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A Method for Risk Response Planning in Project Portfolio Management

Abstract. To improve the effectiveness of *project portfolio risk management*, a portfolio-wide approach is required. Under a proactive strategy, this paper presents a method based on mathematical optimization to select an appropriate set of a priori local and global responses to address risks that threat a project portfolio considering key factors, such as costs, budgets, project preference weights, risk-event probabilities, interdependencies among work packages, and both occurrence- and impact-dependencies among risk events. As the proposed method has new features compared to the existing methods developed for a single project, it can also be used in *project risk management*.

Keywords: Project management; Portfolio management; Risk management; Response planning; Modeling and optimization

Introduction

Uncertainties and risks are undeniable in all projects, which highlight the important role of Project Risk Management (PRM) in project success. Achieving project goals is the purpose of PRM (Pellegrinelli, 1997; Teller & Kock, 2013). PRM process includes risk identification, qualitative/quantitative risk analysis, risk response planning, and risk monitoring and controlling (PMI, 2012).

When performing several projects simultaneously, companies desire to use project portfolio management because of its flexibility to environmental changes in order to remain competitive (Teller et al, 2014). PMI (2013) defines project portfolio as a collection of projects, programs, sub-portfolios, and operations that are grouped together to meet strategic business objectives. Portfolio management objectives are to perform right projects, to align projects with the organization's strategies and to balance portfolio (Teller, 2013). To achieve these objectives, portfolio management applies business strategy by integrating decision-making process about project investments, trading off risks and resources, and improving the value of the portfolio (Kopmann, 2017).

Kock et al. (2016) argue that *portfolio balance* refers to balancing risk and innovation in the portfolio. Any portfolio management approach that neglects risks may result in an unbalanced portfolio. Moreover, organizations cannot be prepared for future without integrating portfolio risks (Teller et al., 2014). In project portfolio environment, it is insufficient to only manage the risks of individual projects (Olsson, 2008), and a portfolio-wide approach seems necessary to deal with portfolio risks (Teller, 2013, Teller et al., 2014). Portfolio risk management is defined as a structured process that appraises and analyzes portfolio risks to raise investments for opportunities and to lessen threats. It actually aims to increase the probabilities and impacts of positive risks, and decrease the probabilities and impacts of negative risks (PMI, 2013).

The review of the existing literature has widely acknowledged the benefits of Project Portfolio Risk Management (PPRM), such as i) considering portfolio components' risks and interrelations among risks (Teller, 2013), ii) facilitating resource allocation for the portfolio projects (Teller, 2013), iii) performing accurate evaluation of the projects, iv) conducting the projects according to the identified risks (Sanchez et al., 2008), v) increasing the portfolio strategic order and balance, vi) enhancing the effectiveness of the risk management, and vii) improving the performance of the portfolio components (PMI, 2013).

Hillson (1999) has mentioned that risk management process is worthless without considering risk responses, which really makes a difference in addressing identified risks. Risk response planning is the process of developing options and determining risk responses that reduce threats to and increase opportunities for project and portfolio objectives (PMI, 2013). Figure 1 gives an overview of the process.

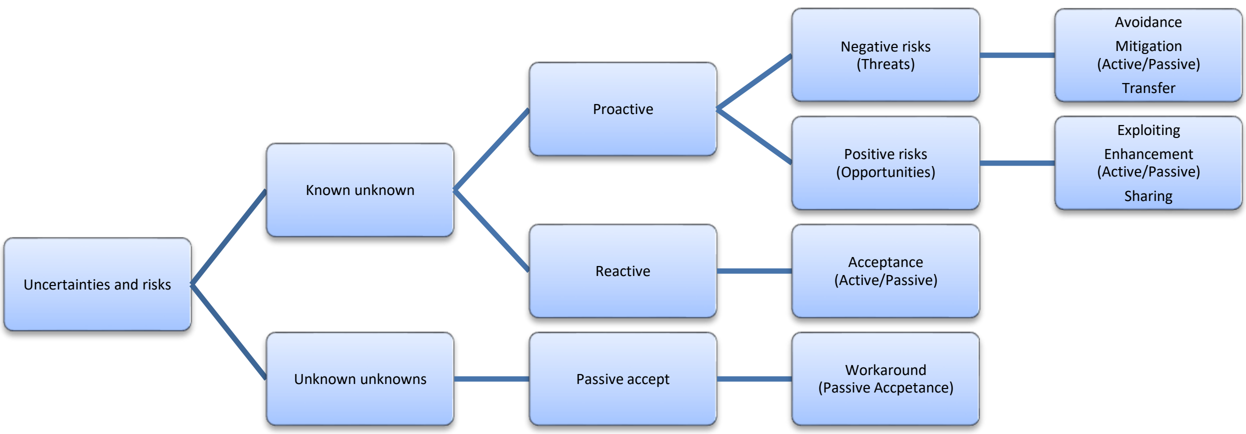

Fig. 1. A categorization of different risk response strategies.

Let us start with the branch of *known unknowns*. They can be addressed reactively or proactively. There is only one strategy for the reactive handling of negative risks, which is the (active or passive) acceptance. In case of proactive handling, there are different strategies for handling negative risks (threats), and positive risks (opportunities). Proactive handling of negative risks includes avoidance, (active or passive) mitigation, and transfer. In the risk avoidance strategy, threats are eliminated or objectives are fully protected from its detrimental impacts. In the mitigation strategy, the probability of occurrence and/or adverse impact of a risk are planned to be reduced by a set of *a priori* responses, which are implemented before the occurrence of the risk. In the transfer strategy, the impacts of a threat are shifted to a third party, together with the ownership of the required responses.

In the active acceptance and mitigation strategies, a set of *a posteriori* responses are planned, which are implemented after the occurrence of the risk; while in the passive acceptance strategy, some workarounds (non-preplanned activities) are carried out.

There are also three strategies for proactively handling positive risks (opportunities), including the exploitation, enhancement, and sharing. The exploiting strategy seeks to eliminate the uncertainty associated with a positive risk by ensuring that the opportunity definitely happens. The enhancement strategy is used to increase the probability and/or the positive impacts of an opportunity. In the sharing strategy, some or all of the ownership of an opportunity is allocated to a third party that is well able to benefit from it.

Unknown unknowns, for which a priori or a posteriori responses cannot be planned because of the perfect lack of information, should inevitably be passively accepted and responded with workarounds.

The contingency and management reserves are budgets that are usually used to handle a posteriori responses and workarounds, respectively, if required; while a part of the risk management budget is aimed at implementing a priori responses and must be paid before occurring risk events.

Although several studies consider risk response planning in PRM, research papers on PPRM mostly concentrated on risk identification and analysis, and *project risk response planning is neglected* (see the next section for a detailed literature review). To the best of our knowledge, no study has yet investigated risk response planning in PPRM.

Padalkar and Gopinath (2016) make a systematic literature review of six decades of research in project management. From a population of 2268 articles, the review identifies the most influential ones published in the leading journals of project management. Their analysis shows that risk management is the third most important research theme, after project methods and success factors. However, identified influential studies on risk management are either explanatory case studies of managing risks in case of single projects, or they are conceptual studies that are concerned with constructing definitions of risk and uncertainty; or models to assess, measure, or manage project risk (Padalkar& Gopinath, 2016, p. 1313). The conceptual studies also focus on single projects. Only Sanchez et al (2009) address risk management approaches at the project portfolio level—but their review article explicitly showed that no study investigated risk response planning at this level. This is a remarkable result because risk management has been such a dominant theme in project management.

We should also recognize a major difference between project management and general management. In general management, the seminal article from Markowitz (1952), focused on optimizing a *portfolio* of investments; whereas in project management, the PERT (Program Evaluation and Review Technique) method, introduced in the late 50ies, considers a project as an *independent* element inside an organization. However, no project is an island (Engwall, 2013). Zhang (2007) explains that previous project risk studies pay much attention to the statistical links between risk events and risk consequences, leaving aside the influence that a project may have on those links. He describes this influence as the *vulnerability* of the project and conceptualizes it by exposure and capacity, where *exposure* is defined as the degree to which a project is exposed to risk events and *capacity* as the capability of a project to deal with the impacts of risk events.

According to our view, this concept should be applied at the project portfolio level. *Exposure* of projects in a portfolio can come from common risk drivers, but it can also stem from interdependencies between projects, e.g. competition among scarce resources, input-output relationships between projects, and bilateral information needs between two projects. Teller et al. (2014) show the importance of analyzing and considering such interdependencies in order to take better-informed measures. However, they do not systematically analyze what it means to increase the *capability* to deal with the impacts of risk events at the *portfolio* level. This is the theme of our current study.

