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Generating project risk response strategies based on CBR: A case study

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ABSTRACT

Risk response is an important work in project risk management (PRM). To generate project risk response strategies, retrieving and reusing information and knowledge of the similar historical cases is important, while research concerning this issue is still relatively scarce. Taking the risk response of the subway project in S city, China as a case problem, this paper proposes a pragmatic method for generating project risk response strategies based on the case-based reasoning (CBR). The procedure of the method include the five parts: first, representing the target case and the historical cases; second, retrieving the available historical cases by judging whether the risks involved in each historical case cover or are the same as those in the target case; third, retrieving the similar historical cases by measuring the similarity between each available historical case and the target case; fourth, revising the inapplicable risk response strategies involved in the similar historical cases by analyzing the response relation between each strategy and each risk of the current project; and generating the desirable risk response strategies by evaluating each candidate risk response strategy set. To illustrate the use of the proposed method, an empirical analysis of generating the risk response strategies for the subway station project is given. The proposed method can support project managers to make the better decision in PRM.

1. Introduction

Project execution is always accompanied by risks. For example, there may exist some risks during the execution of an engineering project, such as management risk, cost risk and so on. Therefore, it is necessary to conduct project risk management (PRM). In general, PRM includes three phases: risk identification, risk assessment and risk response (Fan, Lin, & Sheu, 2008). Risk identification refers to recognizing and documenting associated risks. Risk assessment refers to examining the identified risks, refining the description of the risks, and estimating the value of the risks. Risk response refers to generating and implementing proper strategies to prevent and control the risks. Once risks of the project have been identified and assessed, proper risk response strategies must be generated and adopted (Zou, Zhang, & Wang, 2007). So far, many studies on risk identification and assessment have been found, whereas risk response has seldom been addressed in the existing studies (Seyedhoseini, Noori, & AliHatefi, 2008). Hence, an in-depth study on risk response is necessary.

In the existing studies, the methods for generating project risk response strategies can be mainly classified into four types (Zhang & Fan, 2014): the zonal-based method (Elkjaer & Felding, 1999; Flanagan & Norman, 1993; Jordan, Jørgensen, & Mitterhofer, 2013; Marcelino-Sádaba, Pérez-Ezcurdia, Echeverría Lazcano, & Villanueva, 2014; Miller & Lessard, 2001; Piney, 2002; Sumit, 2001), the trade-off method (Chapman & Ward, 1996; Kujawski, 2002; Pipattanapiwong & Watanabe, 2000), the work breakdown structure (WBS)-based method (Chapman, 1979; Klein, Powell, & Chapman, 1994; Seyedhoseini, Noori, & Hatefi, 2009) and the optimization-model method (Ben-David & Raz, 2001; Fan et al., 2008; Hu, Zhang, Ngai, Cai, & Liu, 2013; Hu et al., 2013; Kayis, Arndt, Zhou, & Amornsawadwatana, 2007). The detailed elaborations of the above four types of methods can been seen from Zhang and Fan (2014). The four types of methods have made significant contributions to generating project risk response strategies from different perspectives. However, it can be seen that the existing methods have some limitations in practical applications. For example, the key of using the zonal-based method is to form a two-axis graph composed of multiple zones for the risks. If more than two criteria concerning the risks are

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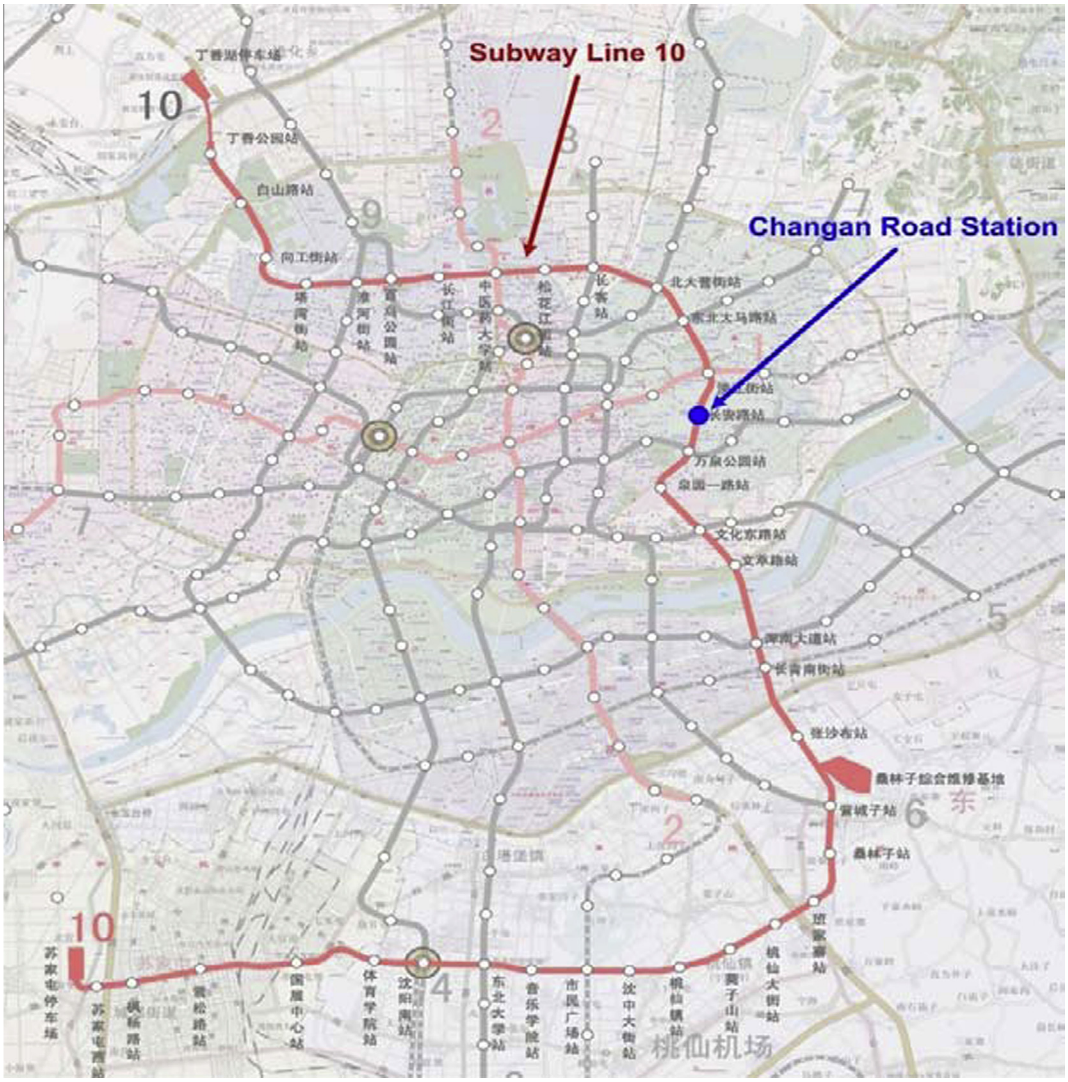

Fig. 1. The subway line 10 of S city.

considered, it will be difficult to form the graph. Likewise, the trade-off method only applies to the situation of two criteria considered. In addition, there are some limitations in the use of the optimization-model method because it is difficult to quantify some project features (e.g., project size or technical complexity) in the process of risk analysis and modeling. Moreover, it is no easy task to determine the WBS for some projects with complicated characteristics. Thus, it will be difficult to generate risk response strategies for the projects using the WBS-based method. Besides, using the WBS-based method, it is unlikely to know whether the obtained strategies are the desirable ones for risk response.

Given the limitations of the exiting methods, it is necessary to conduct further research on how to tackle project risk response problems from a new perspective. Some studies in recent years show that it is feasible to solve the decision-making problems using the case-base decision analysis methods (Amailef & Lu, 2013; Chen, Kilgour, & Hipel, 2008; Ma, 2012; Pla, López, Gay, & Pous, 2013). Thus, to solve the project risk response problem, a way of case-base decision analysis may be considered. That is, the project manager can retrieve the available information and knowledge on risk response from case base. Then appropriate risk response strategy or strategies for the current project can be generated by analyzing and reusing the retrieved information and knowledge. As is known to all, the case-based reasoning (CBR) technique is good at solving problems by retrieving and reusing information and knowledge of the similar historical cases (Aamodt & Plaza, 1994; Abelson & Schank, 1977; Hansen, Meservy, & Wood, 1994). Over the decades, CBR was widely applied in various areas such as medicine (El-Fakdi, Gamero, Meléndez, Auffret, & Haigron, 2014; Guessoum, Laskri, & Lieber, 2014; Ting, Wang, Kwok, Tsang, & Lee, 2010; Zhuang, Churilov, Burstein, & Sikaris, 2009), manufacturing industry (Kuo, 2010; Wu, Lo, & Hsu, 2008) and business (Carmona, Barbancho, Larios, & León, 2013; Li, Adeli, Sun, & Han, 2011), etc. It can been found that there are some studies on risk management based on CBR (Aarts, 1998; Bajo, Borrajo, De Paz, Corchado, & Pellicer, 2012; Chang, Ma, Song, & Gao, 2010; Dingwei & Xinping, 2011; Goh & Chua, 2009; Jung, Han, & Suh, 1999; Kumar & Viswanadham, 2007; Li, Yu, Zhou, & Cai, 2013; Lu, Li, & Xiao, 2013; Yao, Chen, & Yang, 2014). For example, Kumar and Viswanadham (2007) develop a CBR-based framework of the decision support system to support the risk management of construction supply chains. Dingwei and Xinping (2011) develop an audit decision aid system based on analytical hierarchy process and CBR to assess the management fraud risk. Bajo et al. (2012) develop a CBR-based multi-agent system for web-based risk management in small and

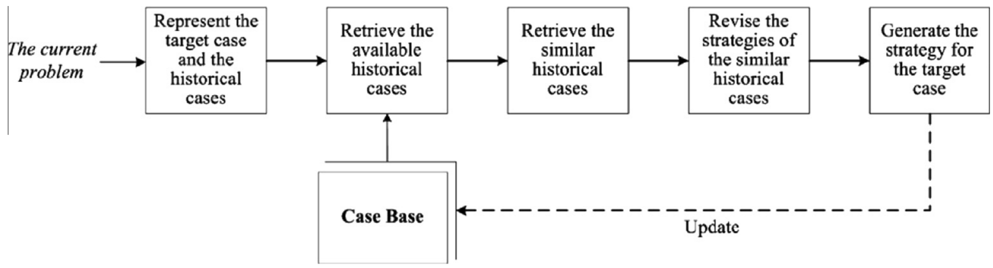

Fig. 2. The solution framework for generating project risk response strategies based on CBR.

medium business. Lu et al. (2013) develop a CBR system which includes a detailed case representation scheme and an automated retrieval mechanism to analyze safety risk on subway operation. Yao et al. (2014) identify the ship repair risk by analyzing causes and consequences of the risk, and propose a CBR-based method for assessing the ship repair risk. Obviously, it is a good way to apply the CBR technique to the risk management for project risk. However, little attention has been paid to problems of generating project risk response strategies in the existing studies. Especially, the study on using the CBR technique to solve the project risk response problem is seldom found. Therefore, it is necessary to investigate the CBR-based method for generating project risk response strategies.

The objective of this paper, taking risk response of the subway project in S city, China as a case problem, is to develop a CBR-based method for generating project risk response strategies. In the method, firstly, the current project risk response problem is regarded as the target case and the available historical cases are retrieved from the case base by judging whether the project risks involved in each historical case cover or are the same as those in the target case. Then, the similar historical cases are retrieved from the available historical case set by measuring similarity between each available historical case and the target case. On the basis of this, by revising the inapplicable risk response strategies involved in the similar historical cases, the candidate risk response strategy sets for the target case are set up. Further, the overall evaluation value concerning each candidate risk response strategy set is calculated. Finally, the desirable risk response strategies for the target case are generated according to the obtained overall evaluation values.

The rest of this paper is organized as follows. Section 2 formulates the case problem of the subway project risk response, along with the solution framework for generating project risk response strategies based on the CBR. To solve the case problem, Section 3 presents a CBR-based method for generating project risk response strategies. In Section 4, an empirical analysis on the case of generating risk response strategies for the subway station project in S city, China is given to illustrate the use of the proposed method. Finally, the conclusions of this study and the directions for the future research are presented in Section 5.

