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Project Risk Identification Based on the Interaction of Risks from the Approach of Multi-agent Simulation

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Abstract. Risk, which is intrinsically a hidden uncertainty, often conceals in all links of a project, making it groundless for reasoning and demonstration in risk identification. In a practical project, risks combine and interact with each other in a complicated manner, so that it is difficult to directly quantify the probability of their occurrence under the impact of interaction. For this reason, this paper utilizes the common risk identification methods to obtain a risk list, and then constructs a risk interaction network to identify their interaction and determine its strength. Subsequently, the approach of multi-agent simulation is taken to determine the probability of risk occurrence while taking into account the interaction of risks.

1. Introduction
Risk identification, as the first step of risk management, provides a significant basis for the subsequent risk analysis and assessment, and development of risk response measures. Risk identification is a process of identifying the risks among various uncertain factors in a project, and determining the probability of risk occurrence and its impact on the losses of the project by taking suitable approaches before or during the implementation of the project. In practical projects, most of project management personnel conduct qualitative and fuzzy risk identification on the basis of their professional knowledge and experience in various projects, but the results of their risk identification are highly subjective due to limited information and process. Nevertheless, more and more project managers have employed the approach of simulation analysis in their risk identification, which may be still difficult to guarantee the perfect match of the results with the actual condition, but actually improve the objectiveness of the results. [1-4]

2. Identification of Risk Interaction

2.1. Construction of Risk Interaction Network
All kinds of interactions between risks form a risk network in which risks relate to each other, and these interactions are identified in the process of constructing this risk network. As defined by Kwan and Leung [63], the interaction between risks can be considered as how a risk occurs to increase or lower the occurrence probability of the other risk. This paper focuses on the adverse effect between risks, so that risk interaction is defined as how a risk occurs to increase the occurrence probability of the other risk.

Considering the studies conducted by Thompson and other scholars, this paper classifies the relationships between risks into three types as follows: [5-6]

(1) Direct impact: There are direct relationships between risks. For instance, the occurrence of risk R_i may affect the occurrence of risk R_j. As shown in Fig. 1, the arrow points at the "upstream" direction. In other words, risk R_i is the "upstream" risk of risk R_j. If the arrow points at the "downstream" direction, risk R_j is the "downstream" risk of risk R_i.

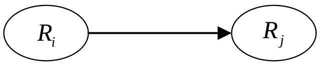

Fig.1 Risk directly affects relationships

(2) Indirect impact: Risks may relate to each other in a larger cycle. For instance, the occurrence of risk R_i may affect the occurrence probability of risk R_j, while the occurrence of risk R_j may affect the occurrence probability of risk R_k. When the occurrence of risk R_k may exert an effect on the occurrence probability of risk R_i, there is the indirect impact between risk R_i and risk R_k. It is presented in Fig. 2:

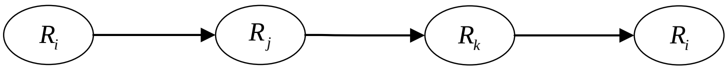

Fig.2 Risk indirect relationship

(3) Independence: Unrelated risks

A project involves a large variety of risks, so that risk R_i may be subjected to various relationships. Risk interaction is intrinsically the potential causal relationship between two risks. In this relationship, the "cause" is that the occurrence probability of risk R_i may be affected by whether the "upstream" risk occurs or not, while the "effect" is that the occurrence of risk R_i may affect the occurrence probability of the "downstream" risk. In the direct impact relationship between risks $R_i \to R_j$ in Fig. 1, risk R_i is the "cause" of risk R_j, while risk R_j is the "effect" of risk R_i. In the indirect impact relationship between risks $R_i \to R_k$, risk R_k is under the impact of both "upstream" risks R_i and R_j, while risk R_j is also affected by risk R_i. Hence, indirect impact relationship is converted into multiple direct impact relationships, i.e. $R_i \to R_j$, $R_j \to R_k$ and $R_k \to R_i$, while identifying risk interaction in this paper.

When the "mutually causal" relationship $R_i \leftrightarrow R_j$ occurs between risks R_i and R_j, either risk R_i or risk R_j must happen first since only a risk may happen at a specific time. In this case, the risk that happens first is the "cause", while the other risk is the "effect".