Hence, the current study is an important attempt to take a forward step toward developing an optimization-based method to determine a suitable set of project-portfolio risk responses. This study is a practical answer to the following question: “How to achieve a set of optimal risk responses in a project portfolio, considering project and portfolio budget constraints, local and global risk events; and their dependencies and effects?.” This research contributes to the current literature of PPRM by developing a multistep method including a mathematical model, which can be solved very efficiently for large-scale real-world cases.

This research study is application-inspired basic research and falls into the Pasteur’s quadrant, which bridges the gap between "basic" and "applied" research. During the modeling phase, authors communicated with high-level managers like portfolio and project managers of project-oriented organizations to consider their concerns and critical elements, and also to align the method with their requirements. In this regard, the method is applied to an example extracted from a real case study.

The rest of the paper is organized as follows. The second section provides a literature review of project risk response planning and PPRM. The third section describes the problem under consideration and presents an optimization-based method to address it. The method uses an integer linear programming model, which can be solved for large-sized instances of the risk response planning problem very efficiently. The fourth section explains an example constructed based on a real case in an Iranian project-oriented organization that is active in oil and gas industry. The fifth section applies the method to this example. The sixth section deliberates the possible generalizations and challenges of the method. The last section concludes the paper and suggests future studies.

Literature review

This section provides a survey of the papers on two topics: risk response planning in project management and risk management in project portfolio management, which are related to the scope of this research.

Literature review: Project risk response planning

There has been an increasing tendency to investigate project risk response planning. In this subsection, the papers on this topic are briefly reviewed. Studies on risk response planning can be classified by the approach they use: the semi-quantitative and the quantitative approaches. The semi-quantitative approach's goal is to present tools and processes to show how to develop and select optimal risk responses using the trade-off approach (Hillson, 1999; Kujawski, 2002; Haimes, 2005; Qazi et al., 2016) and/or using the zonal-based approach (Datta & Mukherjee, 2001; Piney, 2002), while the quantitative approach strives to use mathematical modeling and optimization to evaluate or achieve a set of optimal risk responses considering various criteria

(Fan et al. 2008; Ben-David & Raz, 2001; Kayis et al., 2007; Seyedhoseini et al., 2009; Zhang & Fan, 2014; Zhang, 2016).

Applying the semi-quantitative approach, Hillson (1999) performs an introductory study for developing risk responses in PRM and concludes that risk response planning is the most important step in PRM. The risk reduction leverage factor, suggested by Hillson (1999) for selecting risk responses, can be measured by converting risk impacts into money for each risk response separately. This method does not consider interrelations and mutual impacts of risk events. Kujawski (2002) makes tradeoffs considering objectives and preferences and increases the probability of project success with respect to selecting risk responses based on some of Markowitz's portfolio selection principles. It assumes risks are independent and treated risk response actions as a whole. An efficient set of actions is determined considering the outcome cost vs the probability of success. Various scenarios, decision trees, and cumulative probability distributions are used to characterize risks and responses. Haimes (2005) makes a trade-off analysis between the implementation costs of risk responses and the percentage of work losses, and selects appropriate risk responses based on Pareto optimal solutions. Qazi et al. (2016) establish an iterative process (ProCRiM) to identify risks and to select a set of optimal mitigating strategies by measuring the impacts of different combinations of risk mitigation strategies on the overall utility function of a project.

Piney (2002) uses zonal-based approach and presents a sequenced process to integrate PRM steps, and illustrates how to evolve and use a decision-making tool that he calls risk response planning chart for opportunities and threats. Based on this chart, risk response strategies can be determined by the acceptability of risks' impact and probability, which are mapped to the chart vertical and horizontal axes. Datta and Mukherjee (2001) develop a process to quantify project risks based on immediate and external project risks.

In the other hand, a few papers that apply the quantitative approach use optimization methods. A detailed comparison is also provided in Table 1 for the most important ones. Fan et al. (2008) make contribution to risk response literature by constructing a framework that defines the relationship between risk responses and project characteristics. They also develop a mathematical model to mitigate risk responses' costs, using an optimization analysis. Ben-David and Raz (2001) applied a greedy heuristic algorithm to find a set of cost-effective response actions. Kayis et al. (2007) develop efficient solutions using five heuristic algorithms to minimize the implementation cost with the constraints of response combinations, implementation budget, and acceptable risk effect for new product development in concurrent engineering projects. Specifically, the model minimizes the difference between the upper bound mitigation cost/risk ratio (the most effective risk mitigation target) and the mitigation cost risk ratio generated from the project within the limited budget. Seyedhoseini et al. (2009) introduce a heuristic algorithm to select project risk responses while maximizing an integrated measure, called the Scope Expected Deviation (SED). Applying the technique of simple additive weighting, SED can be calculated. The pairwise judgment method is also recommended to determine the SED required parameters. Zhang and Fan (2014) develop a method to select risk response strategies in a project using an Integer Linear Programming (ILP) model to maximize the sum of estimated risk response effects. Zhang (2016) uses a similar model in which the risk relief values are adpated based on expert judgment to consider occurrence-dependencies among risk events using parameters "strength" and "direction". Considering implementation cost and determined budget of risks' response strategies, Zhang (2016) proposes an ILP model to maximize a weighted sum of risk reliefs with a constraint on the implementation cost.

Table 1. A comparison of papers using optimization for risk response planning.

NO.	Reference	Optimization Method and Objective	Project-wide	Portfolio-wide	Dependency among risk events		Interdependency among work packages
					Occurrence	Impact	
1	Ben-David & Raz (2001)	Using a heuristic algorithm to minimize the total risk cost for one project	✓				
2	Kayis et al. (2007)	Using five heuristic algorithms to maximize a metric based on cost/risk ratio for one project	✓				
3	Seyedhoseini et al. (2009)	Using a heuristic algorithm to maximize scope expected deviation for one project	✓				
4	Zhang & Fan, (2014)	Using an ILP to maximize the total risk relief for one project	✓				
5	Zhang (2016)	Using an ILP to maximize the total risk relief for one project	✓		✓		
6	Current study	Using an optimization-based multi-step method to maximize the weighted sum of expected risk relief for one portfolio	✓	✓	✓	✓	✓

Table 1 categorizes the papers applying optimization methods, which enables us to compare the current study with other similar papers. In this table, there are two types of dependency for risk events: occurrence and impact. The *occurrence-dependency* between two risk events is exactly the concept considered in probability theory, which mathematically means the probability that both events occur simultaneously does not equal the product of the occurrence probabilities of the two risk events. The *impact-dependency* between two risk events refers to the case where a (positive or negative) impact synergy is created whenever both risk events happen together; in other words, the impact of simultaneous occurrence of both risk events is not equal to the sum of the individual impacts of the two risk events.

The reviewed papers have made a significant contribution to selecting an optimal set of risk responses for a single project. So far, however, there has been little discussion about occurrence/impact-dependencies of risk measures or interdependencies of work packages.

Literature review: PPRM

Our survey indicates that there are only a couple of papers that address PPRM in project-oriented companies where their dominant approach is qualitative. These studies are generally classified into three categories, i) proposing conceptual frameworks for PPRM (Sanchez et al., 2008; Teller, 2013), ii) suggesting PPRM methodologies (Olsson, 2008; Petit, 2012) and iii) discussing PPRM correlation with other factors such as success to meet portfolio objectives (Teller & Kock, 2013; Teller et al., 2014).

In the first category, Teller (2013) provides principles for more effective PPRM by developing an RM conceptual model where three important elements of the portfolio are organization, process, and culture. The principles investigate effects of these three important elements on the RM quality and project portfolio success. Sanchez et al. (2008) also present a conceptual framework for the identification of portfolio risks and opportunities. The proposed framework integrates RM concepts to project portfolio management and helps to align decisions with the strategic goals of the organization.

In the second category, Olsson (2008) analyzes risks in a project with portfolio-wide perspective. Moreover, Petit (2012) reviews the impact of uncertainty on project portfolio in dynamic environments by proposing a PPRM method and studying four portfolios from two different companies on the basis of uncertainty impacts.

In the third category, Teller et al. (2014) come up with the idea how PPRM can lead to portfolio success by reviewing 177 companies. The study indicates that RM has a strong relation with portfolio success. Furthermore, Teller and Kock (2013) suggest that risk handling and transparency have significant impacts on the portfolio success.

Literature review: Gap analysis

All mentioned papers have provided significant insights into developing and selecting risk responses in PM and PPRM. Although, risk response planning at the project level considered by several papers (see Table 1), the above review clearly reveals that it has not been addressed at the portfolio level. This motivates the authors to develop a powerful optimization-based method to proactively handle risk response selection in PPRM to cover this research gap by incorporating new features which are not considered in the previous studies on PRM, such as i) occurrence- and impact-dependencies among risk events, ii) interdependencies among work packages, iii) incorporating both palliative and etiological risk responses, and iv) considering both local and global risk responses.