2. Case problem and solution framework

Subway, as a fast and convenient vehicle, has many advantages, such as low energy consumption, low pollution and less affected by weather, etc (Zhao & Hao, 2011). Thus, it has been adopted by more and more cities worldwide. In China, subway construction has stepped into an era of accelerating development. So far, the subways have been put into operation in more than ten cities and the subway constructions of many other cities are in progress (Chen, Wang, Song, & Zhao, 2013).

S city is one of the important integrated transportation hubs in northern China. In recent years, to alleviate traffic pressure of the city, the government has made a plan of subway constructions. Until now, the subway lines 1 and 2 have been put into operation and the subway line 10, as a part of the plan, is under construction. For the project of the subway line 10, the budget is about 297 billion Chinese Yuan (CNY). The total project duration is four years and ten months. The total length of the engineering line is 49.92 km, and there are 37 stations, as shown in Fig. 1. Usually, during the execution of the project, there could exist some risks from several aspects such as schedule, investment, quality, management and so on. The risks may result in delaying construction period, overrunning budget and being not up to quality standard, etc. Thus, it is vital to conduct the risk management for the project.

In this paper, we focus on the risk response problem of the subway station construction projects. In reality, some factors, such as financing, employee skills, land expropriation, surrounding environment and so on, could result in the existence of risks (Wu et al., 2013). To prevent and control the risks, it is necessary to generate and implement proper risk response strategies.

For convenience, this paper takes the risk response of a subway station project as a case problem to develop a new method for generating risk response strategies. The considered subway station is the 14th station, i.e., the Changan Road. This station is located in the densely populated area. The surrounding business is prosperous and traffic is heavy. Additionally, the hydrological and geological conditions of this area are complicated. To identify and assess the risks of the station project, the subway construction company organizes a PRM committee, which is consisted of multiple experts from related fields. The risks of the current project are identified by the committee through full investigation and in-depth discussion. The identified risks can mainly be classified into four categories: the risk of the land and house expropriation compensation, the risk of the ground subsidence, the risk of the groundwater pollution and the risk of the surrounding traffic jam. Further, these risks are assessed by the committee through analysis of the likelihood and severity of each risk. On the basis of risk identification and assessment, it is necessary to generate the corresponding risk response strategies. For this, the committee thinks that it is a suitable way to generate risk response strategies by retrieving and reusing information and knowledge of the similar historical cases.

The case problem addressed in this paper is how to retrieve and reuse information and knowledge of the similar historical cases, as well as to generate the desirable risk response strategies for the current project.

This paper intends to use the CBR technique to solve the above problem. Usually, the CBR technique can be used to support decision-makers in finding the desirable solution(s) to the decision-making problem. It includes five steps (Fan, Li, Wang, & Liu, 2014; Reza Montazemi & Moy Gupta, 1997): (1) *representation*: represent the target case (the current problem) and the historical cases; (2) *retrieval*: retrieve the similar historical cases from the case base; (3) *revision*: generate a solution to the target case based on the similar historical cases and revise the solution using the relevant knowledge; (4) *validation*: validate the solution through the feedback from the decision-maker or the environment; and (5)

Table 1
The related information of the historical cases and the target case.

Historical cases and target case	Project features				Project risks				Risk response strategy sets
	Q_1	Q_2	$\cdots$	Q_h	R_1	R_2	$\cdots$	R_g	
C_1	q_{11}	q_{12}	$\cdots$	q_{1h}	r_{11}	r_{12}	$\cdots$	r_{1g}	$\{S_{11}, S_{12}, \ldots, S_{1m_1}\}$
C_2	q_{21}	q_{22}	$\cdots$	q_{2h}	r_{21}	r_{22}	$\cdots$	r_{2g}	$\{S_{21}, S_{22}, \ldots, S_{2m_2}\}$
$\vdots$	$\vdots$	$\vdots$		$\vdots$	$\vdots$	$\vdots$		$\vdots$	$\vdots$
C_n	q_{n1}	q_{n2}	$\cdots$	q_{nh}	r_{n1}	r_{n2}	$\cdots$	r_{ng}	$\{S_{n1}, S_{n2}, \ldots, S_{nm_n}\}$
C_0	q_{01}	q_{02}	$\cdots$	q_{0h}	r_{01}	r_{02}	$\cdots$	r_{0g}	X

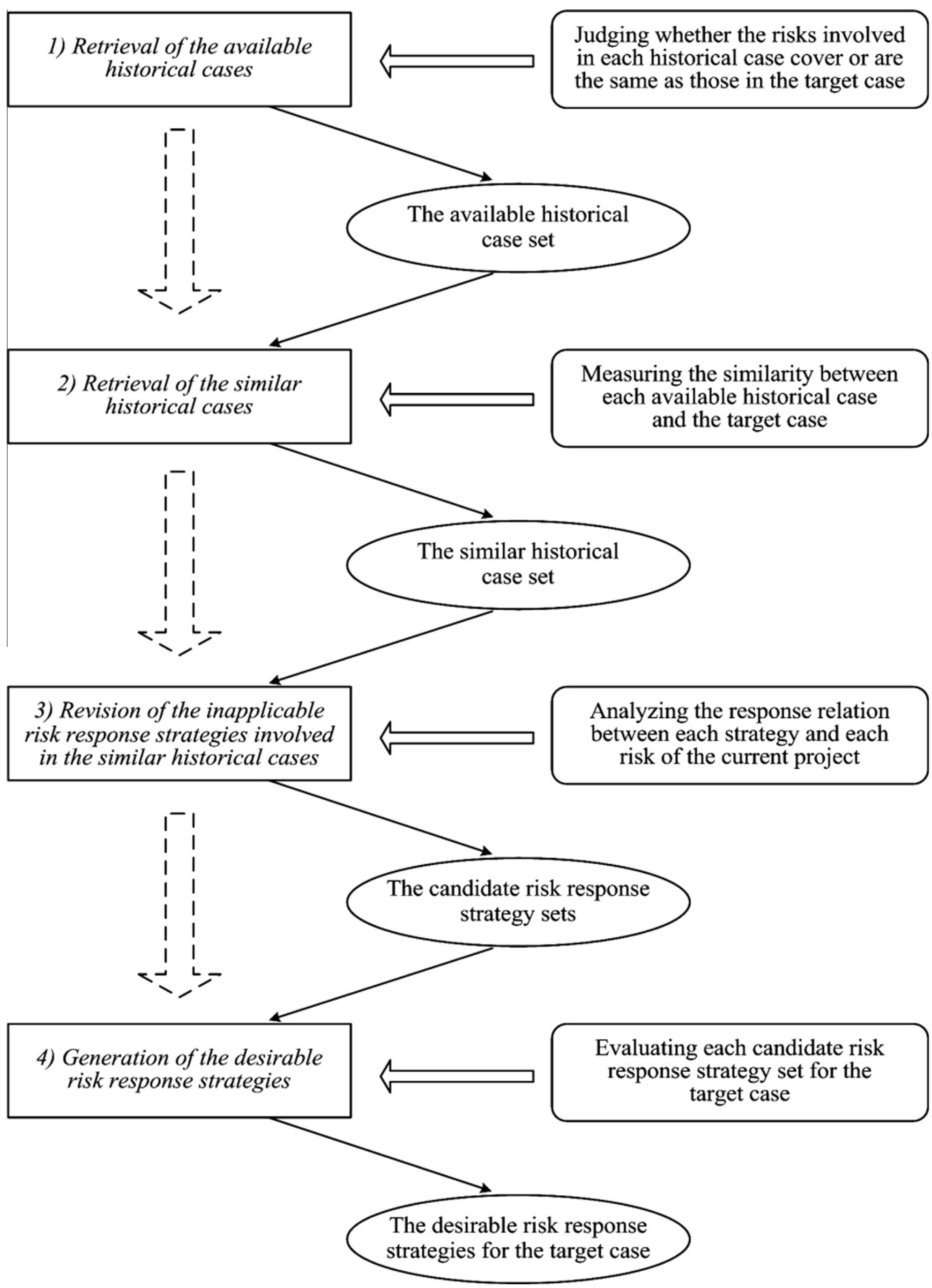

Fig. 3. The resolution procedure.

update: add the validated solution to the case base for solving future problems. In this paper, to solve the case problem, the solution framework for generating project risk response strategies based on the CBR is given, as shown in Fig. 2.

3. The CBR-based method for generating project risk response strategies

Based on the above solution framework, we give a CBR-based method for generating project risk response strategies in this section. First, the case representation and resolution procedure are presented. Then, the specific description of each part of the procedure is given.

3.1. Case representation and resolution procedure

Given the choice of the CBR-based method for solving the aforementioned case problem, an important work is to represent the case used for reasoning. In this research, the case is represented in the form of a three-tuple, i.e., case = ⟨project, project risk, risk response strategy⟩, where the 'project' and 'project risk' are used to describe the project risk response problem, and the 'risk response strategy' is used to describe the solution to the problem. In the following, we give brief descriptions of the 'case', 'project', 'project risk' and 'risk response strategy', respectively.

3.1.1. Case

Two types of cases are involved in this paper, i.e., the historical case and the target case. The historical case is the one stored in the case base. The target case is the current project risk response problem. Here, let $C = \{C_1, C_2, \ldots, C_n\}$ be a finite set of n historical cases, where C_i denotes the i th historical case, $i \in \{1, 2, \ldots, n\}$. Let C_0 denote the target case. For the target case C_0, the risk response strategy is unknown, and it needs to be generated using the method proposed in this paper.

3.1.2. Project

Each project is commonly described by multiple project features. For example, a subway station project can be described by investment amount, construction cycle, station type and so on. Here, let $Q = \{Q_1, Q_2, \ldots, Q_h\}$ be a finite set of h project features, where Q_l denotes the l th project feature, $l \in \{1, 2, \ldots, h\}$; let $\boldsymbol{w}^P = (w_1^P, w_2^P, \ldots, w_h^P)$ be a vector of project feature weights, where w_l^P denotes the weight or the importance degree of project feature Q_l, such that $\sum_{l\in\{1,2,\ldots,h\}} w_l^P = 1$ and $w_l^P \geqslant 0$, $l \in \{1, 2, \ldots, h\}$; let $q_i = (q_{i1}, q_{i2}, \ldots, q_{ih})$ be a vector of project feature values with regard to the historical case C_i, where q_{il} denotes the feature value of the project involved in the case C_i concerning Q_l, $i \in \{1, 2, \ldots, n\}$, $l \in \{1, 2, \ldots, h\}$; let $q_0 = (q_{01}, q_{02}, \ldots, q_{0h})$ be a vector of project feature values with regard to the target case C_0, where q_{0l} denotes the feature value of the project involved in the case C_0 concerning Q_l, $l \in \{1, 2, \ldots, h\}$. According to the situation of real projects, project feature values are usually represented in multiple forms. For example, for project feature 'subway station type', its value is in the form of crisp symbols such as 'two layers of underground island-shaped', 'three layers of underground island-shaped' and so on; for project feature 'investment amount', its value is in the form of crisp number such as 1.84 billion CNY. Here, project feature values q_{il} and q_{0l} can be represented in the two forms, i.e., crisp symbol and crisp number, and forms of feature values q_{il} and q_{0l} concerning the project feature Q_l are the same.

3.1.3. Project risk

Let $R = \{R_1, R_2, \ldots, R_g\}$ be a finite set of g risks, where R_k denotes the kth risk, $k \in \{1, 2, \ldots, g\}$. Here, suppose that the set R includes all the risks with regard to the projects involved in the historical cases and the target case. Let $\boldsymbol{w}^R = (w_1^R, w_2^R, \ldots, w_g^R)$ be a vector of risk weights, where w_k^R denotes the weight or the importance degree of risk R_k, such that $\sum_{k\in\{1,2,\ldots,g\}} w_k^R = 1$ and $w_k^R \geqslant 0$, $k \in \{1, 2, \ldots, g\}$; Let $\boldsymbol{r}_i = (r_{i1}, r_{i2}, \ldots, r_{ig})$ be a vector of risk values of the project with regard to the historical case C_i, where r_{ik} denotes the value of risk R_k in the case C_i. If the risk R_k did not occur in the historical case C_i, we note $r_{ik} = 0$; if occurred, the risk value r_{ik} can be represented in the form of interval number, i.e., $r_{ik} = [r_{ik}^L, r_{ik}^U]$, $r_{ik}^U \geqslant r_{ik}^L \geqslant 0$, where r_{ik}^L and r_{ik}^U denote the low limit and upper limit of r_{ik}, respectively. Particularly, if $r_{ik}^L = r_{ik}^U$, then r_{ik} reduces to a crisp number. Let $\boldsymbol{r}_0 = (r_{01}, r_{02}, \ldots, r_{0g})$ be a vector of risk values of the project with regard to the target case C_0, where r_{0k} denotes the value of risk R_k in the case C_0. Similarly, if the risk R_k are not included in the target case C_0, we note $r_{0k} = 0$; if included, the risk value r_{0k} can be represented in the form of interval number, i.e., $r_{0k} = [r_{0k}^L, r_{0k}^U]$, $r_{0k}^U \geqslant r_{0k}^L \geqslant 0$.