Design structure matrix (DSM) is an approach, which can help analyze this interaction between risks. The risk structure matrix (RSM) developed in this paper is a binary matrix [8-10]. When there is the relationship pointing from risk R_j to risk R_i, $\boldsymbol{RSM}_{ij} = 1$, and risk R_j is the "upstream" risk of risk R_i, while risk R_i is the "downstream" risk of risk R_j, or $\boldsymbol{RSM}_{ij} = 0$. Fig. 3 presents an example.

↵	R_1	R_2	R_3	R_4	R_5
R_1			1		
R_2			1		1
R_3		1		1	
R_4			1		
R_5				1	

Fig.3 Risk Structure Matrix ($\boldsymbol{RSM}$)

In Fig. 3, the occurrence of risk R_3 may affect the occurrence probability of risk R_1, so that there is the relationship $R_3 \to R_1$, and $\boldsymbol{RSM}_{13}$=1. In other words, risk R_3 is the "upstream" risk of risk R_1, while risk R_1 is the "downstream" risk of risk R_3.

2.2. Risk Interaction Strength Assessment Model

The list of authors should be indented 25 mm to match the abstract. The style for the names is initials then surname, with a comma after all but the last two names, which are separated by 'and'. Initials should not have full stops—for example **A J Smith** and *not* **A. J. Smith**. First names in full may be used if desired. If an author has additional information to appear as a footnote, such as a permanent address or to indicate that they are the corresponding author, the footnote should be entered after the surname.

2.3. Formatting author affiliations

After obtaining the risk structure matrix (RSM), it is necessary to assess the strength of risk interaction [7-8].

The strength of risk interaction can be directly or indirectly assessed. Direct assessment means that one or several experts directly determine the risk interaction strength based on their experience or professional knowledge in various projects, while indirect assessment involves the comparison of "causes" and "effects" for each single risk. Under normal circumstances, risk R_i has multiple "causes" and "effects", so the pairwise comparison in AHP [66, 73] is employed in this paper to assess the interaction and determine the strength of risk interaction. This approach is illustrated with R_3 in the $\boldsymbol{RSM}$ matrix given in Fig. 4.

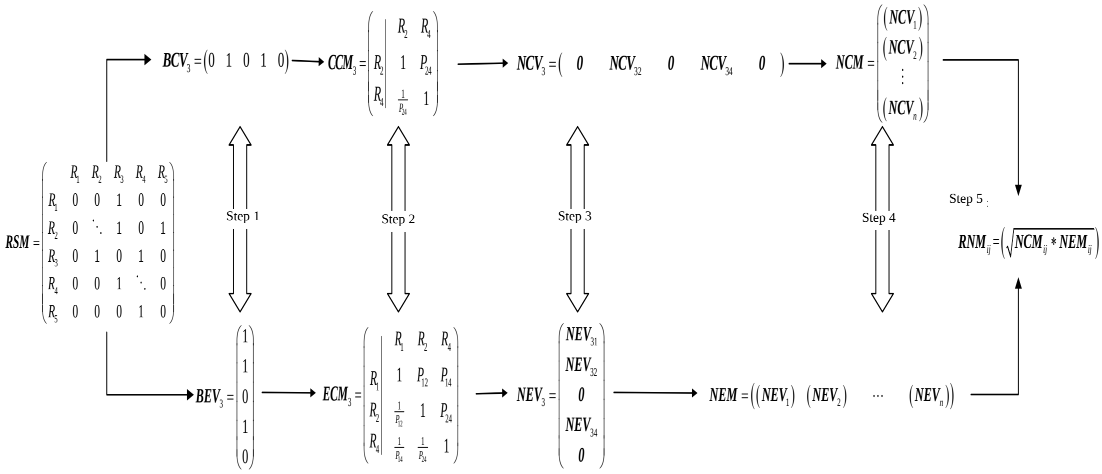

Fig.4 Description of the transformation process from $\boldsymbol{RSM}$ to $\boldsymbol{RNM}$