To increase the applicability of a method that can address these aspects, one needs to avoid formulating a complex mathematical model and to focus on adjusting the input data of the model.

Method

This section presents our method for risk response planning in a project portfolio. To continue our discussion, we need to present our required definitions. Then, the second subsection provides our main assumptions under which our method works. The third subsection illustrates the general steps of the method and its blueprint. The other subsections provide these steps in detail.

Method: Definitions

The important definitions used throughout the paper are briefly presented below. Some of them are known concepts, while a number of them may be defined here for the first time to present our method.

1. **Work Breakdown Structure (WBS):** A hierarchical decomposition of the total scope of work to be carried out by the project and portfolio teams to accomplish the objectives and create the required deliverables.

2. **Work Package (WP):** The work defined at the lowest level of the master schedule plans of projects' WBSs and portfolio's main operations.
3. **Interdependent:** Two WPs are here called interdependent (or have an interdependency) if they have some sorts of relationships, such as serial, pooled, and reciprocal (for more details see the subsection on Step 1 below).
4. **Risk Event (RE):** An uncertain event or condition that has a negative effect on one or more projects or portfolio operations when it occurs (we do not consider positive risk here).
5. **Directly Exposed WP (DE-WP)/Indirectly Exposed WP (IE-WP):** A DE-WP of a given RE is a WP that is directly affected by that RE, while an IE-WP is a WP that is indirectly affected by the RE. Clearly, each IE-WP of an RE must have some interdependencies with the DE-WPs of that RE.
6. **Local/Global RE:** A local RE directly affects only one or more WPs of a single project. Hence, for each local RE, all the DE-WPs belong to the same project. A global RE directly affects at least two portfolio WPs that do not belong to the same project or only a portfolio's operation.
7. **Occurrence-dependent (independent):** Two REs are here called occurrence-dependent if their occurrences are dependent (independent) from the probabilistic point of view, that is, the probability of the simultaneous occurrence of both events is (is not) equal to the product of the occurrence probabilities of the two REs.
8. **Impact-dependent (independent):** Two REs are here called impact-dependent (independent) if there is no (is a) synergy between their impacts when both risk events happen together, that is, the impact of the simultaneous occurrence of both REs is (is not) the sum of the individual impacts of the two REs.

9. **Mutually exclusive:** Two REs are here called mutually exclusive if they cannot occur together, that is, the probability of the simultaneous occurrence of both REs is zero.
10. **Risk Response (RR):** A planned action that reduces threats to project and portfolio objectives created by some REs, by decreasing the REs' occurrence probabilities and/or negative effects. An RR that is implemented before the occurrence of an RE is called *a priori*; otherwise, *a posteriori*.
11. **Palliative/Etiologic RR:** A palliative RR reduces only negative consequences of an RE, while an etiologic RR reduces the occurrence probability of an RE and it may also mitigate negative effects of the RE.
12. **Simple/Compound RR:** A compound RR reliefs an RE at least for one of the IE-WPs of the RE, where the RE can be local or global. An RR that is not compound is called simple.
13. **Local/Global RR:** A local RR reliefs an RE only for some of the DE-WPs and IE-WPs of a single project, where the RE can be local or global. An RR that is not local is called global.
14. **Expected risk relief:** The expected positive effect of implementing an RR for an RE (the expected risk reduction degree for an RE resulting from an RR).
15. **Response budget:** A budget within the cost baseline as a part of RM budget, which is allocated for the implementation of a priori REs to mitigate identified risks.
16. **Project preference weight:** The importance of a project in comparison with other projects from a risk management perspective, which is represented by a number between 0 and 1. These weights should be determined by expert judgment and may reflect different considerations such as the strategic alignment.

Method: Assumptions

Depending on a portfolio environment, risk response planning may differ. Hence, we need to clarify the appropriate setting in which our proposed method is applicable. The main assumptions of our method are as follows:

1. This method concentrates only on risk response planning for the existing projects of a portfolio where the projects were chosen in a separate process; project selection and risk management are not integrated.
2. REs are responded via a proactive handling approach, that is, a set of a priori RRs should be selected and implemented before the occurrence of REs.
3. The projects and operations of the portfolio, the REs, the RRs, and the corresponding information are completely known.
4. REs affect the projects and the portfolio negatively.
5. REs can be local/global, and occurrence- and/or impact-dependent.
6. RRs are a priori responses that can be palliative/etiologic, local/global, and simple/compound.
7. Interdependencies of work packages are considered when computing risk reliefs obtained by implementing RRs.
8. Each project has a limited RM budget for the risk mitigation.
9. There is a limited response budget for the mitigation of the portfolio's risks using a priori RRs.
10. The total implementation cost of global RRs must be less than a given budget.
11. For each RE, only one local or global RR can be implemented.
12. Risk reliefs obtained by RRs can be quantified (by a method such as expert judgment or using historical data) in a way that they are comparable.

13. The portfolio manager (management team) is able to centrally perform risk response planning.
14. The goal is to determine a set of a priori RRs in order to maximize the weighted sum of expected risk reliefs obtained by implementing the selected RRs.

These assumptions can be applied in practical situations after doing some simplifications and adjustments. Based on these assumptions, we will present our method in the next subsections.

Method: General steps

Our method integrates the risk identification and risk response selection for the current ongoing projects in the portfolio. The method's blueprint is illustrated in Fig. 2, which includes eight steps. Steps 1 to 6, explain how intelligent inputs should be prepared to run the optimization model in Step 7. In Step 8, the portfolio manager may analyze and adjust the results by carrying out some sensitivity analyses.

To manage the mathematical modeling issues, the list of REs must be carefully prepared in a specific manner. The outputs of Steps 1 to 6 are the list of REs and RRs with their corresponding occurrence probabilities and risk reliefs, which are used as the inputs for the optimization model in Step 7.

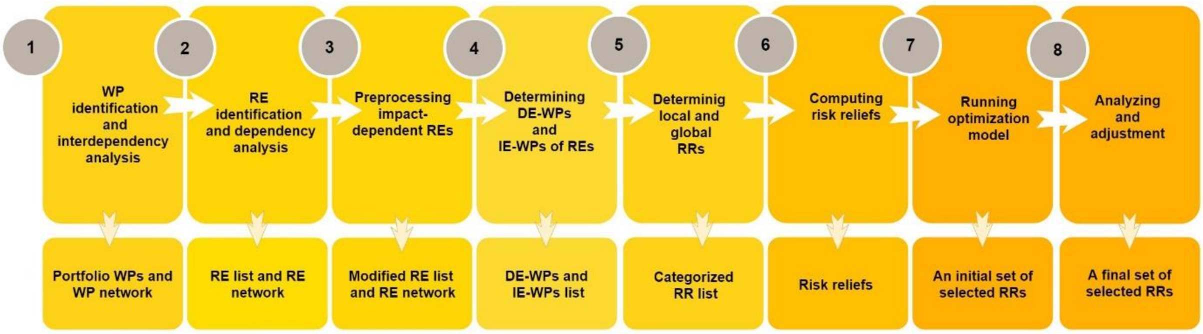

Fig. 2. The method's blueprint.

Steps 1 to 6: Preparation of the model input

Given the fact that considering all details in a mathematical model can make it complex and inapplicable, our method mainly focuses on benefiting from intelligent inputs to make the optimization model computationally tractable. The required six steps for the preparation of the required input data are explained in the following six subsections.

Step 1: WP identification and interdependency analysis

In our method, the risk identification and response selection are performed based on the projects' Work Breakdown Structures (WBSs). Hence, the first step of our method is to develop portfolio WBS. To this, the first level of projects' master schedule plan and the main operations of the portfolio can be accounted as Work Packages (WPs), which are here called portfolio WPs, and numbered sequentially. In Fig. 3, you can find a simple example on a portfolio with two projects and five portfolio WPs.

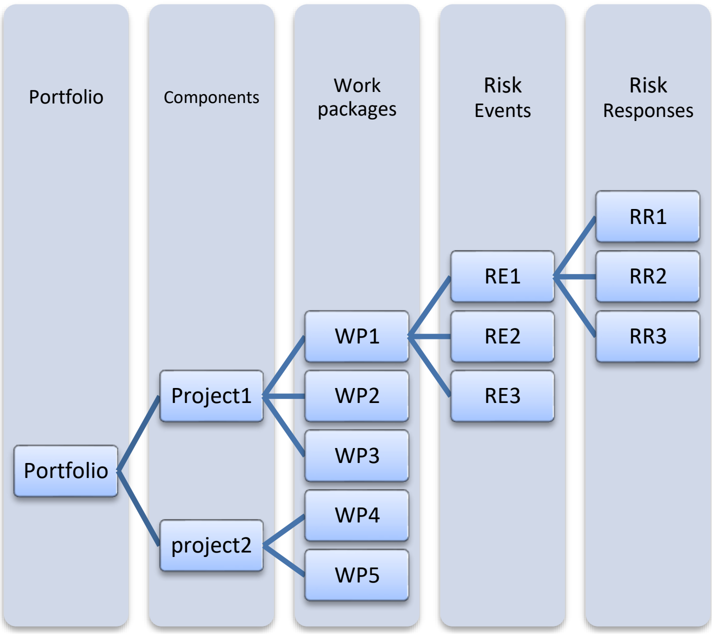

Fig.3. An illustration of the structure of the model input.