3.1.4. Risk response strategy

The multiple risk response strategies involved in each historical case can be represented by a risk response strategy set. Here, let $M_i = \{1, 2, \ldots, m_i\}$, where m_i denotes the total number of the response strategies involved in the historical case C_i. Let S_i denote a finite set of m_i response strategies coping with the risks in the historical case C_i, i.e., $\boldsymbol{S}_i = \{S_{i1}, S_{i2}, \ldots, S_{ie}, \ldots, S_{im_i}\}$, where S_{ie} denotes the e th response strategy in the case C_i, $e \in M_i$, $i \in \{1, 2, \ldots, n\}$. For the set $\boldsymbol{S}_i$, the corresponding cost set can be denoted as $CO_i = \{c_{i1}, c_{i2}, \ldots, c_{ie}, \ldots, c_{im_i}\}$, where c_{ie} denotes the cost of implementing the e th response strategy in the case C_i, i.e., S_{ie}, $e \in M_i$, $i \in \{1, 2, \ldots, n\}$.

In summary, the related information of the historical cases and the target case is shown in Table 1. Thus, the case problem can be further described as how to generate the desirable risk response strategies for the target case C_0 using related information as shown in Table 1 and the weight vectors $\boldsymbol{w}^P = (w_1^P, w_2^P, \ldots, w_h^P)$ and $\boldsymbol{w}^R = (w_1^R, w_2^R, \ldots, w_g^R)$.

According to Fig. 2, the resolution procedure for solving the case problem mentioned above is given, as shown in Fig. 3, and the technological words used in Fig. 3 refer to Allen (1994) and Hunt (1995). The procedure consists of four parts, i.e., (1) retrieval of the available historical cases; (2) retrieval of the similar historical cases; (3) revision of the inapplicable risk response strategies involved in the similar historical cases; (4) generation of the desirable risk response strategies. From Fig. 3, the method and the result concerning each part can be clearly shown.

In the following subsections, the computation process of each part of the procedure is described as follows.

3.2. Retrieval of the available historical cases

In reality, the risks involved in the historical cases may be not exactly the same as those in the target case. In order to retrieve the available historical cases, a judgment on whether the risks involved in the historical cases cover or are the same as those in the target case is conducted. If result of the judgment is covering or the same, then the corresponding historical cases can be retrieved. Here, the retrieved cases are regarded as the available historical cases. In the following, the retrieval process of the available historical case is described.

Let Θ denote the subscript set of all the risks involved in the target case C_0, i.e., $\Theta = \{k|r_{0k} \neq 0, k \in \{1, 2, \ldots, g\}\}$, $\Theta \subset \{1, 2, \ldots, g\}$. Let η_{0k} and η_{ik} denote the indicator functions of risks with regard to the target case C_0 and the historical case C_i, respectively, then η_{0k} and η_{ik} are respectively expressed as

$$\eta_{0k} = \begin{cases} 1, & k \in \Theta, \\ 0, & k \notin \Theta, \end{cases} \tag{1}$$

and

$$\eta_{ik} = \begin{cases} 1, & r_{ik} \neq 0 \text{ and } k \in \Theta, \\ 0, & \text{otherwise}, \end{cases} \quad i \in \{1, 2, \ldots, n\}. \tag{2}$$

By Eqs. (1) and (2), the two indicator vectors of risks can be formed, i.e., $\tau_0 = (\eta_{01}, \eta_{02}, \ldots, \eta_{0g})$ and $\tau_i = (\eta_{i1}, \eta_{i2}, \ldots, \eta_{ig})$, $i \in \{1, 2, \ldots, n\}$.

Let δ_{0i} denote the distance between the vectors τ_0 and τ_i, then the calculation formula of δ_{0i} is given by

$$\delta_{0i} = \sqrt{(\eta_{01} - \eta_{i1})^2 + (\eta_{02} - \eta_{i2})^2 + \cdots + (\eta_{0g} - \eta_{ig})^2}, \quad i \in \{1, 2, \ldots, n\}, \tag{3}$$

If $\delta_{0i} \neq 0$, it means that τ_i is different from τ_0, i.e., the risks involved in historical case C_i do not cover or are different from those in the target case C_0, further, the corresponding historical case C_i is removed. If $\delta_{0i} = 0$, it means that τ_i is the same as τ_0, i.e., the risks involved in the historical case C_i cover or are the same as those in the target case C_0, further, the corresponding historical case C_i, which is regarded as the available historical case, can be retrieved from the set C $i \in \{1, 2, \ldots, n\}$.

Based on the retrieved historical cases, the available historical case set (denoted as $C^A = \{C_i | i \in \Phi\}$) is formed, $C^A \subset C$, where Φ denotes the subscript set of all available historical cases, i.e., $\Phi = \{i | \delta_{i0} = 0, i \in \{1, 2, \ldots, n\}\}$, $\Phi \subset \{1, 2, \ldots, n\}$.

3.3. Retrieval of the similar historical case

As mentioned in Section 3, a case involves three parts, i.e., the 'project', 'project risk' and 'risk response strategy'. To retrieve the similar historical cases from the available historical case set C^A, two similarities should be measured, i.e., the similarity between the available historical case and the target case concerning the 'project' and that concerning the 'project risk'. If the two similarities simultaneously satisfy their respective requirement, the corresponding available historical case, which is regarded as the similar historical case, can be retrieved. In the following, the measurement methods of the two similarities are firstly given, and then the retrieval process of the similar historical cases is described.

3.3.1. Similarity measurement concerning 'project'

Let $sim_l^P(C_i, C_0)$ denote the similarity between the available historical case C_i and the target case C_0 with regard to the project feature Q_l. If the project feature values q_{il} and q_{0l} are in the form of crisp symbols, the calculation formula of $sim_l^P(C_i, C_0)$ is given by

$$sim_l^P(C_i, C_0) = \begin{cases} 1, & q_{il} = q_{0l}, \\ 0, & q_{il} \neq q_{0l}, \end{cases} \quad i \in \Phi, \quad l \in \{1, 2, \ldots, h\}. \tag{4}$$

If the project feature values q_{il} and q_{0l} are in the form of crisp numbers, the calculation formula of $sim_l^P(C_i, C_0)$ is given by

$$sim_l^P(C_i, C_0) = 1 - \frac{dis_l^P(C_i, C_0)}{\max_{i \in \Phi}\{dis_l^P(C_i, C_0)\}}, \quad i \in \Phi, \quad l \in \{1, 2, \ldots, h\}, \tag{5}$$

where

$$dis_l^P(C_i, C_0) = |q_{il} - q_{0l}|, \quad i \in \Phi, \quad l \in \{1, 2, \ldots, h\}. \tag{6}$$

Further, let $Sim^P(C_i, C_0)$ denote the similarity between the available historical case C_i and the target case C_0 concerning the 'project', then it can be obtained by aggregating $sim_1^P(C_i, C_0)$, $sim_2^P(C_i, C_0), \ldots, sim_h^P(C_i, C_0)$, i.e.,

$$Sim^P(C_i, C_0) = \sum_{l \in \{1, 2, \ldots, h\}} w_l^P sim_l^P(C_i, C_0), \quad i \in \Phi. \tag{7}$$

Obviously, $Sim^P(C_i, C_0) \in [0, 1]$, $i \in \Phi$. The greater $Sim^P(C_i, C_0)$ is, the more similar the available historical case C_i and the target case C_0 concerning the 'project' will be.

3.3.2. Similarity measurement concerning 'project risk'

As mentioned in Section 3, risk values with regard to the project are in the form of interval numbers. Here, risk values r_{0k} and r_{ik} are represented by $r_{0k} = [r_{0k}^L, r_{0k}^U]$ and $r_{ik} = [r_{ik}^L, r_{ik}^U]$, respectively. Usually, an arbitrary value in interval $[r_{0k}^L, r_{0k}^U]$ or $[r_{ik}^L, r_{ik}^U]$, x, can be regarded as a random variable that follows a probability distribution, such as the uniform distribution or norm distribution (Fan, Zhang, Chen, & Liu, 2013). Suppose that $f_{0k}(x)$ and $f_{ik}(x)$ are probability density functions of x in intervals $[r_{0k}^L, r_{0k}^U]$ and $[r_{ik}^L, r_{ik}^U]$, respectively, then the corresponding cumulative distribution functions can be respectively represented as

$$F_{0k}(x) = \int_{r_{0k}^L}^{x} f_{0k}(t)dt, \quad x \in [r_{0k}^L, r_{0k}^U], \quad k \in \Theta, \tag{8}$$

$$F_{ik}(x) = \int_{r_{ik}^L}^{x} f_{ik}(t)dt, \quad x \in [r_{ik}^L, r_{ik}^U], \quad i \in \Phi, \quad k \in \Theta. \tag{9}$$

Let $sim_k^R(C_i, C_0)$ denote the similarity between the available historical case C_i and the target case C_0 with regard to risk R_k, then the calculation formula of $sim_k^R(C_i, C_0)$ is given by

$$sim_k^R(C_i, C_0) = 1 - \frac{dis_k^R(C_i, C_0)}{\max_{i \in \Phi}\{dis_k^R(C_i, C_0)\}}, \quad i \in \Phi, \quad k \in \Theta, \tag{10}$$

In Eq. (10), the calculation formula of $dis_k^R(C_i, C_0)$ is given by

$$dis_k^R(C_i, C_0) = \int_{b_{i0}^{k\min}}^{b_{i0}^{k\max}} |F_{ik}(x) - F_{0k}(x)| dx, \quad i \in \Phi, \quad k \in \Theta, \tag{11}$$

where $b_{i0}^{k\min} = \min\{r_{ik}^L, r_{0k}^L\}$, $b_{i0}^{k\max} = \max\{r_{ik}^U, r_{0k}^U\}$, $i \in \Phi$, $k \in \Theta$.

Based on $sim_k^R(C_i, C_0)$, $k \in \Theta$, the similarity between the available historical case C_i and the target case C_0 concerning the 'project risk', $Sim^R(C_i, C_0)$, can be calculated. Its calculation formula is given by

$$Sim^R(C_i, C_0) = \frac{\sum_{k \in \Theta} w_k^R sim_k^R(C_i, C_0)}{\sum_{k \in \Theta} w_k^R}, \quad i \in \Phi. \tag{12}$$

Obviously, $Sim^R(C_i, C_0) \in [0, 1]$, $i \in \Phi$. The great $Sim^R(C_i, C_0)$ is, the more similar the available historical case C_i and the target case C_0 concerning the 'project risk' will be.

3.3.3. Formation of the similar historical case set

Obviously, the greater the two similarities $Sim^P(C_i, C_0)$ and $Sim^R(C_i, C_0)$ are, the more similar the available historical case C_i and the target case C_0 will be, and the corresponding historical case C_i may be retrieved, $i \in \Phi$. To retrieve the desirable available historical cases, the two similarities thresholds (denoted as λ^P and λ^R) usually need to be set beforehand. Based on the simple majority principle (Fishburn & Gehrlein, 1976), the formulae of determining λ^P and λ^R are respectively given by

$$\lambda^P = Sim_{\min}^P + \frac{1}{3}\left(Sim_{\max}^P - Sim_{\min}^P\right), \tag{13}$$

$$\lambda^R = Sim_{\min}^R + \frac{1}{3}\left(Sim_{\max}^R - Sim_{\min}^R\right), \tag{14}$$

where $Sim_{\max}^P = \max_{i \in \Phi}\{Sim^P(C_i, C_0)\}$, $Sim_{\min}^P = \min_{i \in \Phi}\{Sim^P(C_i, C_0)\}$, $Sim_{\max}^R = \max_{i \in \Phi}\{Sim^R(C_i, C_0)\}$ and $Sim_{\min}^R = \min_{i \in \Phi}\{Sim^R(C_i, C_0)\}$.