Step 1: Classify the vectors of $\boldsymbol{RSM}$

With regard to each risk R_i, the line vectors $\boldsymbol{BCV}_i$ (boot cause vectors) and row vectors $\boldsymbol{BEV}_i$ (boot effect vectors) corresponding to risk R_i are separated. For instance, risk R_3 is divided into boot cause vectors $\boldsymbol{BCV}_3$ and boot effect vectors $\boldsymbol{BEV}_3$. Among them, $\boldsymbol{BCV}_3=(0\quad 1\quad 0\quad 1\quad 0)$ indicates only risks R_2 and R_4 may be affected by the occurrence probability of risk R_3, while $\boldsymbol{BEV}_3=(1\quad 1\quad 0\quad 1\quad 0)^T$ means the occurrence of risk R_3 may affect the occurrence probability of risks R_1, R_2 and R_4.

Step 2: Identify relative strength

Two comparative matrixes are constructed for each risk R_i, that is, cause comparative matrix $\boldsymbol{CCM}_i$ and effect comparative matrix $\boldsymbol{ECM}_i$. In Fig. 2.4, there are two pairwise comparison processes. A process is the comparison of risks in two lines. For instance, with regard to risk R_3, there is a pair of "upstream" risks R_2 and R_4 ($\boldsymbol{RSM}_{32}=1$, $\boldsymbol{RSM}_{34}=1$) in the comparison. Hence, it means to compare these risks R_2 and R_4, and find out which exerts stronger impact on risk R_3. The result is represented by a value within the range of 0.1-0.9. The larger value, the stronger impact. The other process is the comparison of risks in two rows, which is carried out in the same way.

Step 3: Calculate maximum characteristic vectors

The characteristic vectors of matrixes $\boldsymbol{CCM}_i$ and $\boldsymbol{ECM}_i$ are calculated to find out the maximum characteristic vectors $\boldsymbol{NCV}_i$ and $\boldsymbol{NEV}_i$ corresponding to the maximum characteristic value. By calculating the maximum characteristic vectors [74], the "upstream" risks affecting risk R_i significantly and the "downstream" risks affected significantly by risk R_i can be selected in the matrixes $\boldsymbol{CCM}_i$ and $\boldsymbol{ECM}_i$, so as to abandon the weak interaction between risks and simplify the problem reasonably. For instance, risk R_3 has two maximum characteristic vectors, i.e. cause characteristic vector $\boldsymbol{NCV}_3$ and effect characteristic vector $\boldsymbol{NEV}_3$.

Step 4: Aggregate maximum characteristic vectors

$\boldsymbol{NCV}_i$ and $\boldsymbol{NEV}_i$ are aggregated into cause matrix $\boldsymbol{NCM}$ and effect matrix $\boldsymbol{NEM}$ respectively. The $\boldsymbol{i}^{th}$ line of $\boldsymbol{NCM}$ corresponds to the maximum characteristic vector $\boldsymbol{NCV}_i$ of $\boldsymbol{CCM}_i$, while the j^{th} row of $\boldsymbol{NEM}$ corresponds to the maximum characteristic vector $\boldsymbol{NEV}_j$ of $\boldsymbol{ECM}_j$.

Step 5: Aggregate into interaction strength matrix

$\boldsymbol{NCM}$ and $\boldsymbol{NEM}$ are aggregated into interaction strength matrix $\boldsymbol{RNM}$. $\boldsymbol{RNM}_{ij}$ stands for the strength of interaction pointing from risks R_j to R_i. In other words, it is the probability that risk R_i is only caused by the "upstream" risk R_j without considering the spontaneous probability of risk. It can be represented by Equation (1) as follows:

$$\boldsymbol{RNM}_{ij} = \sqrt{\boldsymbol{NCM}_{ij} \times \boldsymbol{NEM}_{ij}}\ , \quad \forall(i, j)\ , \quad 0 \le \boldsymbol{RNM}_{ij} \le 1 \tag{1}$$

For instance, $\boldsymbol{RNM}_{43}$=0.25 means that the probability that risk R_4 is caused by R_3 is 0.25 without considering the spontaneous probability of risk R_4.

$\boldsymbol{RNM}$ can be used to not only describe the interaction between risks in risk network, but also demonstrate the strength of the interaction. The calculation for determining the interaction strength in the matrix integrates the "causes" and "effects" of each risk.