The portfolio WPs can be interdependent. Such relationships are influenced by internal and external environment. Thomson (1967) defined three kinds of interdependencies, which can also be used here: sequential, pooled, and reciprocal. A *sequential* relationship is referred to as a serial interdependency between two projects/tasks/WPs where a project/task/WPs requires the other project/task/WP's output as its input (this relationship can also be considered for more than two WPs similar to precedence relations among activities in a project network). A *pooled* interdependency indicates the situation that projects/tasks compete for the same scarce resources, while they are independent. A *reciprocal* interdependency is a mutual relationship between two projects/task/WPs, for example, when two R&D projects exchange knowledge (Chinowsky et al., 2011).

A WP interdependency analysis is required to design compound RRs in Step 5 as well as to more accurately compute risk reliefs in Step 6. To clearly understand WPs' relationships, a network of WPs, here called WP network, can be used. This network extends the concept of project network. In a WP network, different types of interdependencies among portfolio WPs can be visualized by different types of lines. In Fig. 4, you can see the WP network of the illustrative example given in the next section. Note that completed WPs are not required to be considered in our analysis unless they have some interdependencies with other uncompleted WPs and their deliverables may be affected.

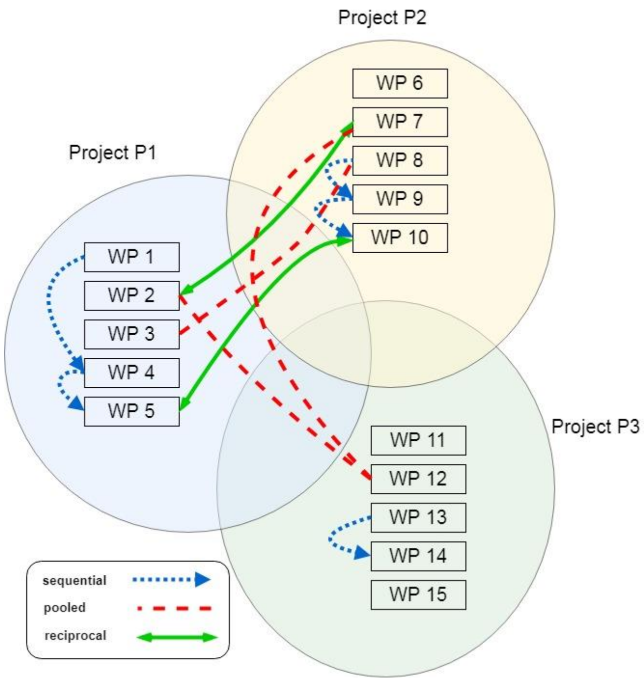

Fig. 4. The WP network for the example provided in the Case Study section.

Step 2: RE identification and dependency analysis

The second step of our method is to identify all possible risks, and list them as REs based on the portfolio WPs identified in Step 1. The occurrence probabilities and negative impacts of REs should be evaluated by expert groups; there is a wide range of tools and techniques for this purpose. To ensure that all REs are considered, risk-aware road mapping can be utilized (Ilevbare et al., 2014). An RE that only impacts some of the WPs of a single project is called local; otherwise, it is called global.

REs can be dependent in some ways. Here, two REs are called *occurrence-dependent* if they are considered dependent events from the perspective of probability theory. Two REs are called *impact-dependent* if they generate some positive or negative synergies when they happen together. Occurrence- and impact-dependencies among REs can be visualized by a network, here called RE network. The RE networks given in Figs. 5 and 6 show four identified REs A, B, C, and D. In both RE networks, there is an occurrence-dependency between C and D. In Fig.

5, REs B and C are only impact-dependent, while they are both impact and occurrence-dependent in Fig. 6.

Our method classifies REs based their exposure not based on their sources. An RE is assigned to a WP, if the WP is exposure to that RE. It is why an RE can affect a number of WPs. The risk sources are not necessarily restricted to WPs and can be project- or organization-wide. Hence, in general, there is no obvious relationship between WP interdependency and RE dependency. Moreover, the interdependency of WPs does not necessarily imply that they have common risk sources. When the sources of (hazards causing) a number of REs are the same, then the REs can be dependent. As a result, if some WPs are exposed to the same hazard, the corresponding REs become dependent. For example, when two WPs are interdependent because of sharing a scare resource, then REs caused by the hazard of losing that resource are expected to be dependent. For another example, when two WPs are not interdependent, their local financial REs can be dependent because of a common portfolio-wide source such as international sanctions.

In this step, the probabilities of simultaneous occurrence must be determined by experts, if required. In fact, these are required in the preprocessing of the next step only for those REs that are both occurrence- and impact-dependent. For example, in Fig. 5 we do not need to compute the probability $\Pr(CD)$ for the occurrence-dependent REs C and D because they are not impact-dependent, but in Fig. 6, for the occurrence-dependent REs B and C we need to compute $\Pr(BC)$ because REs B and C are impact-dependent. In this step, for impact-dependent REs, the synergies caused by the simultaneous occurrence of the REs must also be determined by experts.

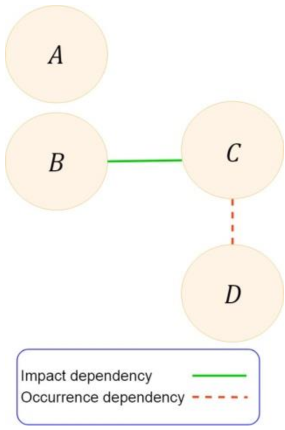

Fig. 5. An example of an RE network without any pair of REs that are both occurrence- and impact-dependent.

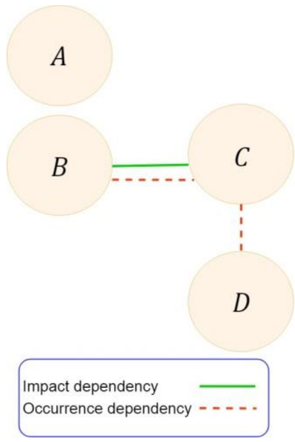

Fig. 6. An example for an RE network with a pair of occurrence- and impact-dependent REs.

To illustrate the situation given in Fig.6, consider the following REs of a real-life case:

A: Risk of fatal damages due to explosions

B: Risk of failure in drilling cooling system

C: Risk of drill-bit breakdown

D: Risk of falling drill bits into holes.

REs C and B have both occurrence- and impact-dependency. The occurrence-dependency follows from the fact that if drilling cooling system fails to cool drill bits (RE B happens), the frequency of drill-bit breakdowns (RE C) increases. These REs are also impact-dependent. Indeed, each one of REs B and C can cause a delay in drilling plan and an extra cost. However, when both REs happen simultaneously, the expected cost is much higher than the sum of the individual extra costs because the drill-bit breakdowns can become more severe.

Step 3: Preprocessing impact-dependent REs

In the third step, those REs that are impact-dependent must be preprocessed and converted to a set of REs that are mutually exclusive. This preprocessing is a required condition for the validity of the objective function of our mathematical model proposed in Step 7 below. The preprocessing procedure is simply demonstrated through presenting an example below.

Consider the RE networks given in Figs. 5 and 6. Two impact-dependent REs B and C can be decomposed to three mutually exclusive REs, that is, BC (both B and C happen together), BC' (B happens, but C does not), and $B'C$ (C happens, but B does not). After this, experts can easily compute the impacts of the new virtual REs BC, BC', and $B'C$. The modified RE network is given in Fig. 7.

Moreover, the occurrence probabilities of the new virtual REs BC, BC', and $B'C$ must be determined. If B and C are occurrence independent (as the one illustrated in Fig. 5), from $\Pr(BC) = \Pr(B)\Pr(C)$, the occurrence probabilities of BC' and $B'C$ are calculated by

$$\Pr(BC') = \Pr(B)(1 - \Pr(C)) \text{ and } \Pr(B'C) = (1 - \Pr(B))\Pr(C).$$

If B and C are occurrence-dependent, these probabilities are specified by

$$\Pr(BC') = \Pr(B) - \Pr(BC) \text{ and } \Pr(B'C) = \Pr(C) - \Pr(BC),$$

where recall that $\Pr(BC)$ was determined in the previous step.

