial activity in project management, as projects are facing a growing complexity with higher uncertainties and tighter constraints. Existing classical methods have limitations for modeling the complexity of project risks. For example, some phenomena like chain reactions and loops are not properly taken into account. This will influence the effectiveness of decisions for risk response planning and will lead to unexpected and undesired behavior in the project. Based on the concepts of DSS and the classical steps of project risk management, we develop an integrated DSS framework including the identification, assessment and analysis of the risk network. In the network, the nodes are the risks and the edges represent the cause and effect potential interactions between risks. The proposed simulation-based model makes it possible to re-evaluate risks and their priorities, to suggest and test mitigation actions, and then to support project manager in making decisions regarding risk response actions. An example of application is provided to illustrate the utility of the model.

1. Introduction

Project risk management (PRM) is crucial and indispensable to the success of projects. Indeed, risks in projects have become higher in terms of number and global impact. Projects are more than ever exposed and averse to risks, and stakeholders are asking for more risk management to cover themselves against financial or legal consequences. That is why it has become increasingly important to effectively and efficiently manage project risks, in order to give a higher guarantee of success and comfort to project stakeholders, or at least to warn them against potential problems or disasters. Several standards have been developed in the field of risk management and specifically in project risk management [2,9,22–24,35]. Classical PRM process is comprised of four major phases: risk identification, risk analysis, risk response planning, and risk monitoring and control [35]. Risk identification is the process of determining events which, if they occurred, could affect project objectives positively or negatively. Risk analysis is the process of evaluating and prioritizing risks, essentially with respect to their characteristics like probability and impact. The process of risk response planning aims to choose actions which can reduce global risk exposure with least cost. Risk monitoring and control is the ongoing process of "implementing risk response plans, tracking identified risks, monitoring residual risks, identifying new risks, and evaluating risk process effectiveness throughout the project" [35].

Projects are facing a growing complexity, in both their structure and context. In addition to the organizational and technical complexities described by Baccarini [5], project managers have to consider a growing number of parameters (e.g., environmental, social, safety, and security) and a growing number of stakeholders, both inside and outside the project. The existence of numerous and diverse elements which are strongly interrelated is one of the main characteristics of complexity [13,14,25]. The complexity of project leads to the existence of a network of interdependent risks. For instance, there might be propagation from one "upstream" risk to numerous "downstream" risks; on the other side, a "downstream" risk may arise from the occurrence of several "upstream" risks which may belong to different categories. The extreme case of this propagation behavior is the chain reaction phenomenon or the "domino effect". Another phenomenon is the loop, namely a causal path that leads from the initial occurrence of an event to the triggering of subsequent consequences until the initial event occurs once more. An example of loop is that one initial risk, project schedule delay, may have an impact on a cost overrun risk, which will influence a technical risk, and then propagate to and amplify the original risk of schedule delay.

Many risk management methods and associated tools have now been developed. They are usually based on two concepts: probability and impact, assessed by qualitative or quantitative approaches. Criticality is an aggregate characteristic used to prioritize risks. It is generally a combination of probability and impact, or is simply defined

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as the product of them. Many of these methods independently evaluate the characteristics of risks, and focus on the analysis of individual risks. Risks are usually listed and ranked by one or more parameters [5,12]. Generally, these methods do not take into account the subsequent influence of risks and cannot represent the interrelation between them. We can also cite the creativity-based or the expertise-based techniques, like expert judgment using Delphi, affinity diagram, peer interviews or risk diagnosis methodology (RDM) [26–28].

To comprehensively understand a risk, it is helpful to identify its causes as well as its effects. Several methods include this principle, but they still concentrate on a single risk for simplifying the problem [11,21]. For instance, failure modes and effects analysis (FMEA) consists in a qualitative analysis of dysfunction modes followed by a quantitative analysis of their effects, in terms of probability and impact [7,33]; fault tree and cause tree analyses determine the conditions which lead to an event and use logical connector combinations [34]. These methods are unable to model complex interactions among different risks.

Few specific methods are able to model risk correlations with a network structure. Several papers on the application of the Bayesian belief network (BBN) have appeared in recent years in the field of project risk management [17,29], which could model risk interrelations, from multiple inputs to multiple outputs. Nevertheless, BBN demands oriented links, is inherently acyclic, and hence does not easily model the loop phenomenon; this oversight could potentially lead to a disaster in real projects. These methods are thus not always applicable for practical purpose and fail in some cases to represent the real complexity of the interdependencies among risks.