If $Sim^P(C_i, C_0) \geqslant \lambda^P$ and $Sim^R(C_i, C_0) \geqslant \lambda^R$ hold, then the corresponding available historical case C_i, which is regarded as the similar historical case, can be retrieved from the set C^A, $i \in \Phi$. Based

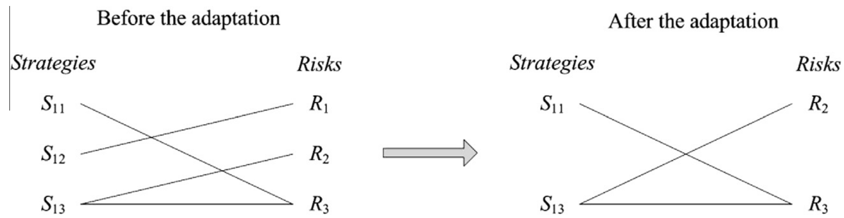

Fig. 4. The situation of deleting the response strategy.

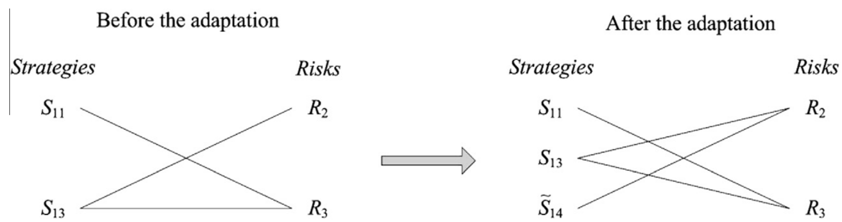

Fig. 5. The situation of adding the response strategy.

on the retrieved available historical cases, the similar historical case set (denoted as $C^{Sim} = \{C_i | i \in \Omega\}$) is formed, $C^{Sim} \subset C^A$, where Ω denotes the subscript set of all similar historical cases, i.e., $\Omega = \{i | Sim^P(C_i, C_0) \geqslant \lambda^P, Sim^R(C_i, C_0) \geqslant \lambda^R, i \in \Phi\}, \quad \Omega \subset \Phi$.

3.4. Revision of the inapplicable response strategies involved in the similar historical cases

The risk response strategies in set $\boldsymbol{S}_i$ are used to cope with the risks occurred in the similar historical cases. However, some of the strategies in set $\boldsymbol{S}_i$ could not fit for the risks considered in the target case. The main reasons include: the risk in the similar historical case is not involved in the target case; the strategy or strategies are not enough to cope with the risk(s) in the target case; the strategy or strategies cannot cope with the risk(s) in the target case according to current practical requirements. Hence, it is necessary to revise the inappropriate risk response strategies. For this, it is necessary to complete the following three aspects of the work:

(1) The response relation between each response strategy and each risk involved in the similar historical case is judged;
(2) Through the judgment, the 'strategy-risk' response relation graph can be drawn. On the basis of the graph, let project managers or experts analyze and find out the applicability of risk response strategies to the risks involved in the target case.
(3) If situations of the inapplicability exist, then the revisions to the inapplicable risk response strategies should be done to make them suitable for the risks involved in the target case.

To complete the above work, it is needed to let multiple project managers or experts analyze the related information and give the judgments according to their knowledge and experience. On the basis of this, the result of the revisions of the inapplicable response strategies is obtained by the discussion and the integration of the judgments.

In the following, the revision process of the response strategies is described.

First, through the judgment of the response relation between each response strategy and each risk involved in the similar historical case, the 'strategy-risk' response relation graph with regard to each similar historical case can be drawn. Usually, there are three possible response relations between the response strategy and risk (Zhang & Fan, 2014), i.e., (a) one to one relation: one response strategy can cope with one risk; (b) one to many relation: one response strategy can cope with multiple risks simultaneously; (c) many to one relation: multiple response strategies need to be simultaneously adopted to cope with one risk.

Then, with the help of the 'strategy-risk' response relations with regard to each similar historical case, it is analyzed whether the strategies are suitable for coping with the risks involved in the target case or not. If not, then the inapplicable response strategies should be revised.

Further, for revisions of the inapplicable response strategies, there are the three situations discussed as follows:

(1) *Deletion:* if the risk in the similar historical case is not involved in the target case, then the corresponding strategy or strategies are redundant and should be deleted.
(2) *Addition:* if the strategy or strategies are not enough to cope with the risk(s) in the target case, then additional strategy or strategies should be added.
(3) *Modification:* if the strategy or strategies cannot cope with the risk(s) in the target case according to current practical requirements, then the corresponding strategy or strategies should be modified.

For the above situations (2) and (3), the addition and modification of response strategies are based on the objective requirements of risk response in the target case and the current conditions, and the completion of this work usually requires the participation of the project managers or experts. In addition, the costs of implementing response strategies in the similar historical cases usually are inapplicable for the target case because of the differences in labor, material, operation and management, market condition and so on. Thus, the costs usually need to be modified as well.

To illustrate the revision of inapplicable response strategies, an example is used. Suppose that C_1 denotes a retrieved similar historical case on a previous subway station project. For case C_1, there are the three risks, i.e., R_1 (the risk of the program), R_2 (the risk of the climate) and R_3 (the risk of the ground subsidence), and there are the three response strategies, i.e., S_{11} (using the surveying and mapping technique to investigate the state of the geological hydrology), S_{12} (learning about the relevant municipal regulations and policies) and S_{13} (employing domain experts). Through the analysis of the case C_1, it can be seen that the 'strategy-risk' response relations are: S_{11} to R_3, S_{12} to R_1, S_{13} to R_2 and R_3. Here, the revision processes of the response strategies are described. First, through the analysis, it can be confirmed that there exist the two risks R_1 and R_3 in the target case C_0. Obviously, the risk R_2 in the case C_1 are not involved in target case C_0, thus, the corresponding response strategy S_{12} should be deleted, as shown in Fig. 4. Then, since the more changeable and unpredictable climate condition causes that the strategy S_{13} is not enough to cope with the risk R_2, the additional response strategy, i.e., $\widetilde{S}_{14}$ (hiring local labors), should be added, as shown in Fig. 5. Additionally, because the response strategy S_{11} cannot meet technique requirements of the current project risk response, it means that S_{11} and S_{13} cannot cope with the risk R_3 in the target case C_0. Thus, S_{11} should be modified into S'_{11} (using the remote-sensing technique to investigate the state of the geological hydrology), as shown in Fig. 6.

If some response strategies in the risk response strategy set $\boldsymbol{S}_i$ are revised, then the elements in the set $\boldsymbol{S}_i$ will be changed. For convenience, the set $\boldsymbol{S}_i$ can be rewritten as $\overline{\boldsymbol{S}}_i$, and the subscript set of the set $\overline{\boldsymbol{S}}_i$ can be denoted as $\overline{M}_i$, $i \in \Omega$. Additionally, for the set $\overline{\boldsymbol{S}}_i$, the corresponding cost set CO_i can be rewritten as $\overline{CO}_i$, where $\bar{c}_{ie}$ denotes the modified cost of implementing the e th response strategy in the set $\overline{\boldsymbol{S}}_i, \bar{c}_{ie} \in \overline{CO}_i, e \in \overline{M}_i$, $i \in \Omega$. In the following, the set $\overline{\boldsymbol{S}}_i$ can be regarded as the candidate risk response strategy set for the target case C_0, $i \in \Omega$.

3.5. Generation of the desirable risk response strategies

The generation of the desirable risk response strategies can be conducted through the evaluation of the candidate risk response strategy set with regard to each similar historical case. Usually, two recognized criteria are considered in the evaluation, i.e., 'cost' and 'expected effect' on project risk response (Chapman & Ward, 1996). The cost on project risk response can be estimated by the experts from the same or similar fields, while the expected effect on project risk response can be obtained through the evaluation of the experts. By aggregating the cost and the evaluation result of the expected effect, the overall evaluation value concerning each candidate risk response strategy set can be calculated. According to the obtained overall evaluation values, the desirable risk response strategies can be generated to cope with the risks in the target case. In the following, the computation process for generating the desirable risk response strategies is described.

First, let $\bar{\bar{c}}_i$ denote the average cost concerning the candidate risk response strategy set $\overline{\boldsymbol{S}}_i$, then it can be calculated by

$$\bar{\bar{c}}_i = \frac{1}{card(\overline{M}_i)} \sum_{e \in \overline{M}_i} \bar{c}_{ie}, \quad i \in \Omega, \tag{15}$$

where $card(\overline{M}_i)$ denotes the total number of the elements in set $\overline{M}_i$, $i \in \Omega$. For convenience of the analysis and computation, $\bar{\bar{c}}_i$ can be normalized into $c(\overline{\boldsymbol{S}}_i)$ using the following formula:

$$c(\overline{\boldsymbol{S}}_i) = \frac{\min_{i \in \Omega}\{\bar{\bar{c}}_i\}}{\bar{\bar{c}}_i}, \quad i \in \Omega. \tag{16}$$

Obviously, $c(\overline{\boldsymbol{S}}_i) \in [0, 1]$, $i \in \Omega$.

Then, we assume that the d experts use the scale of scores of 1–10 (1: the worst; 10: the best) to evaluate the expected effect of the candidate risk response strategies, and the weight or importance degree of each expert is the same. Let v_{iks} denote the evaluation value of the expected effect of the risk response strategy set $\overline{\boldsymbol{S}}_i$ with regard to the risk R_k in the target case C_0 provided by the s th expert, $i \in \Omega$, $k \in \Theta$, $s \in \{1, 2, \ldots, d\}$, then by aggregating the evaluation results of the d experts, the group evaluation value of the expected effect of $\overline{\boldsymbol{S}}_i$ with regard to R_k can be calculated, i.e.,

$$v_{ik} = \frac{1}{d} \sum_{s \in \{1,2,\ldots,d\}} v_{iks}, \quad i \in \Omega, \quad k \in \Theta. \tag{17}$$

Based on v_{ik}, $i \in \Omega$, $k \in \Theta$, the average expected effect value of $\overline{\boldsymbol{S}}_i$ with regard to all the risks involved in the target case C_0 can be calculated, i.e.,

$$\bar{\bar{v}}_i = \frac{1}{card(\Theta)} \sum_{k \in \Theta} v_{ik}, \quad i \in \Omega, \tag{18}$$

where $card(\Theta)$ denotes the total number of the elements in set Θ. For convenience of the analysis and computation, $\bar{\bar{v}}_i$ can be normalized into $v(\overline{\boldsymbol{S}}_i)$ using the following formula:

$$v(\overline{\boldsymbol{S}}_i) = \frac{\bar{\bar{v}}_i}{\max_{i \in \Omega}\{\bar{\bar{v}}_i\}}, \quad i \in \Omega. \tag{19}$$

Obviously, $v(\overline{\boldsymbol{S}}_i) \in [0, 1]$, $i \in \Omega$.

Further, the overall evaluation value concerning the set $\overline{\boldsymbol{S}}_i$ can be calculated by aggregating $c(\overline{\boldsymbol{S}}_i)$ and $v(\overline{\boldsymbol{S}}_i)$, i.e.,

$$u_i = c(\overline{\boldsymbol{S}}_i)\, v(\overline{\boldsymbol{S}}_i), \quad i \in \Omega. \tag{20}$$

Obviously, the greater u_i is, the better the corresponding risk response strategy set $\overline{\boldsymbol{S}}_i$ will be. Thus, in accordance with a descending order of u_i ($i \in \Omega$), the desirable risk response strategies for the target case C_0 can be generated.

In summary, the procedure for generating project risk response strategies is given as follows.