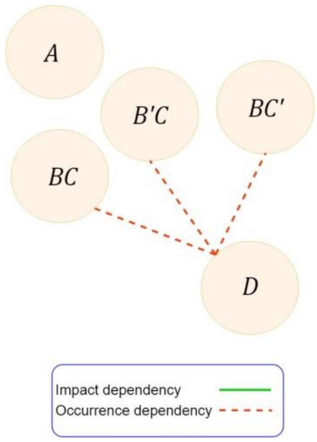

Fig. 7. The modified RE network for the RE network given in Figure 6 where REs B and C are occurrence- and impact-dependent.

Carefully note that determining the occurrence-dependence status of new REs BC, BC', and $B'C$ is not required for computing the objective function (1). However, in the following, some technical details are provided for readers who are curious to have deeper analysis of this status. In fact, REs BC, BC', and $B'C$ can be depnedent on or independent of RE D. In Fig. 7, between each one of BC, BC', and $B'C$ and D a dotted line is now considered, but some of them may not really required; we keep them all to highlight the possibility of dependence. If we had more information about the basic REs C, B, and D, we could determine exactly which of these lines are actually needed.

Recall that D and C are independent if and only if D and C' are independent; indeed,

$$\Pr(DC') = \Pr(D) - \Pr(DC) = \Pr(D) - \Pr(D)\Pr(C) = \Pr(D)(1 - \Pr(C)) = Pr(D)\Pr(C').$$

Hence, in Figure 1, as C and D are occurrence-dependent, the events C' and D are also occurrence-dependent. Although we know that both of the pairs C and D, and C' and D are impact dependent, BC, BC', and $B'C$ may be dependent on or independent of D even if B is independent of D. To show this, consider a simple experiment of picking a random number from $\{1, 2, 3, 4\}$ uniformly. Two examples are now explained below:

- For the events, $D = \{1,2\}$, $C = \{3, 1, 4\}$, and $B = \{2, 4\}$, we can see that D and C depend on each other, while B is independent of D. In this case, D and BC are dependent.
- Now define events $D = \{1,2\}$, $C = \{3, 2, 4\}$, and $B = \{2, 4\}$, where again D and C are dependent, but B and D are independent. In this case, D and BC are independent.

The preprocessing explained above is used to make the computation of the objective function (1) based on our decision variables possible. It will not affect the decision process because it only divides the current events into smaller events and does not eliminate/add any new outcome. In the above example, one can see that the events BC, BC', and $B'C$ *partitions* the event $B \cup C$. This partitioning is required to truly compute the impacts of BC, BC', and $B'C$ when B and C are impact-dependent.

The preprocessing of impact-dependency for REs would have an effect on the project decision results from the perspective of actual project risk management rather than just from the aspect of mathematics. Fortunately, the newly defined REs in the preprocessing phase are not pure mathematical objects and can simply be understood by managers. In Fig. 7, RE BC is the event that both REs B and C happen together, $B'C$ is a situation that only C happens, and BC' relates to the case that only B happens. Actually, the impacts of these new REs can easily be computed by a risk analyzer, while evaluating the impact of each basic RE (B or C) individually seems impossible. We conclude that the project decisions for impact-dependent REs need to be redefined for newly decomposed REs that are not impact-dependent and can easily be understood in practice.

Step 4: Determining DE-WPs and IE-WPs of REs

Considering that REs may affect WPs that have interdependencies with other WPs, we can define two types of WPs, Directly-Exposed WPs (DE-WPs) and Indirectly-Exposed WPs (IE-

WPs). DE-WPs are those WPs that are directly affected by an RE. For an RE, IE-WPs are those WPs that have interdependencies with the DE-WPs, which may be indirectly exposed to negative consequences created by that RE. Recognizing the DE-WPs and IE-WPs of an RE is important for the computation of risk reliefs of RRs, and the design of compound RRs.

Step 5: Determining local and global RRs

The aim of this step is to identify possible and feasible RRs for each one of the REs finalized in Step 3. After qualitative and quantitative risk analysis, appropriate RRs should be determined. As it can be seen from Fig. 3, different RRs can be defined for each RE.

An RR that is considered to cover a local or global RE only for one project is called local RR; otherwise, it is called global. Both local and global RRs can cover a set of the DE-WPs and IE-WPs of an RE, rather than only one WP. Distinguishing local and global RRs is required to control the budget limitations considered for the projects and the whole portfolio.

An RR that protects at least one IE-WP is called compound, else it is called simple. Designing compound RRs is possible only by considering the WP network and needs more deep and creative analysis.

Step 6: Computing Expected Risk Reliefs

In this step, an expected risk relief obtained by executing each RR for each RE is computed as follows:

$$\boldsymbol{Expected\ risk\ relief} = \begin{pmatrix}\text{RE's negative effect}\\ \text{before}\\ \text{implementing RR}\end{pmatrix}\begin{pmatrix}\text{RE's occurrence probability}\\ \text{before}\\ \text{implementing RR}\end{pmatrix} - \begin{pmatrix}\text{RE's negative effect}\\ \text{after}\\ \text{implementing RR}\end{pmatrix}\begin{pmatrix}\text{RE's occurrence probability}\\ \text{after}\\ \text{implementing RR}\end{pmatrix}.$$

which can be used for both palliative and etiologic responses; input parameters α_{ij} and β_{klj} (defined and used in the next step) are to be computed based on the above formula.

When computing negative effects of an RE before and after the implantation of an RR, one should carefully consider the negative consequences of the RE on all DE-WPs and IE-WPs. To clearly understand the procedure, see the detailed example provided in the next section.

Steps 7 and 8: Modeling, optimization, and sensitivity analysis

This subsection shows how one can formulate the risk response planning problem under the assumptions provided above and based on the input prepared via Steps 1 to 6. The resulting formulation is an ILP model, which can be solved using many available ILP solvers. The following subsections provide the details of this model.

Required sets

P: The set of the projects of the portfolio, which includes an additional virtual project v_0 whose WPs are the portfolio operations, if required.

E_l: The set of (local and global) REs that affect the project l, $l \in P$.

E: The set of all (local and global) REs, i.e., $E = \bigcup_{l \in P} E_l$.

$A_l(j)$: The set of local RRs that eliminate/transfer/mitigate the RE j for the project l; $l \in P$, $j \in E$.

A: The set of all local RRs, i.e., $A = \bigcup_{l \in P, j \in E_l} A_l(j)$.

$B(j)$: The set of global RRs for eliminating/transferring/mitigating the RE j, $j \in E$.

B: The set of all global RRs, i.e., $B = \bigcup_{j \in E} B(j)$.

Input parameters

w_l: The RM preference weight of the project l, $l \in P$.

α_{ij}: The expected risk relief for the RE j that is obtained by implementing local RR i; $i \in A_l(j)$, $j \in E_l$, $l \in P$

β_{klj}: The expected risk relief for the RE j of project l that is obtained by implementing the global RR k; $k \in B(j)$, $l \in P$, $j \in E$.

c_{ij}^{L}: The expected implementation cost of the local RR i for RE j; $i \in A_l(j)$, $j \in E_l$, $l \in P$.

c_k^G: The expected implementation cost of the global RR k, $k \in B$.

rb^T: The total response budget for the implementation of all the selected local and global RRs in the portfolio.

rb_l^L: The response budget for the implementation of the selected local RRs for project l, $l \in P$.

rb^G: The response budget for the implementation of the selected global RRs.

Variables

V: The overall expected risk relief; the weighted sum of expected risk reliefs obtained by implementing the selected RRs.

X_{ij}: A binary variable that is equal to 1 if the local RR i is selected for the RE j; $i \in A_l(j)$, $j \in E_l$, $l \in P$.

Y_k: A binary variable that is equal to 1 if the global RR k is selected, $k \in B$.

Note that the parameters α_{ij} and c_{ij}^L, and the variables X_{ij} are not required to be defined for any pair of $i \in A$ and $j \in E$, because each RR $i \in A$ is applicable to a limited number of REs. Indeed, any pair of i and j is reasonable if $i \in A_l(j)$ and $j \in E_l$ for some project $l \in P$.