3. Determination of Risk Occurrence Probability

In a risk network, it is very difficult to quantify the impact of interaction. Moreover, projects feature high investment and long period, so that it is quite difficult to carry out the empirical study on these projects. However, the approach of simulation can be taken to simulate the operation of a project, and then determine the occurrence probability of risks under the impact of interaction. In this section, the software Anylogic is utilized to construct a simulation model and study the interaction of risks.

3.1 Determination of Risk Occurrence Probability

Risk occurrence probability varies with the change in the number of the "upstream" risks affecting risk R_i [9]. It can be divided into two conditions:

(1) If risk R_i is only affected by one "upstream risk" R_j, that is, $R_j \to R_i$, the occurrence probability of risk R_i can be represented by Equation (7).

$$SP_i = P_i + \boldsymbol{RNM}_{ij} \tag{7}$$

SP_i stands for the occurrence probability of risk R_i, which is the sum of the spontaneous probability of risk R_i and its probability of being caused by risk R_j. Hence, there may be $SP_i \ge 1$. When $SP_i \ge 1$, risk R_i occurs inevitably. In other words, the maximum value of SP_i is 1. P_i denotes the spontaneous probability of risk R_i.

(2) If risk R_i is affected by j "upstream" risks, that is, $R_1 \to R_i, R_2 \to R_i, \cdots, R_j \to R_i$, the occurrence probability of risk R_i is as presented in Equation (8).

$$SP_i = \frac{SP_1}{\sum_{j=1} SP_j} \cdot (P_i + \boldsymbol{RNM}_{i1}) + \frac{SP_2}{\sum_{j=1} SP_j} \cdot (P_i + \boldsymbol{RNM}_{i2}) + \cdots + \frac{SP_j}{\sum_{j=1} SP_j} \cdot (P_i + \boldsymbol{RNM}_{ij}) \quad (8)$$

SP_i denotes the occurrence probability of risk R_i; SP_j stands for the occurrence probability of its "upstream risk" R_j; and $\sum_{j=1} SP_j$ is the sum of the occurrence probabilities of all its "upstream" risks R_j.

3.2 Risk Occurrence Probability Simulation Model with Risk Interaction

To determine the occurrence probability of risks under the impact of risk interaction, a simulation model is constructed to study it. In this section, the simulation model consists of three elements, i.e. risk unit, risk status, and risk network [10].

(1) Risk unit

In the simulation model, the most fundamental element is risk element, which is defined by agent in the software Anylogic, as shown in Fig. 2.5.

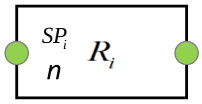

Fig.5 Risk unit

In the risk unit presented in Fig. 5, R_i is the serial number of risk; SP_i stands for the occurrence probability of risk R_i; n represents the number of the "upstream" risks affecting the risk. After the first simulation is completed, n can be used to record the specific number of the "upstream" risks affecting risk R_i, and verify the existence of risk interaction; the left point is the entry point of the "upstream" risk; and the right point is the entry point of the "downstream" risk.

(2) Risk status

Risk status reflects the mechanism of risk transition from "Await" to "Occurred" or "Not Occurred" as shown in Fig. 6.

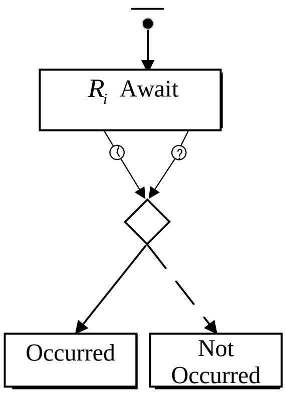

Fig.6 Risk status

While describing the risk status, risk R_i may face two conditions after the status "Await": 1. When the risk is not affected by any "upstream" risk, if exceeding the preset time (which may be one day or month, but it is set to 1s in this paper for the purpose of shortened simulation duration), the risk will occur under the spontaneous probability P_i. This process is called Risk Occurrence Timeout Transition; 2. When the risk is affected by any "upstream" risk, there are two situations: (1) The "upstream" risk has occurred, so that the interaction continues, and the risk will occur under the occurrence probability SP_i, which is called Risk Occurrence Conditional Transition; (2) The "upstream" risk has not occurred yet, so that the interaction is interrupted, and the risk will occur under the spontaneous probability P_i, which is also Risk Occurrence Timeout Transition. The final status is either "Occurred" or "Not

Occurred" no matter whether risk R_i occurs under the probability P_i or SP_i, and the information of this final status is sent to the "downstream" risk.