Step 1. Represent the target case and the historical cases.
Step 2. Construct the available historical case set C^A using Eqs. (1)–(3).
Step 3. Calculate the similarities $Sim^P(C_i, C_0)$ and $Sim^R(C_i, C_0)$ using Eqs. (4)–(12), $i \in \Phi$.
Step 4. Retrieve the similar historical cases from set C^A based on the similarity thresholds λ^P and λ^R obtained by Eqs. (13) and (14), and then construct the similar historical case set C^{Sim}.
Step 5. Revise inapplicable response strategies in the set $\boldsymbol{S_i}$ through the analysis of the 'strategy-risk' response relations, and then construct the candidate risk response strategy set $\overline{biS}_i$, $i \in \Omega$.
Step 6. Calculate the cost $c(\overline{\boldsymbol{S}}_i)$ and the expected effect value $v(\overline{\boldsymbol{S}}_i)$ using Eqs. (15)–(19), and then calculate the overall evaluation value u_i concerning the candidate risk response strategy set $\overline{\boldsymbol{S}}_i$ using Eq. (20), $i \in \Omega$.

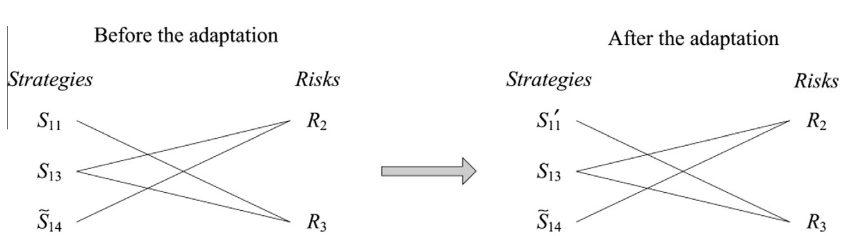

Fig. 6. The situation of modifying the response strategy.

Table 2
The project feature values with regard to the historical cases and the target case.

Historical cases and target case	Project features							
	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7	Q_8
C_1	1.84	165	188	480.13	Cover and cut	First-level station	Hybrid island and side-shaped	Transportation junction
C_2	2.35	179	164	538.24	Underground excavation pile beam arch	Second-level station	Two layers of underground island-shaped	Commercial district
C_3	3.48	238	197	628.18	Open cut	Third-level station	Two layers of underground side-shaped	Institutes and colleges district
C_4	2.22	216	149	605.38	Underground excavation pile beam arch	First-level station	Hybrid island and side-shaped	Residential district
C_5	1.09	133	182	509.74	Mixed excavation	Second-level station	Hybrid island and side-shaped	Leisure and recreation district
C_6	2.13	189	162	533.18	Underground excavation pile beam arch	Second-level station	Two layers of underground island-shaped	Commercial district
C_7	4.05	304	242	673.79	Subsurface excavation	First-level station	Two layers of underground side-shaped	Commercial and service district
C_8	2.22	182	164	528.49	Underground excavation pile beam arch	Second-level station	Two layers of underground island-shaped	Commercial district
C_9	2.15	173	202	567.48	Cover and cut bottom up	Third-level station	Two layers of underground side-shaped	Institutes and colleges district
C_{10}	2.03	181	165	525.68	Underground excavation pile beam arch	First-level station	Three layers of underground island-shaped	Administrative Region
C_{11}	2.24	187	168	531.87	Underground excavation pile beam arch	Second-level station	Two layers of underground island-shaped	Commercial district
C_{12}	1.23	165	177	508.47	Cover-and-cut	Second-level station	Hybrid island and side-shaped	Transportation junction
C_{13}	2.32	183	167	537.51	Underground excavation pile beam arch	Second-level station	Two layers of underground island-shaped	Commercial district
C_{14}	3.32	219	182	648.54	Cover and cut top down	Third-level station	Two layers of underground side-shaped	Transportation junction
C_{15}	1.86	155	212	557.33	Cover and cut	First-level station	Two layers of underground side-shaped	Residential district
C_0	2.23	183	162	530.11	Underground excavation pile beam arch	Second-level station	Two layers of underground island-shaped	Commercial district

Step 7. Determine the desirable risk response strategies for the current project according to the obtained overall evaluation values.

4. Empirical analysis

This section focuses on the case problem mentioned in Section 2. An empirical analysis of generating the risk response strategies for the Changan Road station project is given to illustrate the use of the method mentioned above. It is known that the investment amount of this project is 22.3 million CNY, the construction area is 530.11 square meter and the construction cycle is half a year. The subway station is designated as a second level station and will be constructed in the type of two layers of underground island-shaped. The risks of this project include four aspects: the risk of the land and house expropriation compensation, the risk of the ground subsidence, the risk of the groundwater pollution and the risk of the surrounding traffic jam. To implement the PRM, the desirable strategies need to be generated to cope with the risks of the current project. For this, the process of generating risk response strategies using the aforementioned method is illustrated as follows.

First, the PRM committee regards the current project risk response problem as the target case C_0 and determines the eight project features to describe the project in case C_0, i.e.,

Q_1: investment amount (billion CNY),
Q_2: construction cycle (day),
Q_3: number of employees (person),
Q_4: construction area (square meter),
Q_5: construction method,
Q_6: station function,
Q_7: station type,
Q_8: surrounding urban function.

Table 3
The project risk values with regard to the historical cases and the target case.

Historical cases and target case	Risks								
	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9
C_1	0	[0.15, 0.21]	0	[0.24, 0.28]	[0.11, 0.23]	0	[0.11, 0.21]	[0.22, 0.27]	[0.15, 0.22]
C_2	[0.13, 0.21]	[0.11, 0.17]	[0.08, 0.11]	0	[0.12, 0.17]	[0.14, 0.19]	[0.12, 0.15]	[0.11, 0.23]	[0.11, 0.14]
C_3	0	0	[0.17, 0.23]	0	[0.18, 0.27]	[0.21, 0.28]	0	[0.07, 0.15]	0
C_4	[0.20, 0.28]	0	[0.15, 0.21]	[0.22, 0.27]	[0.08, 0.15]	[0.11, 0.16]	0	[0.09, 0.18]	0
C_5	[0.09, 0.15]	[0.08, 0.14]	[0.11, 0.18]	0	0	[0.08, 0.11]	[0.13, 0.18]	0	[0.10, 0.17]
C_6	[0.11, 0.23]	[0.09, 0.17]	[0.06, 0.12]	0	[0.13, 0.17]	[0.13, 0.17]	0	[0.10, 0.21]	0
C_7	[0.19, 0.29]	0	0	0	[0.17, 0.19]	[0.21, 0.27]	0	[0.19, 0.27]	[0.20, 0.24]
C_8	[0.12, 0.24]	0	[0.05, 0.10]	[0.14, 0.18]	[0.11, 0.16]	0	0	[0.13, 0.22]	0
C_9	[0.19, 0.32]	0	[0.13, 0.21]	[0.10, 0.21]	[0.13, 0.24]	0	[0.17, 0.23]	0	[0.14, 0.23]
C_{10}	[0.18, 0.26]	[0.05, 0.13]	[0.13, 0.17]	0	[0.13, 0.18]	0	[0.07, 0.15]	[0.18, 0.32]	0
C_{11}	[0.14, 0.28]	0	[0.06, 0.11]	0	[0.15, 0.19]	[0.14, 0.16]	0	[0.11, 0.21]	[0.09, 0.15]
C_{12}	[0.16, 0.19]	0	[0.21, 0.28]	[0.15, 0.26]	[0.06, 0.17]	[0.08, 0.15]	[0.14, 0.21]	0	[0.14, 0.19]
C_{13}	[0.13, 0.23]	[0.11, 0.17]	[0.07, 0.18]	0	[0.12, 0.17]	0	0	[0.17, 0.23]	0
C_{14}	[0.21, 0.29]	[0.12, 0.23]	[0.12, 0.15]	[0.13, 0.25]	0	0	0	[0.07, 0.15]	[0.15, 0.23]
C_{15}	[0.08, 0.15]	0	0	0	[0.18, 0.26]	[0.11, 0.16]	[0.22, 0.31]	[0.19, 0.31]	0
C_0	[0.14, 0.23]	0	[0.07, 0.11]	0	[0.13, 0.17]	0	0	[0.11, 0.20]	0

Table 4
The risk response strategy sets with regard to the historical cases.

Historical cases	Risk response strategy sets
C_1	$\boldsymbol{S}_1 = \{S_{11}, S_{12}, S_{13}, S_{14}, S_{15}, S_{16}\}$
C_2	$\boldsymbol{S}_2 = \{S_{21}, S_{22}, S_{23}, S_{24}, S_{25}, S_{26}, S_{27}, S_{28}, S_{29}, S_{2,10}, S_{2,11}\}$
C_3	$\boldsymbol{S}_3 = \{S_{31}, S_{32}, S_{33}, S_{34}\}$
C_4	$\boldsymbol{S}_4 = \{S_{41}, S_{42}, S_{43}, S_{44}, S_{45}, S_{46}\}$
C_5	$\boldsymbol{S}_5 = \{S_{51}, S_{52}, S_{53}, S_{54}, S_{55}, S_{56}\}$
C_6	$\boldsymbol{S}_6 = \{S_{61}, S_{62}, S_{63}, S_{64}, S_{65}, S_{66}, S_{67}\}$
C_7	$\boldsymbol{S}_7 = \{S_{71}, S_{72}, S_{73}, S_{74}, S_{75}\}$
C_8	$\boldsymbol{S}_8 = \{S_{81}, S_{82}, S_{83}, S_{84}, S_{85}, S_{86}\}$
C_9	$\boldsymbol{S}_9 = \{S_{91}, S_{92}, S_{93}, S_{94}, S_{95}, S_{96}\}$
C_{10}	$\boldsymbol{S}_{10} = \{S_{10,1}, S_{10,2}, S_{10,3}, S_{10,4}, S_{10,5}, S_{10,6}\}$
C_{11}	$\boldsymbol{S}_{11} = \{S_{11,1}, S_{11,2}, S_{11,3}, S_{11,4}, S_{11,5}, S_{11,6}, S_{11,7}\}$
C_{12}	$\boldsymbol{S}_{12} = \{S_{12,1}, S_{12,2}, S_{12,3}, S_{12,4}, S_{12,5}, S_{12,6}, S_{12,7}\}$
C_{13}	$\boldsymbol{S}_{13} = \{S_{13,1}, S_{13,2}, S_{13,3}, S_{13,4}, S_{13,5}, S_{13,6}\}$
C_{14}	$\boldsymbol{S}_{14} = \{S_{14,1}, S_{14,2}, S_{14,3}, S_{14,4}, S_{14,5}, S_{14,6}\}$
C_{15}	$\boldsymbol{S}_{15} = \{S_{15,1}, S_{15,2}, S_{15,3}, S_{15,4}, S_{15,5}\}$

By analyzing and collecting the similar projects on subway stations from some domestic cities, the PRM committee determines a set of fifteen historical cases according to the above project features, i.e., $C_1, C_2, \ldots, C_{15}$. The risks involved in the fifteen historical cases include:

R_1: the risk of the land and house expropriation compensation,
R_2: the risk of the human resource,
R_3: the risk of the groundwater pollution,
R_4: the risk of the funding,
R_5: the risk of the surrounding traffic jam,
R_6: the risk of the climate,
R_7: the risk of the safety,
R_8: the risk of the ground subsidence,
R_9: the risk of program.

To determine the weights concerning the project features and risks, the subjective method, i.e., 'statistical average method', is employed based on the consideration that it is difficult to obtain the objective information concerning some project features and risks. Using the method, the project feature weight vector and the risk weight vector are determined, respectively, i.e., $\boldsymbol{w}^P = (0.18, 0.19, 0.1, 0.1, 0.11, 0.12, 0.13, 0.07)$ and $\boldsymbol{w}^R = (0.17, 0.09, 0.13, 0.09, 0.14, 0.07, 0.12, 0.13, 0.06)$. The project feature values with regard to the historical cases and the target case are shown in Table 2. The normalized project risk values with regard to the historical cases and the target case are shown in Table 3, where the project risk values with regard to the historical cases are the recorded data, and the ones with regard to the target case are estimated by the PRM committee according to the likelihoods and severities of the risks. The risk response strategy sets with regard to the historical cases are shown in Table 4.