Optimization model

Using the above notation our decision problem can be formulated as follows:

ILP model for project portfolio:

$$\max \quad V = \sum_{j\in E}\left[\sum_{l\in P} w_l \left(\sum_{i\in A_l(j)} \alpha_{ij}X_{ij} + \sum_{k\in B(j)} \beta_{klj}Y_k\right)\right] \tag{1}$$

subject to:

$$\sum_{i\in A_l(j)} X_{ij} + \sum_{k\in B(j)} Y_k \le 1 \qquad j\in E_l, l\in P \tag{2}$$

$$\sum_{j\in E_l}\sum_{i\in A_l(j)} c_{ij}^L X_{ij} \le rb_l^L \qquad l\in P \tag{3}$$

$$\sum_{k\in B} c_k^G Y_k \le rb^G \tag{4}$$

$$\sum_{l\in P}\left(\sum_{j\in E_l}\sum_{i\in A_l(j)} c_{ij}^L X_{ij}\right) + \sum_{k\in B} c_k^G Y_k \le rb^T \tag{5}$$

$$X_{ij}, Y_k \in \{0,1\} \qquad i\in A_l(j), j\in E_l, l\in P, k\in B. \tag{6}$$

The objective (1) maximizes the sum of weighted excepted risk reliefs (the weighted sum of expected risk reliefs) obtained by implementing the selected RRs. Equivalently, the objective function in (1) can read as

$$V = \sum_{l\in P} w_l \left[\sum_{j\in E_l}\left(\sum_{i\in A_l(j)} \alpha_{ij}X_{ij} + \sum_{k\in B(j)} \beta_{klj}Y_k\right)\right],$$

which is the weighted sum of the total expected reliefs associated with the projects. To obtain (1), we need to make sure that the occurrence-dependent REs are not impact independent, which is guaranteed here due to the preprocessing of initially identified REs in Step 3 of the method.

Note that extending the objective function in (1) is not straightforward and results in a complex formula for the case where the decision maker is not risk-neutral (with an affine utility function) and interested in using a nonlinear utility function. Actually, the suggested computational procedure used in Zhang (2016) to apply a nonlinear utility function to its objective function is not mathematically correct.

Constraint (2) guarantees that only one local or global RR can be selected to mitigate each RE. Constraint (3) ensures that the total implementation cost of the selected local RRs for each project meets its budget requirement. Constraint (4) controls the global RR implementation budget. Constraint (5) ensures that the total implementation cost of all the selected local and global RRs does not exceed the portfolio response budget.

In Step7, the model (1)–(6) can be solved by advanced ILP solvers such as Cplex, or elementary ones contained in general-purpose packages, such as Excel or Matlab. Then, the optimal set of RRs and the optimal amount of overall expected risk relief are determined.

In Step 8, the portfolio manager should evaluate the optimization results. The manager can also request for carrying out sensitivity analyses on different budgets to determine the most appropriate budgets after consulting with the other managers and experts. Moreover, the portfolio manager can assess the impact of considering a class of RRs, such as global RRs. In the fifth section, it is shown how such analyses can be conducted.

			Local REs																								Global REs														
			WP 1		WP 2		WP 3		WP 4		WP 5	WP 6		WP 7		WP 8		WP 9		WP 10	WP 11		WP 12	WP 13	WP 14	WP 15															
			RE 1	RE 2	RE 3	RE 4	RE 5	RE 6	RE 7	RE 8	RE 9	RE 10	RE 11	RE 12	RE 13	RE 14	RE 15	RE 16	RE 17	RE 18	RE 19	RE 20	RE 21	RE 22	RE 23	RE 24	RE 25			RE 26			RE 27			RE 28			RE 29		
			P1	P1	P1	P1	P1	P1	P1	P1	P1	P2	P2	P2	P2	P2	P2	P2	P2	P2	P3	P3	P3	P3	P3	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
Occurrence probability → Implementation cost ↓			0.50	0.25	0.30	0.40	0.15	0.25	0.60	0.70	0.15	0.15	0.45	0.10	0.70	0.35	0.50	0.40	0.35	0.50	0.60	0.65	0.15	0.20	0.35	0.35	0.50			0.70			0.50			0.70			0.50		
Local RRs	L1	150	250																																						
	L2	100	**275**																																						
	L3	500		50																																					
	L4	270			201																																				
	L5	120			**156**																																				
	L6	320				**288**																																			
	L7	190					37.5																																		
	L8	210						**75**																																	
	L9	230							**378**																																
	L10	300								140																															
	L11	220									15																														
	L12	150										**82.5**																													
	L13	110										76.5																													
	L14	240											45																												
	L15	170												15																											
	L16	190												25																											
	L17	300													70																										
	L18	310														**248.5**																									
	L19	130															**265**																								
	L20	270																**320**																							
	L21	470																	70																						
	L22	100																		**250**																					
	L23	160																			**318**																				
	L24	300																			240																				
	L25	290																				65																			
	L26	420																					**123**																		
	L27	380																					118.5																		
	L28	180																						104																	
	L29	250																						**134**																	
	L30	260																							**185.5**																
	L31	390																							147																
	L32	470																								175															
	L33	390																								157.5															
	L34	160																								175															
	L35	320																								**245**															
Global RRs	G1	600								**700**			**450**								**600**																				
	G2	1500								700			405								420						100														
	G3	500													**140**							**650**												**500**		**490**		**630**			
	G4	1200													490							455						300					100				70				
	G5	400																	350											**490**	**350**	**420**								**300**	**400**

Fig. 9. The outputs of Steps 2–6 of the method for the case study; the RRs selected in Step 7 are highlighted with green color.

Case study

This section provides an example that is a simplified extraction of a real-world case, which is used to illustrate how our proposed method can be used in practice. It should be noted that the authors are allowed to report only some limited parts of the case study. The case is the portfolio of an Iranian project-oriented organization that is active in oil and gas industry. As shown in Fig. 8, the portfolio includes two similar onshore seismic projects and one offshore drilling project.

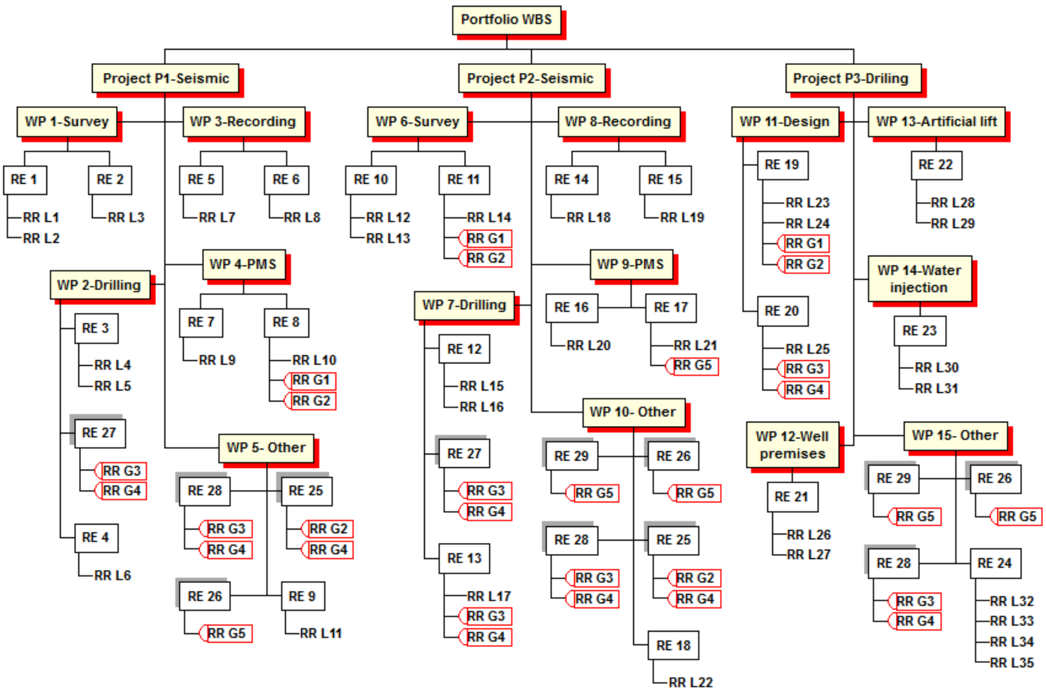

Fig. 8. The local and global REs and RRs for the hypothetical case study (gray-shadowed and red circle-edged boxes indicate global REs and RRs, respectively).

The WPs of the seismic projects are surveying, drilling, recording, project management services, and other activities; while the WPs of the drilling project are design, well premises, artificial lift, water injection, and other activities.

Fig. 4 (already used in the Method section) depicts the interdependencies among WPs of the three projects of our case study. From this WP network, one can see that, for instance, the project managers of Projects P1 and P2 compete for scarce and expensive resources for WPs 3 and 8, and any RE that threats these resources when they are used by one of these WPs can have adverse effects on the other WP. Hence, the pooled interdependency between them is considered for these WPs. For another example, it can be seen that to properly manage WPs 2 and 7, professional data and knowledge are needed to exchange, so the reciprocal interdependency is considered. By performing Steps 2–6 of the method, we obtain the local and global REs, their occurrence probabilities and impacts, and their corresponding local and global RRs. Figure 9 presents the parameters related to these REs and RRs, which include also the occurrence probability of each RE, the implementation cost of each RR, and the expected risk relief obtained by implementing each RR for each relevant RE. Based on Fig. 9, one can simply determine which local or global RRs can relieve a given RE. For example, RE 1 is a local RE affecting Project P1 with the occurrence probability of 0.5. Two RRs L1 and L2, (with implementation costs of 150 and 100) can be used to mitigate RE 1 where the expected risk relief obtained for RE 1 by implementing them are 250 and 275, respectively.

