An analytical model for budget allocation in risk prevention and risk protection

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1 Introduction

In project risk management (PRM), the underlying risks that would affect the project objectives will be identified and evaluated, and those risks above a certain level are considered intolerable, which need to be mitigated in the process of risk response. Since projects are always executed within a limited budget, it is imperative for project managers (PMs) to reduce project risks in a cost-efficient way. Therefore, the purpose of this study is to propose a method to reasonably allocate budget for mitigating the project risks. Based on the proposed method, the optimal budget allocation decision can be obtained and the effects of the characteristics of the project risk and the risk response on the optimal budget allocation are investigated according to the analytical solutions.

2 Budget allocation in project risk response

In the current practice, project risk is often reduced through prevention policies enforced to reduce the occurrence likelihood of the risk or contingency measures taken to alleviate the negative impacts after the risk occurs. In this study, taking measures before the risk occurs aiming at preventing the risk from happening is defined as *risk prevention*. Implementing actions after the risk occurs aiming at alleviating the negative impacts result from the occurrence of the risk is recognized as *risk protection*. Despite that both risk prevention and risk protection can contribute to the risk reduction in terms of either risk probability or risk impact, any of them entails some cost, and the cost may be different. Thus, to reduce the risk to a certain level, determining the budget allocated for risk prevention and/or risk protection is of great practical need for effective project risk response.

Although budget allocation problems have become a central issue in project risk response, few attempts have been made to solve it. Most of the existing studies related to project risk response focused on the selection of risk response actions (Ben-David and Raz 2001, Fan *et. al.* 2008, Sherali *et. al.* 2011, Dey 2012, Zhang and Fan 2014) rather than the budget allocation problem. They typically assumed the costs and effects of risk response actions are known. This assumption overlooks the complex relations between the costs and effects of risk response actions, so that the generated decision support may be not enough for practical application.

To the best of our knowledge, only two studies have focused on the budget allocation problem in project risk response. Sherali *et. al.* (2008) modelled the possible progressive consequences following the safety risk as an event tree and built an optimization model to lower the losses of these consequences by allocating resources among safety measures. Sato and Hirao (2013) proposed an optimization method to reduce the failure probabilities of project activities and maximize the risk-based project value by allocating the available budget among project activities. Although these two studies deal with the budget allocation problem in project risk response, risk prevention in combination with risk protection are not considered simultaneously. In addition, the characteristics of project risks and risk response strategy are ignored, which may lead to an inferior performance or a misuse of budget resources in project risk response. Therefore, this study will first analyse the costs and effects of risk response with the consideration of the risk and risk response characteristics. Then, an optimization model to obtain an optimal budget allocation is constructed. Finally, some results are drawn from the analytical solutions.

3 Methodology

3.1 Risk response analysis

Since both risk prevention and risk protection can be used to mitigate the risk, the total cost for risk response consists of the cost used for risk prevention and the cost used for risk protection. Generally, the cost for achieving a certain reduction in risk probability or loss depends on the characteristics of the risk and the risk response strategy. Thus, this study models the cost for risk prevention or protection as linear and non-linear functions of these characteristics.

Eqs. (1) - (2) present the linear functions of risk preventive cost and risk protective cost, respectively.

$$q_l = a(P_0 - P), \quad a > 1 \tag{1}$$

$$r_l = b(L_0 - L), \quad 0 < b < 1 \tag{2}$$

with q_l (r_l) the risk preventive (protective) cost in linear relation, P_0 (L_0) the initial risk probability (loss) referred as the risk characteristics, a (b) the unit preventive (protective) cost recognized as the risk response characteristics and P (L) the ex-post probability (loss).

The non-linear functions of the costs for risk prevention and risk protection are shown in Eqs. (3) - (4) (Fan *et. al.* 2008).

$$q_n = \int_{P_0}^{P} c_P dP = a \ln(\frac{P_0 - \varepsilon}{P - \varepsilon}), \quad a > 0 \tag{3}$$

$$r_n = \int_{L_0}^{L} c_L dL = b \ln(\frac{L_0 - \delta}{L - \delta}), \quad b > 0 \tag{4}$$

with q_n (r_n) the risk preventive (protective) cost in non-linear relation, ε (δ) the minimum risk probability (loss) after risk prevention (protection) regarded as the risk characteristics, and c_P (c_L) the marginal cost for risk prevention (protection), denoted as $c_P = -\frac{a}{P-\varepsilon}$ and $c_L = -\frac{b}{L-\delta}$.

3.2 Model formulation

Based on the functions of the costs proposed above, a mathematical model for the budget allocation problem (BAP) in project risk response, which aims at minimizing the total cost (Z), is built as below.

$$\textbf{BAP} \quad \text{Minimize } Z = q + r \tag{5}$$

subject to

$$P \cdot L = R \tag{6}$$

$$q, r \geq 0 \tag{7}$$

Constraint (6) ensures the risk can be reduced to an accepted level R. Herein, the accepted level is defined as a percentage of the initial expected loss, namely $R = \mu P_0 L_0$. Thus, μ can be regarded as the requirement for risk response. A small μ implies a strict risk response requirement, which means a large amount of expected loss needs to be reduced. q and r denote the cost for risk prevention and risk protection, respectively. In the linear relation, q (r) equals to q_l (r_l). Otherwise, q (r) equals to q_n (r_n).

4 Results

We plan to analyse the optimality conditions of the model, propose some propositions and proofs, and conduct some computational results, which is still work in process. So far, we have obtained some preliminary results as presented in the followings.

The results with linear relations show that only one risk response strategy, either risk prevention or risk protection, but never both, is required for risk response. The preference for risk prevention or risk protection depends on the values of aP_0 and bL_0, but has no relation with μ, which indicates the decision for using risk prevention or risk protection in project risk response is affected by the characteristics of the risk and risk response. With respect to the budget allocated for risk prevention and risk protection, the results report that the optimal budget allocated to risk prevention has no relation to the initial risk loss and the risk protection characteristics, but increases with the initial risk probability and the unit risk preventive cost, and decreases with the risk response requirement. Similarly, the optimal budget allocated for risk protection increases as the initial risk loss increases, the unit protective cost increases or the risk response requirement becomes loose.

The results with non-linear relations suggest that risk prevention, risk protection or a combination of them can be the optimal option for risk response. Risk prevention is preferred at a high initial probability and a low initial loss, while risk protection is preferred at a low probability and a high loss. When the initial risk probability and loss are taken medium values, both risk prevention and risk protection are required. Regarding to budget amount allocated to risk prevention and protection, the result shows that, if only risk prevention is opted, the budget allocated for it depends on the initial probability, the risk response requirement and the unit preventive cost. Specifically, more budget is required at a strict risk response requirement, a low initial probability or a high unit preventive cost. Similarly, when only risk protection is preferred, more budget is required at a strict response requirement, a low initial loss or a high unit protective cost. The result that a low initial probability (loss) leads to more budget is a little different from that in the linear relations. If both risk prevention and risk protection are selected for risk response, the effects of the risk characteristics, risk response characteristics and the risk response requirements all have effects on the optimal budget allocation, and an interaction among these effects are observed.

To conclude, the characteristics of the project risk and risk response can affect the optimal budget allocation decision, and their effects vary with the relations between the costs and the effects of risk response strategies.

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