Then, by comparing the four risks involved in the target case with the nine risks involved in all the historical cases, it can be seen that the risks in the target case are R_1, R_3, R_5 and R_8. By Eqs. (1) and (2), the indicator vectors of risks can be constructed, i.e.,

$$\begin{aligned}
&\tau_0 = (1,0,1,0,1,0,0,1,0), \quad \tau_1 = (0,0,0,0,1,0,0,1,0),\\
&\tau_2 = (1,0,1,0,1,0,0,1,0), \quad \tau_3 = (0,0,1,0,1,0,0,1,0),\\
&\tau_4 = (1,0,1,0,1,0,0,1,0), \quad \tau_5 = (1,0,1,0,0,0,0,0,0),\\
&\tau_6 = (1,0,1,0,1,0,0,1,0), \quad \tau_7 = (1,0,0,0,1,0,0,1,0),\\
&\tau_8 = (1,0,1,0,1,0,0,1,0), \quad \tau_9 = (1,0,1,0,1,0,0,0,0),\\
&\tau_{10} = (1,0,1,0,1,0,0,1,0), \quad \tau_{11} = (1,0,1,0,1,0,0,1,0),\\
&\tau_{12} = (1,0,1,0,1,0,0,0,0), \quad \tau_{13} = (1,0,1,0,1,0,0,1,0),\\
&\tau_{14} = (1,0,1,0,0,0,0,1,0), \quad \tau_{15} = (1,0,0,0,1,0,0,1,0).
\end{aligned}$$

By Eq. (3), the distance between τ_0 and τ_i can be calculated, and the computation results are: $\delta_{01} = 1.4142$, $\delta_{02} = 0$, $\delta_{03} = 1$, $\delta_{04} = 0$, $\delta_{05} = 1.4142$, $\delta_{06} = 0$, $\delta_{07} = 1$, $\delta_{08} = 0$, $\delta_{09} = 1$, $\delta_{0,10} = 0$, $\delta_{0,11} = 0$, $\delta_{0,12} = 1$, $\delta_{0,13} = 0$, $\delta_{0,14} = 1$, $\delta_{0,15} = 1$. Based on the computation results, we know that the risks involved in the historical cases (C_2, C_4, C_6, C_8, C_{10}, C_{11}, C_{13}) cover or are the same as those in the target case C_0 since $\delta_{02} = \delta_{04} = \delta_{06} = \delta_{08} = \delta_{0,10} = \delta_{0,11} = \delta_{0,13} = 0$. Thus, these historical cases can be retrieved from the set C, and the available historical case set C^A can be constructed, i.e., $C^A = \{C_2, C_4, C_6, C_8, C_{10}, C_{11}, C_{13}\}$. By Eqs. (4)–(6), the similarity $sim_l^P(C_i, C_0)$ concerning each project feature can be calculated, $l \in \{1, 2, \ldots, 10\}$, $i \in \{2, 4, 6, 8, 10, 11, 13\}$, and the computation results are shown in Table 5. According to Table 5, the similarity $Sim^P(C_i, C_0)$ concerning 'project' can be calculated using Eq. (7), $i \in \{2, 4, 6, 8, 10, 11, 13\}$, and the computation results are: $Sim^P(C_2, C_0) = 0.9982$, $Sim^P(C_4, C_0) = 0.6668$, $Sim^P(C_6, C_0) = 0.9994$, $Sim^P(C_8, C_0) = 0.9987$, $Sim^P(C_{10}, C_0) = 0.6779$, $Sim^P(C_{11}, C_0) = 0.9961$, $Sim^P(C_{13}, C_0) = 0.9967$. According to Table 3, the similarity $sim_k^R(C_i, C_0)$ concerning each risk can be calculated using Eqs. (10) and (11), $i \in \{2, 4, 6, 8, 10, 11, 13\}$, $k \in \{1, 3, 5, 8\}$, and the computation results are shown in Table 6. In the calculation process, an arbitrary value in the intervals $r_{ik} = [r_{ik}^L, r_{ik}^U]$ and $r_{0k} = [r_{0k}^L, r_{0k}^U]$ is regarded as a random variable that follows uniform distributions, and corresponding cumulative distribution functions $F_{ik}(x)$ and $F_{0k}(x)$ can be determined using Eqs. (8) and (9), $i \in \{2, 4, 6, 8, 10, 11, 13\}$, $k \in \{1, 3, 5, 8\}$. Here, to save the space, we only give the calculation results of cumulative distribution functions corresponding to r_{01} and r_{21}, i.e.,

$$F_{01}(x) = \begin{cases} 0, & x < 0.14 \\ 11.11x - 1.56, & 0.14 \leqslant x < 0.23, \\ 1, & x \geqslant 0.23 \end{cases}$$

$$F_{21}(x) = \begin{cases} 0, & x < 0.13 \\ 12.5x - 1.625, & 0.13 \leqslant x < 0.21\,0 \\ 1, & x \geqslant 0.21 \end{cases}$$

According to Table 6, the similarity $Sim^R(C_i, C_0)$ concerning 'project risk' can be calculated using Eq. (12), $i \in \{2, 4, 6, 8, 10, 11, 13\}$, and the computation results are $Sim^R(C_2, C_0) = 0.9897$, $Sim^R(C_4, C_0) =$

Table 5
The computation results of $sim_l^P(C_i, C_0)$ concerning each project feature.

Project features	Similarities						
	$sim_l^P(C_2, C_0)$	$sim_l^P(C_4, C_0)$	$sim_l^P(C_6, C_0)$	$sim_l^P(C_8, C_0)$	$sim_l^P(C_{10}, C_0)$	$sim_l^P(C_{11}, C_0)$	$sim_l^P(C_{13}, C_0)$
Q_1	0.9999	1	0.9999	1	0.9998	1	0.9999
Q_2	0.9984	0.9868	0.9976	0.9996	0.9992	0.9984	1
Q_3	0.9882	0.9231	1	0.9882	0.9822	0.9645	0.9704
Q_4	0.9967	0.9699	0.9988	0.9994	0.9982	0.9993	0.997
Q_5	1	1	1	1	1	1	1
Q_6	1	0	1	1	0	1	1
Q_7	1	0	1	1	0	1	1
Q_8	1	0	1	1	0	1	1

Table 6
The computation results of $sim_k^R(C_i, C_0)$ concerning each risk.

Risks	Similarities						
	$sim_k^R(C_2, C_0)$	$sim_k^R(C_4, C_0)$	$sim_k^R(C_6, C_0)$	$sim_k^R(C_8, C_0)$	$sim_k^R(C_{10}, C_0)$	$sim_k^R(C_{11}, C_0)$	$sim_k^R(C_{13}, C_0)$
R_1	0.985	0.945	0.985	0.995	0.965	0.975	0.995
R_3	0.995	0.91	1	0.985	0.94	0.995	0.965
R_5	0.995	0.965	1	0.985	0.995	0.98	0.995
R_8	0.985	0.98	1	0.98	0.905	0.995	0.955

0.9499, $Sim^R(C_6, C_0) = 0.9955$, $Sim^R(C_8, C_0) = 0.9868$, $Sim^R(C_{10}, C_0) = 0.9530$, $Sim^R(C_{11}, C_0) = 0.9854$, $Sim^R(C_{13}, C_0) = 0.9790$.

Next, by Eqs. (13) and (14), the similarity thresholds λ^P and λ^R can be obtained, i.e., $\lambda^P = 0.7777$ and $\lambda^R = 0.9651$. When $i = 2, 6, 8, 11, 13$, we find that $Sim^P(C_i, C_0) \geqslant \lambda^P$ and $Sim^R(C_i, C_0) \geqslant \lambda^R$ hold. Thus, the corresponding available historical cases (C_2, C_6, C_8, C_{11}, C_{13}) can be retrieved from the set C^A, and the similar historical case set C^{Sim} can be constructed, i.e., $C^{Sim} = \{C_2, C_6, C_8, C_{11}, C_{13}\}$.

Afterwards, through the analysis of the response relation between each strategy and each risk involved in the similar historical case C_i, $i \in \{2, 6, 8, 11, 13\}$, the 'strategy-risk' response relation graph can be drawn. To save the space, we only give the response relation graph concerning the similar historical case C_2, as shown in Fig. 7.

According to the 'strategy-risk' response relations with regard to each similar historical case, it is judged whether the strategies in the sets ($\boldsymbol{S}_2$, $\boldsymbol{S}_6$, $\boldsymbol{S}_8$, $\boldsymbol{S}_{11}$, $\boldsymbol{S}_{13}$) are suitable for coping with the risks involved in the target case or not. If not, then the inapplicable strategies should be revised, i.e., some response strategies should be deleted, added or modified. More specifically, the results of revising strategies are as follows:

For $\boldsymbol{S}_2$, delete S_{26}, S_{28} and $S_{2,11}$;
For $\boldsymbol{S}_6$, delete S_{66} and add $\widetilde{S}_{68}$;
For $\boldsymbol{S}_8$, delete S_{83} and modify S_{81} into S'_{81};
For $\boldsymbol{S}_{11}$, delete $S_{11,5}$ and $S_{11,7}$, and add $\widetilde{S}_{11,8}$;
For $\boldsymbol{S}_{13}$, add $\widetilde{S}_{13,7}$.

Thus, the sets S_2, S_6, S_8, S_{11} and S_{13} are modified into $\overline{\boldsymbol{S}}_2, \overline{\boldsymbol{S}}_6, \overline{\boldsymbol{S}}_8, \overline{\boldsymbol{S}}_{11}$ and $\overline{\boldsymbol{S}}_{13}$, respectively, i.e.,

$$\overline{\boldsymbol{S}}_2 = \{S_{21}, S_{22}, S_{23}, S_{24}, S_{25}, S_{27}, S_{29}, S_{2,10}\},$$
$$\overline{\boldsymbol{S}}_6 = \{S_{61}, S_{62}, S_{63}, S_{64}, S_{65}, S_{67}, \widetilde{S}_{68}\},$$
$$\overline{\boldsymbol{S}}_8 = \{S'_{81}, S_{82}, S_{84}, S_{85}, S_{86}\},$$
$$\overline{\boldsymbol{S}}_{11} = \{S_{11,1}, S_{11,2}, S_{11,3}, S_{11,4}, S_{11,6}, \widetilde{S}_{11,8}\},$$
$$\overline{\boldsymbol{S}}_{13} = \{S_{13,1}, S_{13,2}, S_{13,3}, S_{13,4}, S_{13,5}, S_{13,6}, \widetilde{S}_{13,7}\}.$$

Through the revisions of the strategies, the candidate risk response strategy set $\overline{\boldsymbol{S}}_i$ for the target case C_0 can be determined, $i \in \{2, 6, 8, 11, 13\}$, as shown in Fig. 8. Based on Fig. 8, the description of each strategy to the risk(s) is shown in Table 7. In addition, because there are some differences in labor, material, and market condition between the previous project and the current project, the costs of response strategies are modified and the modified result is shown in Table 7. According to Table 7, normalized value of the average cost concerning each candidate risk response strategy set can be obtained using Eqs. (15) and (16), i.e., $c(\overline{\boldsymbol{S}}_2) = 0.8604$, $c(\overline{\boldsymbol{S}}_6) = 0.7906, c(\overline{\boldsymbol{S}}_8) = 0.9898, c(\overline{\boldsymbol{S}}_{11}) = 0.9872, c(\overline{\boldsymbol{S}}_{13}) = 1$.

Further, the expected effects of the candidate risk response strategy sets ($\overline{\boldsymbol{S}}_2, \overline{\boldsymbol{S}}_6, \overline{\boldsymbol{S}}_8, \overline{\boldsymbol{S}}_{11}, \overline{\boldsymbol{S}}_{13}$) with regard to the risks (R_1, R_3, R_5, R_8) are evaluated by the five experts from the PRM committee, and the evaluation results are shown in Table 8. Based on Table 8, the group evaluation results about the candidate strategy sets with regard to the risks can be obtained using Eq. (17), as shown in

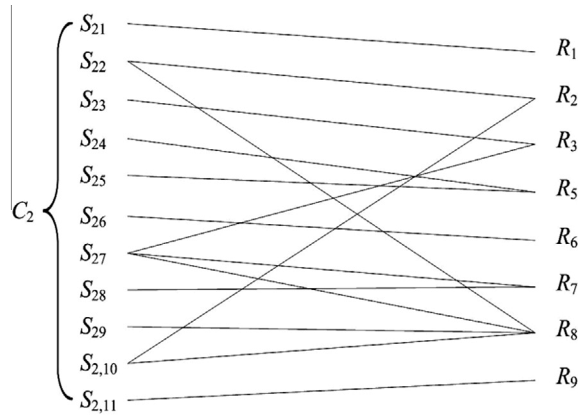

Fig. 7. The 'strategy-risk' response relations concerning the similar historical case C_2.