Table 2. Instances of local and global REs, and their corresponding local and global RRs.

RE type	REs	Corresponding RRs
Global	(RE 25) Core businesses professionals and experts leave their jobs	(RR G2) Contracting with an HR consulting company to develop HR rewarding systems and competitive direct payments (RR G4) Employing professional experts and training them as alternative experts
	(RE 26) Noncooperation among different levels of the portfolio because of the low integration of portfolio systems and processes	(RR G5) Designing and developing integrated business management systems like ERP (Enterprise Resource Planning) by outsourcing
Local	(RE 1) Weakness of satellite signals during surveying operation	(RR L1) Using special equipment (RR L2) Creating access corridors based on the offset policy
	(RE8) Noncooperation among different levels of the project because of the low integration of project systems and processes	(RR L10) Developing an internal web-based portal
	(RE 15) Delay in the procurement of explosive materials due to security and legal problems	(RR L19) Hiring a local agent

The REs and RRs were obtained by the risk analysis team of the company based on expert judgment and the historical data available for similar projects after several meetings with the three projects' and the portfolio's stakeholders. Table 2 provides some instances of REs and their corresponding RRs.

Table 3. The procedure for calculating expected risk reliefs obtained by applying RRs L4 and L5 for RE 3, where both RRs L4 and L5 are compound and etiological.

RE 3	Before implementing		After implementing	
			RR L4	RR L5
Impact on DE-WP	WP 2	400	50	122
Impact on IE-WP	WP 7	200	33	80
	WP 12	137	17	50
Total impact	730		100	252
Occurrence probability	0.3		0.18	0.25
Expected risk relief			201 $= 0.3 \times 730 - 0.18 \times 100$	156 $= 0.3 \times 730 - 0.25 \times 252$

In Table 3, it is illustrated how the expected risk reliefs of the RRs for the local RE 3 can be calculated based on the formula given in Step 6 of our method. This table indicates that the only DE-WP of RE 3 is WP 2; hence, from Figs. 4 and 8 one can find that the IE-WPs of RE 3 are WPs 7 and 12. Table 3 shows that expected risk reliefs obtained by performing RRs L4 and L5 for RE 3 are 201 and 156, respectively. Both RRs L4 and L5 are compound because they cover some IE-WPs of RE 3, so they include a set of actions that mitigate direct and indirect effects of RE 3 on WPs 2, 7, and 12. They also decrease the occurrence probability of RE 3 from 0.3 to 0.18 and to 0.25, respectively, which shows both RRs are etiological.

Table 4. The other parameters that should be determined by portfolio management team based on their policies.

Inputs	Project P1	Project P2	Project P3	Global Risks
Project response budget	1000	1000	1500	2000
Project preference weight	0.3	0.2	0.5	NA

Finally, Table 4 provides the other parameters required to run our optimization model in Step 7 of our method, which should be determined by the portfolio management team. The response budget of each project can generally be determined as a predefined percentage of each project budget. The total portfolio response budget is assumed to equals the sum of all projects' response budgets and an additional budget considered for the whole portfolio.

Results

In the following, the optimization-based method proposed in the Method section is applied to the case-oriented example explained in the Case Study section. The data sets given in Tables 3 and 4, and Fig. 9 were used as inputs for the optimization model (1)–(6). The model was implemented in GAMS IDE 24.8.5 and solved using Cplex optimizer, on a personal computer with Intel Core i5 2.66 GHz CPU and 4 GB RAM.

The following subsections report our numerical results. The first subsection reports the selected RRs which obtained by running the model (1)–(6). The second subsection assesses the impact of our integrated approach to risk response planning for the whole portfolio. The other two subsections carry out sensitivity analyses with respect to the total response budget rb^T, and the response budget rb^G for the implementation of the global RRs, respectively.

Results: Optimal response plan for case study

After solving the model (1)–(6) for the example examined above, the optimal value of the objective function is determined as $V^* =$1223.825. In the optimal solution, the variables X_{ij} whose (i, j) are (2,1), (5,3), (6,4), (8,6), (9,7), (12,10), (18,14), (19,15), (20,16), (22,18), (23,19), (26,21), (29,22), (30,23), and (35,24), the variables Y_k with $k =$1, 2, and 5 become 1; and the other variables are zero. This solution is used to determine the selected responses. Figure 9 illustrates how the selected RRs cover the REs. From this figure, one can see that 15 out of 35 local RRs are selected. It can also be seen that the three global RRs G1, G3, and G5 are chosen, which cover 6 local REs and 4 global REs. In fact, this risk response plan is a differentiated hybridization of local and global RRs to cover local and global REs.

Results: Portfolio-based approach vs. project-based approach

This subsection compares the portfolio-based approach to risk response planning with the traditional approach in which risk response selection is done independently for each project.

In the project-based approach, the following mathematical model is solved for each project $l \in P$ separately where the global RRs are not considered and where global REs are treated as local REs for those projects influenced by them.

ILP model for a single project:

$$\max \quad V_l = \sum_{j \in E} \sum_{i \in A_l(j)} \alpha_{ij} X_{ij} \tag{7}$$

subject to:

$$\sum_{i \in A_l(j)} X_{ij} \leq 1 \qquad j \in E_l \tag{8}$$

$$\sum_{j \in E_l} \sum_{i \in A_l(j)} c_{ij}^L X_{ij} \leq rb_l^L + \frac{rb_l^L}{\sum_{k \in P} rb_k^L} rb^G \tag{9}$$

$$X_{ij} \in \{0,1\}, \qquad i \in A_l(j), j \in E_l. \tag{10}$$

As seen above, for a fair comparison, in the project-based approach the total response budget dedicated for global RRs is shared among the projects proportionally to the budget of each project considered for its local RRs in the integrated approach.

After obtaining the optimal value of the above model for each project $l \in P$, denoted by V_l^*, the overall expected risk relief (i.e., the weighted sum of expected risk relief) based on the project-based approach is computed by $\hat{V} = \sum_{l \in P} w_l V_l^*$.

For our case study, we have $V_1^* =$1357, $V_2^* =$262.275, and $V_3^* =$769.5. Hence, the total expected risk relief obtained by the project-based approach becomes $\hat{V} =$844.305, which significantly decreases up to 397.52 units (about 32%) compared to the optimal total expected risk relief obtained by the portfolio-based approach. This clearly shows the advantage of using our proposed approach, into which local and global REs and RRs can be incorporated simultaneously.

Results: Impact of portfolio response budget

This subsection shows how the optimal overall expected risk relief varies with the total portfolio response budget rb^T. As it is clear from Fig. 10, there exists a direct relationship between the optimal overall expected risk relief and the total response budget. Indeed, an increase in the total budget may significantly increase the optimal overall expected risk relief. The optimal overall expected risk relief for the budget 5500 is equal to 1223.825, but this considerably improves when the budget increases to 6500 or 7500. However, small variations in the optimal overall expected risk relief can be seen as the total response budget exceeds 9500. According to this analysis, the effective range of the total response budget in our case can be between 3500 and 8500, from which the right amount of budget can finally be selected by the portfolio manager.

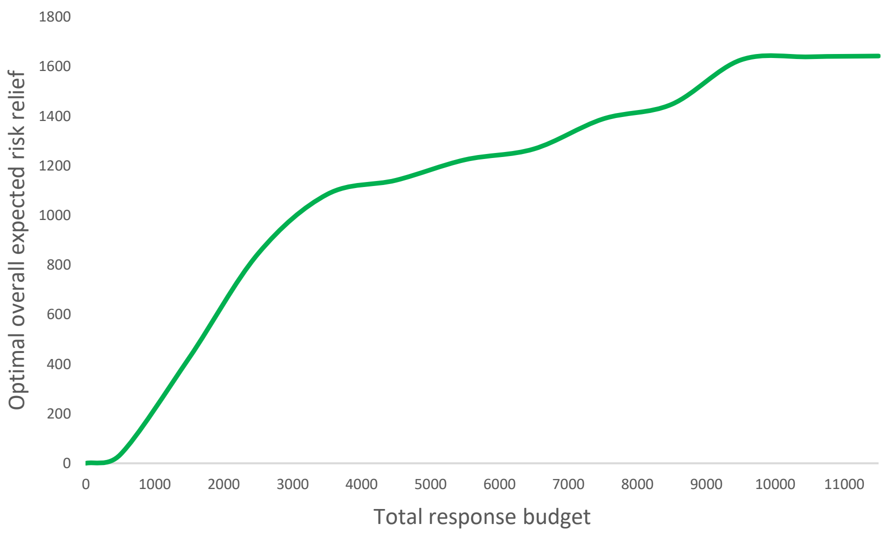

Fig. 10. The optimal overall expected risk relief versus the total response budget of the portfolio.