(3) Risk interaction network

Based on the existing risk interaction, risks are connected into risk network in which each risk may be an "upstream" or "downstream" risk, as shown in Fig. 7.

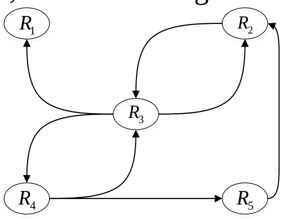

Fig.7 Risk interaction network

The simulation model based on the above elements can rely on multiple simulation calculations to analyze the occurrence probability of risk R_i under the impact of interaction.

4. Risk Identification in an Assembled Building Construction Project

An assembled building construction project has a total floor area of around 21,300m^2 (including the equipment warehouse of around 18,000m^2 and the office building of around 3,300m^2). On the whole, it is estimated to take 784 days to complete the project, and it is planned to need a total investment of RMB123.62 million.

First of all, the possible risks in similar construction projects are analyzed. After that, a risk list is prepared for the project by reading literature, consulting with relevant laws and standards, and communicating with experts with practical experience. The list contains 30 risks in such categories as social risks, economic risks, natural risks, technical risks, participants' performance risks, and organizational management.

In this paper, simulation is carried out for 10,000 times to obtain the occurrence probability of each risk. After considering the interaction between risks, the difference between the spontaneous probability and occurrence probability of each risk is presented in Fig. 8.

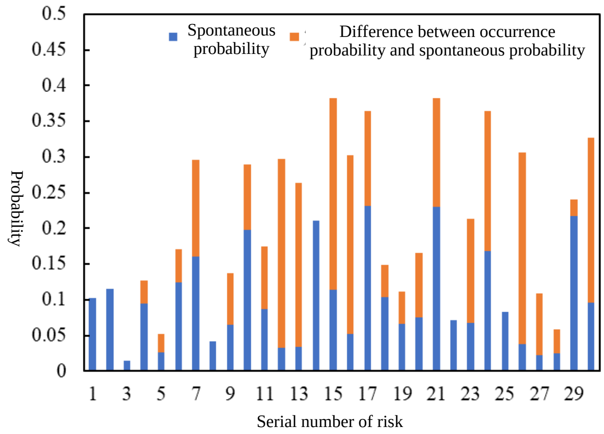

Fig.8 Risk spontaneous probability and probability of occurrence

For instance, as shown in Fig. 9, Tab.6, and Fig. 8, risk R_{30} is affected by the "upstream" risks R_{18}, R_{23}, and R_{25}, but does not affect any "downstream" risk. This interaction accumulates at the risk R_{30}, and does not spread "downstream", so that its spontaneous probability is 0.0961, while its occurrence probability increases to 0.327, resulting in their difference of 0.2309. The simulation calculation has clearly proved the importance of risk interaction, so that it is indispensible in the assessment of risk probability.

5. Summary

To eliminate the defect of ignoring the impact of risk interaction in the conventional risk identification process, this paper prepares a risk list to introduce risk interaction model into project risk identification process, and constructs a risk network model with interaction to obtain the strength of interaction between risks by means of matrix calculation. In the calculation process, the difference between the interaction strengths of risks is obtained through pairwise comparison. Hence, this provides a new approach to the risk identification while considering risk interaction, especially determination of risk occurrence probability. In the meanwhile, risks are classified into four types, i.e. constant, absorber, carrier and multiplier risks considering different characteristics of risk interaction in a project. This classification is highly applicable to risks, and provides a good reference for the development of risk response measures, so as to effectively enhance the benefits of risk management. At last, the software Anylogic is employed to construct a simulation model for studying the risk interaction in the risk network, while the occurrence probability of each risk after considering risk interaction is obtained. As revealed in the results of simulation, risk interaction will increase the actual occurrence probability of risks.

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