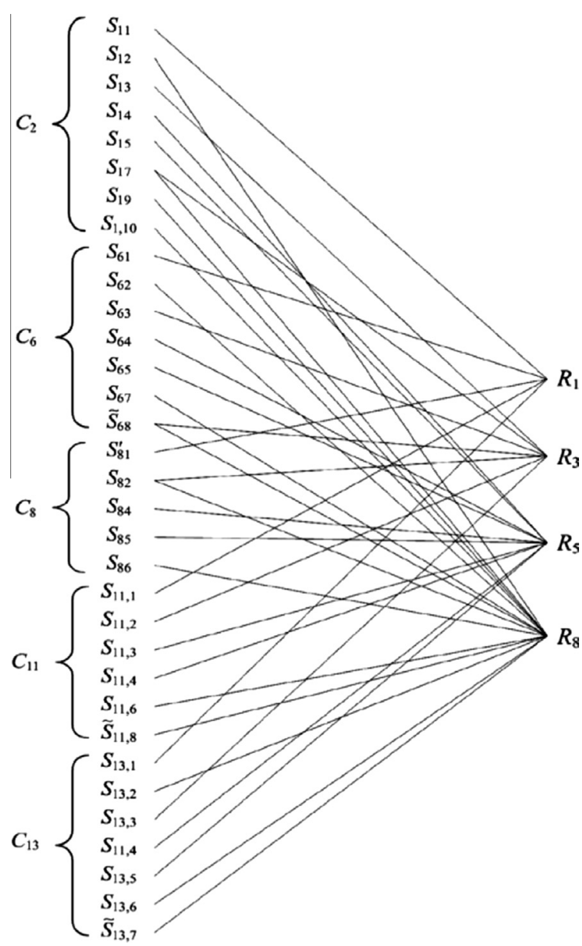

Fig. 8. The 'strategy-risk' response relations for the target case C_0.

Table 7
The candidate risk response strategies and the corresponding costs for the target case C_0.

Candidate strategy sets	Risk response strategies	Costs (thousand CNY)
$\bar{\boldsymbol{S}}_2$	S_{21}: opening compensation standards and doing propagandas well	$\bar{c}_{21} = 174.8$
	S_{22}: employing domain experts	$\bar{c}_{22} = 595.7$
	S_{23}: keeping emissions of the waste water, gas and residue up to standard	$\bar{c}_{23} = 632.5$
	S_{24}: paying attention to public opinions closely, and doing guidance jobs well	$\bar{c}_{24} = 121.9$
	S_{25}: investigating owners' intentions in detail, and adopting reasonable traffic dispersion measures	$\bar{c}_{25} = 172.5$
	S_{27}: entrusting a qualified and experienced construction company	$\bar{c}_{27} = 837.2$
	$S_{2,9}$: investigating the geological hydrology condition in depth	$\bar{c}_{29} = 308.2$
	$S_{2,10}$: training related technicians	$\bar{c}_{2,10} = 225.4$
$\bar{\boldsymbol{S}}_6$	S_{61}: conducting the expropriation compensation according to requirements of the state and local government	$\bar{c}_{61} = 225.4$
	S_{62}: employing domain experts	$\bar{c}_{62} = 595.7$
	S_{63}: adopting improved technologies, and reducing pollution as far as possible	$\bar{c}_{63} = 607.8$
	S_{64}: paying attention to public opinions closely, and doing guidance jobs well	$\bar{c}_{64} = 121.9$
	S_{65}: arranging specialized workers to take charge of traffic safeties near schools, marketplaces and vital transportation hubs, and prohibiting overload or overspend construction vehicles	$\bar{c}_{65} = 225.4$
	S_{67}: investigating the geological hydrology condition in depth	$\bar{c}_{67} = 308.2$
	$\tilde{S}_{68}$: entrusting a qualified and experienced construction company	$\bar{c}_{68} = 837.2$
$\bar{\boldsymbol{S}}_8$	S'_{81} : confirming acquisition solutions with related departments and avoiding enforcement	$\bar{c}_{81} = 200.8$
	S_{82}: entrusting a qualified and experienced construction company	$\bar{c}_{82} = 837.2$
	S_{84}: paying attention to public opinions closely, and doing guidance jobs well	$\bar{c}_{84} = 121.9$
	S_{85}: adopting appropriate traffic dispersion measures, and reducing impacts on traffic as far as possible	$\bar{c}_{85} = 198.7$
	S_{86}: investigating the geological hydrology condition in depth	$\bar{c}_{86} = 308.2$
$\bar{\boldsymbol{S}}_{11}$	$S_{11,1}$: opening compensation standards, and doing propagandas well	$\bar{c}_{11,1} = 174.8$
	$S_{11,2}$: keeping emissions of the waste water, waste gas and waste residue up to standard	$\bar{c}_{11,2} = 632.5$
	$S_{11,3}$: paying attention to public opinions closely, and doing guidance jobs well	$\bar{c}_{11,3} = 121.9$
	$S_{11,4}$: investigating owners' intentions in detail, and adopting reasonable traffic dispersion measures	$\bar{c}_{11,4} = 172.5$
	$S_{11,6}$: investigating the geological hydrology condition in depth	$\bar{c}_{11,6} = 308.2$
	$\tilde{S}_{11,8}$: employing domain experts	$\bar{c}_{11,8} = 595.7$
$\bar{\boldsymbol{S}}_{13}$	$S_{13,1}$: opening compensation standards, and doing propagandas well	$\bar{c}_{13,1} = 225.4$
	$S_{13,2}$: employing domain experts	$\bar{c}_{13,2} = 595.7$
	$S_{13,3}$: adopting the improved technology, and reducing pollution as far as possible	$\bar{c}_{13,3} = 607.8$
	$S_{13,4}$: paying attention to public opinions closely, and doing guidance jobs well	$\bar{c}_{13,4} = 121.9$
	$S_{13,5}$: arranging specialized workers to take charge of traffic safeties near schools, marketplaces and vital transportation hubs, and prohibiting overload or overspend construction vehicles	$\bar{c}_{13,5} = 225.4$
	$S_{13,6}$: investigating the geological hydrology condition in depth	$\bar{c}_{13,6} = 308.2$
	$\tilde{S}_{13,7}$: training related technicians	$\bar{c}_{13,7} = 225.4$

Table 8
The evaluation matrix about the expected effects of the risk response strategy sets with regard to the risks in the target case.

Experts	Candidate risk response strategy sets	Risks			
		R_1	R_3	R_5	R_8
Expert 1	$\bar{\boldsymbol{S}}_2$	7	10	7	10
	$\bar{\boldsymbol{S}}_6$	9	9	8	9
	$\bar{\boldsymbol{S}}_8$	8	7	8	7
	$\bar{\boldsymbol{S}}_{11}$	7	8	7	7
	$\bar{\boldsymbol{S}}_{13}$	7	6	8	8
Expert 2	$\bar{\boldsymbol{S}}_2$	8	9	6	9
	$\bar{\boldsymbol{S}}_6$	7	6	9	7
	$\bar{\boldsymbol{S}}_8$	9	8	8	6
	$\bar{\boldsymbol{S}}_{11}$	8	7	6	6
	$\bar{\boldsymbol{S}}_{13}$	8	8	9	8
Expert 3	$\bar{\boldsymbol{S}}_2$	8	10	6	10
	$\bar{\boldsymbol{S}}_6$	10	8	7	8
	$\bar{\boldsymbol{S}}_8$	9	6	8	6
	$\bar{\boldsymbol{S}}_{11}$	8	7	6	6
	$\bar{\boldsymbol{S}}_{13}$	8	5	7	7
Expert 4	$\bar{\boldsymbol{S}}_2$	6	9	7	9
	$\bar{\boldsymbol{S}}_6$	10	8	8	8
	$\bar{\boldsymbol{S}}_8$	8	6	9	7
	$\bar{\boldsymbol{S}}_{11}$	6	7	7	7
	$\bar{\boldsymbol{S}}_{13}$	6	6	8	8
Expert 5	$\bar{\boldsymbol{S}}_2$	7	9	8	8
	$\bar{\boldsymbol{S}}_6$	10	8	7	7
	$\bar{\boldsymbol{S}}_8$	8	6	9	5
	$\bar{\boldsymbol{S}}_{11}$	7	7	8	5
	$\bar{\boldsymbol{S}}_{13}$	7	6	10	7

Table 9
The evaluation matrix about group expected effects of the risk response strategy sets with regard to the risks in the target case.

Candidate risk response strategy sets	Risks			
	R_1	R_3	R_5	R_8
$\bar{\boldsymbol{S}}_2$	7.2	9.4	6.8	9.2
$\bar{\boldsymbol{S}}_6$	9.2	7.8	7.8	7.8
$\bar{\boldsymbol{S}}_8$	8.4	6.6	8.8	6.2
$\bar{\boldsymbol{S}}_{11}$	7.2	7.2	6.8	6.2
$\bar{\boldsymbol{S}}_{13}$	7.2	6.2	8.2	7.6

Table 9. Based on Table 9, the normalized value of the expected effect of the candidate strategy sets with regard to the risks can be obtained using Eqs. (18) and (19), i.e., $v(\bar{\boldsymbol{S}}_2) = 1$, $v(\bar{\boldsymbol{S}}_6) = 1$, $v(\bar{\boldsymbol{S}}_8) = 0.9202$, $v(\bar{\boldsymbol{S}}_{11}) = 0.8405$, $v(\bar{\boldsymbol{S}}_{13}) = 0.8957$. By Eq. (20), the overall evaluation value concerning each candidate risk response strategy set can be obtained, i.e., $u_2 = 0.8604$, $u_6 = 0.7906$, $u_8 = 0.8987$, $u_{11} = 0.8297$, $u_{13} = 0.9018$.

At last, according to the obtained overall evaluation values, a ranking order of the five candidate risk response strategy sets can be determined, i.e., $\bar{\boldsymbol{S}}_{13} \succ \bar{\boldsymbol{S}}_8 \succ \bar{\boldsymbol{S}}_2 \succ \bar{\boldsymbol{S}}_{11} \succ \bar{\boldsymbol{S}}_6$. Therefore, $\bar{\boldsymbol{S}}_{13}$ is the desirable risk response strategy set, i.e., the strategies shown in Table 7, $S_{13,1}$, $S_{13,2}$, $S_{13,3}$, $S_{13,4}$, $S_{13,5}$, $S_{13,6}$ and $S_{13,7}$, can be adopted to cope with the risks of the current project.

To further evaluate the feasibility or validity of the generated strategies, the project manager invites some experts who are not members of the PRM committee to participate in a consultation. In the consultation, first, let the experts express their own opinions and make a full discussion. Then, let the experts provide their own evaluations on the feasibility or validity of each strategy using the scale of scores of 1–10 (1: the worst; 10: the best). By aggregating the evaluation information of each expert, the overall evaluation result is obtained, and the average score concerning each strategy is greater than 8. It can be seen from the evaluation result that the opinions of the experts are basically consistent. Therefore, the generated strategies are feasible.

5. Conclusions and future works

This paper presents a CBR-based method for generating project risk response strategies using the risk response of the subway project as a background. In the method, firstly, the target case and the historical cases are represented. Then, the available historical cases are retrieved from the case base by judging whether the risks involved in each historical case cover or are the same as those in the target case. Afterwards, the similar historical cases are retrieved from the available historical cases by measuring the similarity between each available historical case and the target case. Further, through the analysis of the response relation between each strategy and each risk of the current project, the inapplicable risk response strategies involved in each similar historical case are revised, and the candidate risk response strategy sets for the target case are determined. By evaluating each candidate strategy set, the desirable risk response strategies for the target case can be generated. To illustrate the use of the proposed method, an empirical analysis on risk response of the subway station project is given. Compared with the existing project risk response methods, the contributions of the proposed method are summarized as follows:

First, a new solution framework for generating project risk response strategies based on the CBR is proposed. Compared with the framework of the traditional CBR, the process of retrieving the available historical cases is added. The goal is to enhance the efficiency of the retrieval of the similar historical cases and to ensure the retrieved historical cases are available.

