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Measuring the effect of project risks based on Shapley value for project risk response

Dengsheng Wu[a,*], Qianzhi Dai[a,b], Xiaoqian Zhu[a]

a Institute of Policy and Management, Chinese Academy of Sciences, Beijing 100190, P. R. China
b School of Economics, Hefei Univeristy of Technology, Hefei 230009, P. R. China

Abstract

Project risk response is an important phase in project risk management to ensure project success. In practice, some of risk factors may occur simultaneously and the negative effects of these risk factors are usually no less than the sum of negative effects when they occur separately, which accords with the super-additivity characteristic in cooperative game when the negative effect is seen as the characteristic function. In this paper, we propose a method based on Shapley value to measure the actual effect of risk factors. A numeric example is provided to illustrate the proposed method. The result can be helpful to not only find the optimal/ideal risk response plan, but also provide decision making support for allocating the risk response resources to risk response actions.

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Keywords: Risk response; Shapley value; Project risk management; Resource allocation; Cooperative game

1. Introduction

Nowadays, the importance of risk management has been recognized by practitioners and scholars [1-3]. In the development of projects, risk can appear in any aspect of projects and may have negative effects on projects, such as schedule delays, cost overruns and poor quality [4-5]. Therefore, project risk management (PRM) is necessary for ensuring project success. In PRM, project manager and his/her team first identify potential risk factors before the beginning of the project. Then the effect of risk factors is assessed. It is important for the final risk response decision.

Traditional risk assessment is made under the potential assumption that each risk factor occurs separately, such as [6-11]. However, the occurrence of risk factors is not independent in practice. That is to say, some of risk factors may occur simultaneously. Besides, some of project risk factors may be correlated with each other

* Corresponding author. Tel.: 86-10-59358813.
E-mail address: wds@casipm.ac.cn.

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and their correlation relationship could constitute a risk correlation network. Nodes in the network represent risk factors and the line linked between the nodes represents their correlation relationship. If one (or several) of risk nodes occur, then other correlated risk nodes would be triggered by the risk contagion process. Therefore, the negative effects of a set of risk factors are usually no less than the sum of negative effects when they occur separately. Thus it accords with the super-additivity characteristic in cooperative game theory when the negative effect is seen as the characteristic function.

This paper proposes a Shapley value-based method for measuring the actual effects of risk factors. Shapley value is proposed by Shapley [12]. It is an important solution concept in cooperative game theory for measuring the expected marginal contribution of players. It has been widely applied in many areas, such as [13-17]. If risk factors are seen as players and the negative effect of risk factors is seen as characteristic function, then we can apply Shapley value to measure the expected marginal effect of each risk factor since the characteristic function is super-additive. The result can not only find the key risk factors for risk response decision, but also provide decision making support for allocating risk response resources to risk response actions.

The rest of this study is given as follows. In section 2, we propose the Shapley value-based method for project risk response. In section 3, a numeric example is used to illustrate the proposed method. Conclusions are given in section 4.

2. Method

Suppose *n* project risk factors are identified and they are denoted as R_j ($j \in N = \{1,...,n\}$). $V(R_j)$ represents the effect of R_j on project outcomes. Besides, suppose *C* is a subset of $N = \{1,...,n\}$, then the effect of *C* is denoted as $V(C)$. Apparently, $V(\varnothing) = 0$. From the perspective of the cooperative game framework, *C* is a coalition and *V* can be seen as the characteristic function.

In practice, some of risk factors may occur simultaneously and their negative effects are usually no less than the sum of negative effects from these risk factors when they occur separately. The general mathematical expression can be represented as: for any $S \subset N, T \subset N$ and $S \cap T = \varnothing$, we have $V(S) + V(T) \le V(S+T)$. Apparently, the characteristic function *V* is super-additive. Therefore, if risk factors are seen as players, then the negative effect contribution of some players may be more to the coalition than others. Thus it could be seen as a cooperative game problem, and the bargaining power possessed by each players may be different. We need to compute the expected marginal effect of each individual risk factor under the framework of cooperative game, which can provide an effective decision making support for project managers in practice.

The Shapley value [12] is an important solution concept in cooperative game theory for measuring the expected marginal contribution of players. It has been widely used in many areas because the solution of Shapley value must exist and unique and the computation process is quite simple. It has the following desirable properties:

(1) Efficiency. It means that the total gain is distributed and its mathematical expression is given as follows:

$$\sum_{i \in N} \varphi_i(V) = V(N) \tag{1}$$

(2) Symmetry. Suppose *i* and *j* are two players who are equivalent in the sense that

$$V(S \cup \{i\}) = V(S \cup \{j\}) \tag{2}$$

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