Therefore, to manage a project with complexly interrelated risks, it is important to firstly integrate the multiple dimensions of risks, including classical characteristics like probability and impact, and secondly to bring the modeling of risk interactions into the PRM process. Risk interactions should be modeled with a network structure instead of a classical list or tree structure for representing the real complexity of the project. In this paper, we propose an integrated framework for modeling and analyzing the risk network behavior to support decision-making for risk management. We use classical project risk list, which usually only takes into account the negative aspects of risks, as the inputs of the network model. Thus, this paper mainly focuses on the conventional risks with negative effects. Existing methods like the design structure matrix (DSM) for dependency modeling and the analytic hierarchy process (AHP) for pairwise comparison evaluation are employed to identify and evaluate risk interactions. Simulation technique is used to analyze propagation phenomena and to re-evaluate risks. The aim is to support decision-makers in planning risk response actions with a structured and repeatable approach.

The paper is organized as follows. Section 2 presents the framework of decision support system for risk management. Section 3 introduces the process of building the project risk network model. Section 4 describes the potential applications of this model to support managerial decision-making. An example of an application to a real project in the entertainment industry is presented in Section 5 to illustrate the proposed method. We conclude the paper in Section 6 with a discussion of the utility of the model and the perspective on the future work.

2. The framework of decision support system for PRM

Our framework is a decision support system (DSS) with five phases: (1) risk network identification; (2) risk network assessment; (3) risk network analysis; (4) risk response planning; and (5) risk monitoring and control. Fig. 1 illustrates this framework. The innovative steps based on the classical risk management process and the new generated outcomes are highlighted in the figure.

In phase (1), potential project risks are identified by classical methods and the result is usually a project risk list. Based on this list, risk interactions are identified and represented using a matrix-based method. In phase (2) of the risk network assessment, the probability and impact of identified risks are evaluated by classical methods; then the strength of risk interactions is assessed with an AHP-based method, in terms of the causal probability between risks. One innovation of this framework is that in the first two phases, in addition to project risks, risk interactions are also identified and evaluated. This makes it possible to construct the project risk network. In phase (3), the risk network is modeled and run in a discrete-event simulation context. This enables an analysis of the propagation behavior in the network and thus a re-evaluation of risks considering their correlations. Sensitivity analysis is also performed to enhance the reliability of the network analysis phase. The response planning phase (4) consists of three activities: (a) potential mitigation actions are identified according to the analytical results from the previous phase, and they are preliminarily evaluated by experts (some unfeasible actions can be screened out through this activity); (b) candidate actions are tested in the simulation model for estimating their effects on a specific target or on the global risk network; and (c) mitigation actions are re-evaluated in terms of their effects, i.e., the level of residual risks that is expected to remain after the implementation

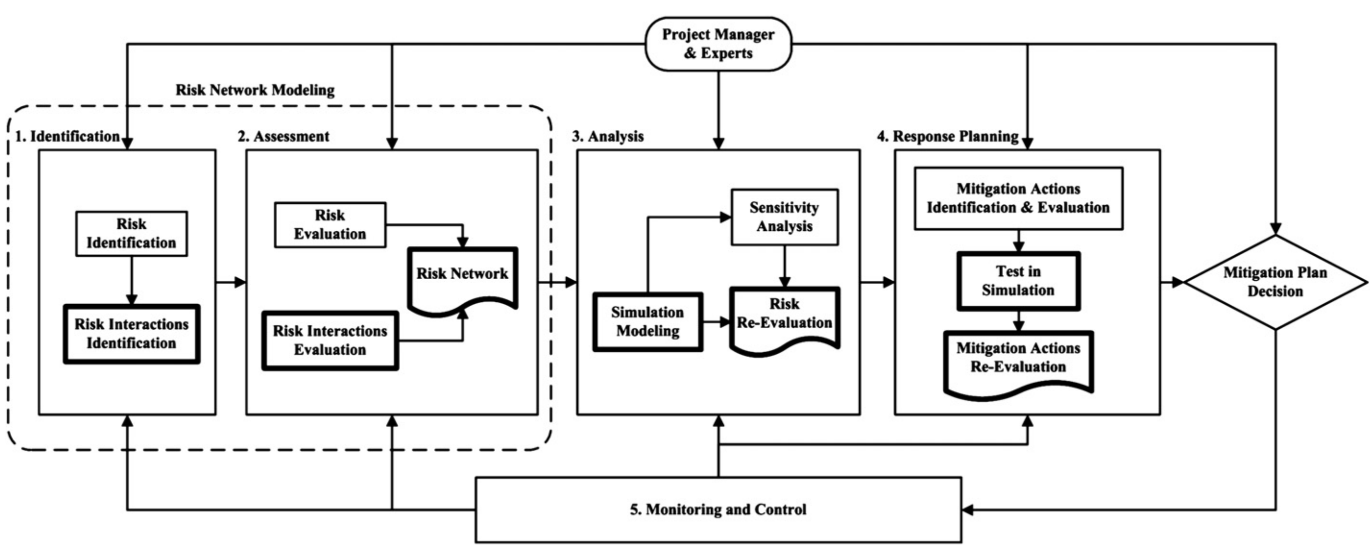

Fig. 1. Framework of the decision support system for PRM.