Second, the proposed method is the one based on the extension of the CBR technique. It has made the distinct improvements to the traditional CBR technique. One is the improvement on the technique of retrieving the similar historical cases, i.e., the available historical cases are firstly retrieved from the case base by judging whether the risks involved in each historical case cover or are the same as those in the target case, then the similar historical cases are retrieved from the available historical cases by measuring the similarity between each available historical case and the target case. The other is that the technique of revising the inapplicable strategies for the target case is given through the analysis of the 'strategy-risk' response relations, while this is seldom involved in the existing studies.

Third, the proposed method is to use a novel decision-making paradigm to solve the project risk response problem. It is a new method and differs from the exiting methods for generating risk response strategies (e.g., the zonal-based method, the trade-off method, the WBS-based method, the optimization-model method). Using the proposed method, the desirable risk response strategies can be obtained by retrieving and reusing information and knowledge of the similar historical cases.

The proposed method has a clear logic and a simple computation procedure. Since the proposed method is new and different from the existing methods, it gives project managers or decision makers one more choice for solving the project risk response problem. The proposed method represents a significant contribution to not only research on generating the risk response strategies but also application in PRM practice.

The study also has some limitations, which may serve as directions for future research. First, in the practical application of the proposed method, some required information such as the individual risks involved in the target case may not exist in the case base. Under the situation of lack of some information in the case base, how to retrieve the available similar historical cases is a noteworthy research job. Second, in the use of the proposed method, some results are not obtained directly using the calculation formulae. For example, the revision of the inapplicable strategies usually requires the in-depth analysis and the support of the related information and knowledge. Thus, to make the proposed method more available and practical, developing a support system for the method is needed. To help the project managers generate the desirable risk response strategies in PRM, not only the calculation formulae involved in the proposed method but also lots of related information and knowledge will be embedded into the support system. Last, the proposed method can also be applied to solve project risk response problems in other areas, such as the new product development project, the service outsourcing project and so on.

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References

Aamodt, A., & Plaza, E. (1994). Case-based reasoning: Foundational issues, methodological variations, and system approaches. *AI Communications, 7*(1), 39–59.

Aarts, R. J (1998). A CBR architecture for project knowledge management. In *Advances in case-based reasoning* (pp. 414–424). Berlin Heidelberg: Springer.

Abelson, R. P., & Schank, R. C. (1977). Scripts, plans, goals and understanding. An inquiry into human knowledge structures New Jersey 10.

Allen, B. P. (1994). Case-based reasoning: Business applications. *Communications of the ACM, 37*(3), 40–42.

Amailef, K., & Lu, J. (2013). Ontology-supported case-based reasoning approach for intelligent m-Government emergency response services. *Decision Support Systems, 55*(1), 79–97.

Bajo, J., Borrajo, M. L., De Paz, J. F., Corchado, J. M., & Pellicer, M. A. (2012). A multi-agent system for web-based risk management in small and medium business. *Expert Systems with Applications, 39*(8), 6921–6931.

Ben-David, I., & Raz, T. (2001). An integrated approach for risk response development in project planning. *Journal of the Operational Research Society, 52*(1), 14–25.

Carmona, M. A., Barbancho, J., Larios, D. F., & León, C. (2013). Applying case based reasoning for prioritizing areas of business management. *Expert Systems with Applications, 40*(9), 3450–3458.

Chang, C., Ma, X., Song, X., & Gao, B. (2010). CBR based emergency case generating system under engineering accidents. In *IEEE international conference on progress in informatics and computing, PIC 2010* (Vol. 1, pp. 145–149).

Chapman, C. B. (1979). Large engineering project risk analysis. *IEEE Transactions on Engineering Management, 26*(3), 78–86.

Chapman, C., & Ward, S. (1996). *Project risk management*. John Wiley.

Chen, Y., Kilgour, D. M., & Hipel, K. W. (2008). A case-based distance method for screening in multiple-criteria decision aid. *Omega-International Journal of Management Science, 36*(3), 373–383.

Chen, G. X., Wang, H. C., Song, J. L., & Zhao, Y. Q. (2013). The review of risk management on subway station building. *Advances in Civil Engineering II, Pts 1–4, 256–259*, 2993–2998.

Dingwei, S., & Xinping, S. (2011). An audit decision aid system for management fraud risk assessment using AHP-CBR. In *IEEE international conference on management and service science, MASS 2011* (pp. 1–4).

El-Fakdi, A., Gamero, F., Meléndez, J., Auffret, V., & Haigron, P. (2014). EXiTCDSS: A framework for a workflow-based CBR for interventional clinical decision support systems and its application to TAVI. *Expert Systems with Applications, 41*(2), 284–294.

Elkjaer, M., & Felding, F. (1999). Applied project risk management – introducing the project risk management loop of control. *Project Management, 5*(1), 16–25.

Fan, Z. P., Li, Y. H., Wang, X. H., & Liu, Y. (2014). Hybrid similarity measure for case retrieval in CBR and its application to emergency response towards gas explosion. *Expert Systems with Applications, 41*(5), 2526–2534.

Fan, M., Lin, N. P., & Sheu, C. (2008). Choosing a project risk-handling strategy: An analytical model. *International Journal of Production Economics, 112*(2), 700–713.

Fan, Z. P., Zhang, X., Chen, F. D., & Liu, Y. (2013). Multiple attribute decision making considering aspiration-levels: A method based on prospect theory. *Computers & Industrial Engineering, 65*(2), 341–350.

Fishburn, P. C., & Gehrlein, W. V. (1976). Borda's rule, positional voting, and Condorcet's simple majority principle. *Public Choice, 28*(1), 79–88.

Flanagan, R., & Norman, G. (1993). *Risk management and construction*. Oxford: Blackwell Scientific.

Goh, Y. M., & Chua, D. K. H. (2009). Case-based reasoning for construction hazard identification: Case representation and retrieval. *Journal of Construction Engineering and Management, 135*(11), 1181–1189.

Guessoum, S., Laskri, M. T., & Lieber, J. (2014). RespiDiag: A case-based reasoning system for the diagnosis of chronic obstructive pulmonary disease. *Expert Systems with Applications, 41*(2), 267–273.

Hansen, J. V., Meservy, R. D., & Wood, L. E. (1994). Indexing tree and pruning concepts to support case-based reasoning. *Omega-International Journal of Management Science, 22*(4), 361–369.

Hu, Y., Du, J., Zhang, X., Hao, X., Ngai, E. W. T., Fan, M., et al. (2013). An integrative framework for intelligent software project risk planning. *Decision Support Systems, 55*, 927–937.

Hu, Y., Zhang, X., Ngai, E. W. T., Cai, R., & Liu, M. (2013). Software project risk analysis using Bayesian networks with causality constraints. *Decision Support Systems, 56*, 439–449.

Hunt, J. (1995). Evolutionary case based design. In *Progress in case-based reasoning* (pp. 17–31). Berlin Heidelberg: Springer.

Jordan, S., Jørgensen, L., & Mitterhofer, H. (2013). Performing risk and the project: Risk maps as mediating instruments. *Management Accounting Research, 24*(2), 156–174.

Jung, C., Han, I., & Suh, B. (1999). Risk analysis for electronic commerce using case-based reasoning. *International Journal of Intelligent Systems in Accounting, Finance & Management, 8*(1), 61–73.

Kayis, B., Arndt, G., Zhou, M., & Amornsawadwatana, S. (2007). A risk mitigation methodology for new product and process design in concurrent engineering projects. *CIRP Annals-Manufacturing Technology, 56*(1), 167–170.

Klein, J. H., Powell, P. L., & Chapman, C. B. (1994). Project risk analysis based on prototype activities. *Journal of the Operational Research Society, 45*(7), 749–757.

Kujawski, E. (2002). Selection of technical risk responses for efficient contingencies. *Systems Engineering, 5*(3), 194–212.

Kumar, V., & Viswanadham, N. (2007). A CBR-based decision support system framework for construction supply chain risk management. In *IEEE international conference on automation science and engineering, CASE 2007* (pp. 980–985).

Kuo, T. C. (2010). Combination of case-based reasoning and analytical hierarchy process for providing intelligent decision support for product recycling strategies. *Expert Systems with Applications, 37*(8), 5558–5563.

Li, H., Adeli, H., Sun, J., & Han, J. G. (2011). Hybridizing principles of TOPSIS with case-based reasoning for business failure prediction. *Computers & Operations Research, 38*(2), 409–419.

Li, H., Yu, J. L., Zhou, Q., & Cai, J. H. (2013). Forecasting firm risk in the emerging market of china with sequential optimization of influence factors on performance of case-based reasoning: An empirical study with imbalanced samples. *Intelligent Systems in Accounting, Finance and Management, 20*(3), 141–161.

Lu, Y., Li, Q. M., & Xiao, W. J. (2013). Case-based reasoning for automated safety risk analysis on subway operation: Case representation and retrieval. *Safety Science, 57*, 75–81.

Ma, L. C. (2012). Screening alternatives graphically by an extended case-based distance approach. *Omega-International Journal of Management Science, 40*(1), 96–103.

Marcelino-Sádaba, S., Pérez-Ezcurdia, A., Echeverría Lazcano, A. M., & Villanueva, P. (2014). Project risk management methodology for small firms. *International Journal of Project Management, 32*(2), 327–340.

Miller, R., & Lessard, D. (2001). Understanding and managing risks in large engineering projects. *International Journal of Project Management, 19*(8), 437–443.

Piney, C. (2002). Risk response planning: select the right strategy. In *Fifth project management conference*. France.

Pipattanapiwong, J., & Watanabe, T. (2000). Multi-party risk management process (MRMP) for a construction project financed by an international lender'. In *Proceedings of the 16th ARCOM conference* (pp. 219–228).

Pla, A., López, B., Gay, P., & Pous, C. (2013). EXiT∗CBR.v2: Distributed case-based reasoning tool for medical prognosis. *Decision Support Systems, 54*(3), 1499–1510.

Reza Montazemi, A., & Moy Gupta, K. (1997). A framework for retrieval in case-based reasoning systems. *Annals of Operations Research, 72*, 51–73.

Seyedhoseini, S. M., Noori, S., & AliHatefi, M. (2008). Two polar concept of project risk management. In D. Olson & D. Wu (Eds.), *New frontiers in enterprise risk management* (pp. 69–92). Berlin Heidelberg: Springer.

Seyedhoseini, S. M., Noori, S., & Hatefi, M. A. (2009). An integrated methodology for assessment and selection of the project risk response actions. *Risk Analysis, 29*(5), 752–763.

Sumit, D. (2001). Developing a risk management matrix for effective project planning: An empirical study. *Project Management Journal, 32*(2), 45.

Ting, S. L., Wang, W. M., Kwok, S. K., Tsang, A. H. C., & Lee, W. B. (2010). RACER: Rule-associated CasE-based Reasoning for supporting general practitioners in prescription making. *Expert Systems with Applications, 37*(12), 8079–8089.

Wu, X. G., Liu, H. T., Zhang, L. M., Ding, B. J., Zhai, H. Z., & Li, X. (2013). The reliability theory based expert system research for Subway construction safety risk identification. *Advances in Civil and Industrial Engineering, Pts 1–4, 353–356*, 1739–1748.

Wu, M. C., Lo, Y. F., & Hsu, S. H. (2008). A fuzzy CBR technique for generating product ideas. *Expert Systems with Applications, 34*(1), 530–540.

Yao, L., Chen, Z. C, & Yang, J. J (2014). Research on risk assessment of ship repair based on case-based reasoning. In *Knowledge engineering and management* (pp. 53–59). Berlin Heidelberg: Springer.

Zhang, Y., & Fan, Z.-P. (2014). An optimization method for selecting project risk response strategies. *International Journal of Project Management, 32*(3), 412–422.

Zhao, P., & Hao, F. T. (2011). Risk study on subway construction based on reliability theory. *Frontiers of Manufacturing and Design Science, Pts 1–4, 44–47*, 1872–1877.

Zhuang, Z. Y., Churilov, L., Burstein, F., & Sikaris, K. (2009). Combining data mining and case-based reasoning for intelligent decision support for pathology ordering by general practitioners. *European Journal of Operational Research, 195*(3), 662–675.

Zou, P. X. W., Zhang, G., & Wang, J. (2007). Understanding the key risks in construction projects in China. *International Journal of Project Management, 25*(6), 601–614.