Results: Impact of response budget for global RRs

Figure 11 shows the relationship between the optimal overall expected risk relief and the response budget for implementing global RRs. Increasing this budget considerably impacts the optimal risk relief. When there is no budget for global RRs, the optimal overall expected risk relief becomes 491.47, while it can be improved up to 1537.524 if the budget increases to 3000. This reveals that incorporating global RRs plays a central role in PPRM.

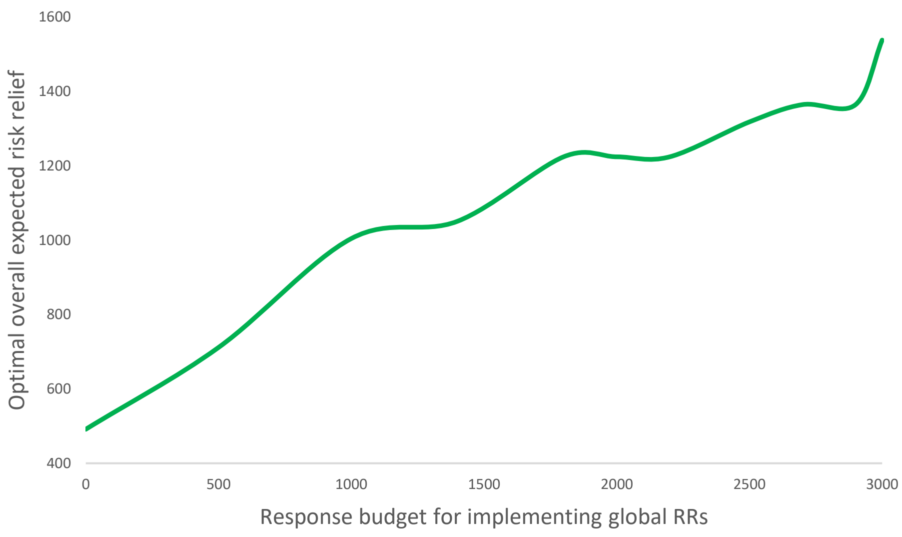

Fig. 11. The optimal overall expected risk relief versus the response budget for implementing global RRs.

Generalizations and challenges

The method presented here is developed and applied in an Iranian oil company. It has been useful for the case company, and theoretically, it seems possible that this method can also be used for other kinds of project portfolios and other kinds of industries. However, in practice, the conditions for the application of the model must be satisfied, and the expected benefits of applying the method should justify the expenditures of its implementation.

Nowadays, people spend about one-third of their working time on projects, and about 80% of these projects are internal projects; only 20% are externally commissioned (Schoper et al. 2018). These internal projects contribute strongly to future value creation. There is a trend that the time spent on projects, and the value generated by projects will further increase, particularly in emerging catch-up economies. The fact that a high percentage of projects are internal projects implies that the human resources of these projects can be better planned and controlled, and that projects of a similar kind using a shared resource can be bundled in project portfolio regimes. In addition, the high amount of working time, the strong impact on value generation, and the fact that projects usually face a higher uncertainty and risk than operations indicate that there is a great potential for benefit generation by using better methods of risk response planning at the project portfolio level.

To use the method developed in this article a certain level of project-management development is required. Gemünden et al. (2018) suggest a model of project-oriented organization that contributes to the high value creation by successfully implementing innovative products, services, processes, and business models; and by adapting its innovation system to changes required in the competitive context. Their model comprises three sectors: structures, people, and values. *Structures* include the organization of roles, responsibilities, and processes, the planning and controlling systems; and the information systems for projects, programs, and project portfolios. *People* include the cooperation of people within and between teams through better leadership and teamwork, a better development of individual project management competencies and motivations through human resource management measures, in particular, value-generating career systems; and knowledge management approaches to capture, to secure, and to re-use learnings from projects. *Values* include strategic orientations that drive and direct behaviors in support of project success, i.e., future, entrepreneurial, and stakeholder orientations.

For the application of the proposed method, structures for project portfolio should be implemented at a high level of maturity and sophistication. Kock et al. (2015) show that organizations using Project Portfolio Management Information Systems (PPMISs) generate a significantly higher project portfolio success. There are significant positive interaction effects with the maturity of the processes of managing single projects and project portfolios, and risk management in single projects and project portfolios. The most often used functions that are supported by PMMISs are resource allocation decisions, short-term planning and control of project portfolios, and prioritization decisions of projects. Risk management functions are used by about 50% of the firms, and functions to support competence management and lessons learned are used by only a minority of users. The study of Kock et al. (2015) uses a sample of 184 matched dyads, where the project portfolio coordinators assessed the processes and PPMISs, and where the decision-makers assessed the project portfolio success. The sample comprises a variety of different project portfolios covering a bundle of industries and different kinds of project portfolios. The implication of this study is that the current model should become an integrated part of a PPMIS and that specific measures and tools for training and motivating users and for creating a software module with a high usability are needed. In addition, the processes need a sufficiently high level of maturity, particularly in the risk management processes.

The findings of Teller (2013), Teller and Kock (2013), and Teller et al. (2014) show that risk culture also plays a crucial role in providing and exchanging information. Therefore, steps to improve cooperation among stakeholders should also be applied.

Regarding strategic orientations, Kock and Gemünden (2017) show that the two components of entrepreneurial orientation, i.e., the innovation orientation and the willingness to take risks, have a decisive influence on project portfolio success, while they have a significant positive influence on business success (if the perspectives for higher success are good). When holding constant the four well-documented success factors of project portfolio management (i.e., stakeholder involvement, strategic clarity, business case monitoring, and agility), which are also significant in their study, the innovation orientation and willingness to take risks show positive significant moderation effects in 6 out of 8 predicted interaction effects. This means that the model developed here can be applied particularly well in project portfolio contexts that contain highly innovative projects and where decision-makers show a high propensity to take risks. In such cases, an effective plan of risk responses will very likely pay back. It is important to note that the firms with the highest market value of their shares at stock exchanges and those with the highest value increase probably belong to the candidates that may profit from a better risk response planning.

The discussion of empirical studies that indicate potential benefits of the model developed in this study could be enlarged, and in a similar vein the number of studies that give hints which competencies would foster the likelihood of a successful usage. On the other hand, the basic model developed here could also be elaborated so that it fits better to differing requirements of different contexts.

In many industries, risk measures have to be taken in order to increase the safety and reliability of their processes. For example, in the pharmaceutical and healthcare sector extensive, clinical studies have to be made in order to prove that the products fulfill effectively their desired functions and that the potential customers will comply to use them correctly. These studies also have to show that a long list of harmful side-effects will not occur. Thus, planning risk responses is not only used to improve economic performance. Rather, it is a sine qua non to get the permission to be in business. In many industries, such regulations exist. Indeed, high-reliability organizations may also profit from the method developed here for good ethical reasons, irrespective of the economic gain.

Conclusions

The paper concentrates on managing risks in Project Portfolio Risk Management (PPRM). Research papers on PPRM mostly concentrated on risk identification and analysis, whereas considering project risk responses has strongly been neglected. However, the risk management process is worthless without risk response planning, which really makes a difference in addressing identified risks.

This paper contributes to the current literature of PPRM by developing a quantitative method for planning a priori responses under a proactive approach. The method has eight steps and uses an optimization model to determine a set of risk responses that maximizes the overall expected risk relief subject to different budget constraints. The method incorporates two types of dependencies among risk events as well as interdependencies among work packages. Our numerical study demonstrates that using our integrated method to portfolio risk response planning leads to a remarkable increase in the overall expected risk relief.

Adding any new assumption may significantly result in a very complex optimization model that cannot be solved in large scales or requires advanced optimization skills. Therefore, we strongly recommend that risk management teams avoid complicating assumptions and mostly focus on the processing of large amount of input data required by applicable methods such as our method.

Despite the mentioned benefits, there are also some constraints and challenges because of the simplifications considered here to make our method applicable in practice. The method can be extended to consider both negative and positive risks, or to integrate risk response selection with other important planning tasks such as scheduling where multi-stage stochastic programming should be used to address the problem. Integrated planning of a priori and a posteriori responses is a research direction, where chance constraints can be used to model the problem. Another important open area may be to integrate risk response planning with the portfolio selection. Relaxing other assumptions of our method is another open area. For example, a challenging question is how the method can be extended to the cases where risk reliefs are expressed as more complex uncertain models such as fuzzy numbers or cannot be quantified, where the occurrence probabilities are not known, or where the decision maker is not risk-neutral and uses a nonlinear utility function.

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